38. Savetovanje proizvodnog mašinstva Srbije
38th International Conference on Production Engineering of Serbia

ZBORNIK RADOVA
PROCEEDINGS

SPMS 2021
ICPE - S 2021

14 - 15. Oktobar 2021, Čačak

FAKULTET TEHNIČKIH NAUKA U ČAČKU
UNIVERZITETA U KRAGUJEVCU
KATEDRA ZA MEHATRONIKU
Čačak, Srbija

38. SAVETOVANJE PROIZVODNOG MAŠINSTVA SRBIJE
- SPMS 2021 -
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EDITORS: Jelena Baralić, Nedeljko Dučić

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III	Ljubljana	1967.	XXII	Ohrid	1989.
IV	Sarajevo	1968.	XXIII	Zagreb (nije održano)	1991.
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Prof. dr Bogdan Sovilj, dipl. inž., Fakultet tehničkih nauka, Novi Sad
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za 2015. godinu
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za 2018. godinu
Prof. dr Vidosav Majstorović, Mašinski fakultet, Beograd
Prof. dr Miroslav Radovanović, Mašinski fakultet, Niš

PREDGOVOR

Savetovanje proizvodnog mašinstva Srbije je savetovanje sa dugom tradicijom. Prvo Savetovanje proizvodnog mašinstva Jugoslavije održano je u Beogradu 1965. na inicijativu prof. dr Vladimira Šolaje. Tada je formirana Zajednica naučno-istraživačkih institucija proizvodnog mašinstva, koju su sačinjavali Mašinski fakulteti i istraživački instituti proizvodnog mašinstva iz skoro svih republičkih centara tadašnje države. Ove godine se navršava I 100 godina od rođenja prof. dr Vladimira Šolaje. Jedno od uvodnih predavanja je posvećeno prof. dr V. Šolaji. Po prvi put, na 38. Savetovanju proizvodnog mašinstva Srbije biće dodeljena i Medalja prof. dr V. Šolaja, najboljem mladom istraživaču iz oblasti proizvodnog mašinstva.

38. Savetovanje proizvodnog mašinstva Srbije se održava u Čačku, u organizaciji Katedre za mehatroniku Fakulteta tehničkih nauka u Čačku. Prethodna Savetovanja proizvodnog mašinstva koja je organizovao Fakultet tehničkih nauka u Čačku su:
1980 godine - 14. Savetovanje proizvodnog mašinstva Jugoslavije i
2005 godine - 30. Savetovanje proizvodnog mašinstva Srbije.

Ovo Savetovanje proizvodnog mašinstva Srbije se održava u vreme obnavljanja industrije u Srbiji. Veliki broj giganata u oblasti metaloprerađivačke industrije je nestao u prethodnom periodu. Od ukupno 105.593 preduzeća, koliko ih je u Srbiji bilo 2020 godine, najviše je mikro preduzeća 90.106, zatim malih 12.187, srednjih 2. 716, dok je najmanje bilo velikih preduzeća čiji je broj iznosio 584.

Na ovoj konferenciji biće izloženi radovi autora iz Srbije i inostranstva iz različitih oblasti proizvodnog mašinstva. Posebno aktuelna tema je Industrija 4.0, odnosno novije tehnologije i značaj njihovog uvođenja u proizvodne procese. Integracija proizvodnih sa informaciono-komunikacionim tehnologijama treba da omogući revitalizaciju privrede Srbije i društva u celini i priključivanje Srbije četvrtoj industrijskoj revoluciji.

Nadamo se da će rezultati istraživanja koji će biti saopšteni na konferenciji i diskusija na okruglom stolu, doprineti ponovnom oživljavanju industrije prerade metala na ovim prostorima.

Zahvaljujemo se svim domaćim i stranim autorima, članovima recenzentskog tima, kao i institucijama i pojedincima koji su doprineli realizaciji 38. Savetovanja proizvodnog mašinstva Srbije.

Čačak,
05.10.2021.

Predsednik organizacionog odbora 38. SPMS
Predsednik Izvršnog odbora Zajednice IPMS
dr Jelena Baralić, vanr. prof.

PREFACE

Conference of Production Engineering of Serbia is the Conference with a long tradition. The first Conference of Production Engineering of Yugoslavia was held in Belgrade in 1965 on the initiative of professor PhD Vladimir Šolaja. Then the Association of scientific-research institutions of production engineering was founded, ant it consisted of the faculties of mechanical engineering and research institutes from almost all republic centers of the former state. This year marks the 100th anniversary of the birth of prof. dr Vladimir Šolaja. In honor of prof. PhD Vladimir Šolaja, one of the introductory lectures is dedicated to him. For the first time, at the 38th Conference of Production Engineering of Serbia, the prof. PhD Vladimir Šolaja Medal will be awarded to the best young researcher in the field of production engineering.

The 38th Conference of Production Engineering of Serbia is held in Čačak, in the organization of the Department of Mechatronics at the Faculty of Technical Sciences in Čačak. The previous Conferences of Production Engineering of Serbia organized by the Faculty of Technical Sciences in Čačak were:
1980- 14th Conference of production Engineering of Yugoslavia and
2005- 30th Conference of production Engineering of Serbia.

This Conference of Production Engineering of Serbia is being held at the time of the renewal of industry in Serbia. A large number of giants in the field of metal processing industry disappeared in the previous period. Out of a total of 105,593 companies, as many as there were in Serbia in 2020, the most were micro companies 90,106, followed by small 12,187, medium 2,716, while the least were large companies whose number was 584.

This conference will feature papers by authors from Serbia and abroad in various fields of production engineering. A particularly current topic is Industry 4.0, i.e. new technologies and the importance of their introduction into production processes. The integration of production with information and communication technologies should enable the revitalization of the Serbian economy and society as, and the accession of Serbia to the fourth industrial revolution.

We hope that the results of the research that will be announced at the conference and the round table discussion, will contribute to the revival of the metal processing industry in this area.

We thank all domestic and foreign authors, members of the review team, as well as institutions and individuals who contributed to the realization of the 38th Conference of Production Engineering of Serbia.

In Čačak,
05.10.2021.

Chairman of the Organizing Committee of the 38th SPMS
Chairman of the Executive Board of IPMS Association
Jelena Baralić, PhD, Assoc. prof.

Prof. dr Ljubomir LUKIĆ

Prof. dr Ljubomir Lukić je rođen u Mionici (Kosjerić) 1954. godine. Mašinski fakultet u Beogradu upisao je 1973. godine i diplomirao na grupi za proizvodno mašinstvo 1978. godine, na predmetu Mašinska obrada, pod mentorstvom prof. dr Vladimira Šolaje. Odmah po diplomiranju se zaposlio u lnstitutu za alatne mašine i alate (IAMA) u Beogradu.

Magistrirao je na grupi za proizvodno mašinstvo i primenu kompjutera Mašinskog fakulteta u Beogradu 1981. godine, na temu "Razvoj tehnološke banke režima rezanja pri obradi brušenjem na bazi sistematskog ispitivanja obradljivosti" pod rukovodstvom prof. dr Joka Stanića. Kao saradnik Instituta IAMA radio je na istraživanju alata i tehnologije obrade dubokih otvora, pa mu je u toj oblasti odobrena izrada doktorske disertacije 1981. godine, a za mentora je imenovan prof. dr Vladimir Šolaja. Posle specijalističkog boravka u razvojnom centru SANDVIK Coromant u Švedskoj 1982. godine i naučno istraživačkog rada kod profesora Dr lng. Ludolfa Cronjaegera (*lnstitut für Spanende Fertigung*) na Tehničkom univerzitetu u Dortmundu 1984. godine, odbranio je doktorsku disertaciju na Mašinskom fakultetu u Beogradu 1985. godine, na temu "Prilog teoriji i praksi dubokog bušenja - istraživanje i razvoj specijalnih alata".

Prof. dr Ljubomir Lukić je radio u svim istraživačkim zvanjima u lnstitutu za alatne mašine i alate (IAMA) od 1978. do 1986. godine, kada je lnstitut IAMA ušao u sastav novoosnovanog LOLA lnstituta u Beogradu. U LOLA lnstitutu, koji je poslovao u kategoriji naučnih instituta Republike Srbije, radio je u zvanju naučni saradnik, viši naučni saradnik, a od 1994. godine u zvanju naučni savetnik. Rukovodio je realizacijom 89 velikih istraživačko-razvojnih projekata u oblasti proizvodnih tehnologija, razvoja i projektovanja mašina za duboko bušenje, CNC mašina alatki i obradnih centara, fleksibilnih tehnoloških sistema, automatizovanih i robotizovanih proizvodnih linija i industrijskih postrojenja, računarsko upravljačkih sistema, informacionih tehnologija i razvojnih projekata vežbovnih i trenažnih sistema u oblasti ratnog vazduhoplovstva.

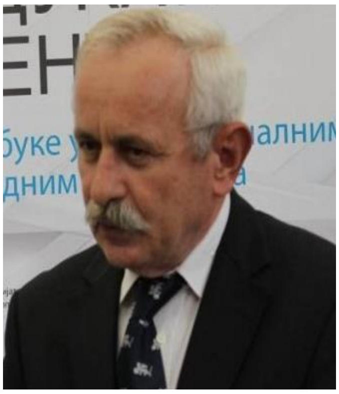
U vreme najtežih uslova rada za našu privredu, pod sankcijama Saveta bezbednosti Ujedinjenih nacija, u vreme hiperinflacije, raspada države, ratova na prostorima bivše Jugoslavije i tokom NATO bombardovanja, u periodu od 1993. do 2002. godine, dr Ljubomir Lukić je obavljao dužnost direktora LOLA lnstituta, a istovremeno je sve vreme bio i zamenik generalnog direktora korporacije IVO LOLA RIBAR u Beogradu, zadužen za istraživanje i razvoj.

Prvu polovinu svog radnog veka prof. dr Ljubomir Lukić je proveo u istraživanju, razvoju, projektovanju novih proizvoda i tehnologija i neposrednoj saradnji sa privredom, gde je ostvario veoma značajne rezultate u supstituciji uvoza i revitalizaciji domaće industrije, prerade metala, ne samo kao istraživač, već i kao istaknuti privredni rukovodilac.

Drugu polovinu radnog veka je proveo radeći kao univerzitetski profesor, izvodeći nastavu na grupi predmeta u oblasti proizvodnog mašinstva. Na Mašinskom fakultetu u Kraljevu prof. dr Ljubomir Lukić je radio od 2002. godine u zvanju vanrednog profesora, a od 2013. godine u zvanju redovnog profesora. Izvodio je nastavu iz 22 predmeta proizvodnog mašinstva, na osnovnim, master i doktorskim studijama, za koje je razvio savremene studijske programe. Bio je mentor 82 diplomska i master rada, 5 magistarskih radova i 3 odbranjene doktorske disertacije iz oblasti proizvodnog mašinstva. Publikovao je 349 naučnih i stručnih radova na naučnim konferencijama i časopisima. Autor je 7 monografija iz oblasti proizvodnog mašinstva, od kojih se može izdvojiti monografija "Fleksibilni tehnološki sistemi" objavljena 2008. godine u izdanju Mašinskog fakulteta u Kraljevu. Rukovodio je realizacijom 15 tehnoloških i inovacionih projekata Ministarstva za nauku i tehnološki razvoj.

Prof. dr Ljubomir Lukić je bio prodekan za naučno-istraživački rad Mašinskog fakulteta u Kraljevu u četiri mandata, član Saveta Univerziteta u Kragujevcu, član stručnih odbora Ministarstva za nauku, član Skupštine Privredne komore Srbije i niza drugih stručnih tela i komisija. Redovni je član Inženjerske akademije Srbije od 2005. godine. Zajedno sa Prof. dr Milisavom Kalajdžićem organizovao je XXV Savetovanje proizvodnog mašinstva 1994. godine u Beogradu. Učestvovao je na sedamnaest dosadašnjih Savetovanja proizvodnog mašinstva u periodu od 1980-2018. godine, na kojima je objavio kao autor 37 radova. Prof. dr Ljubomir Lukić je izvodio nastavu na 6 predmeta iz oblasti proizvodnog mašinstva na Mašinskom fakultetu u Istočnom Sarajevu u periodu 2003-2018. godine, gde je bio mentor 43 diplomska rada i 5 magistarskih radova.

Redovni je profesor Filološko-umetničkog fakulteta Univerziteta u Kragujevcu na doktorskim studijama harmonike, gde je objavio 2 monografije. Autor je svetski značajne monografije "Akustika i konstrukcija savremene koncertne harmonike" u izdanju FILUM-a 2018. godine.



Prof. dr Milan ZELJKOVIĆ

Prof. dr Milan Zeljković rođen je 22.11.1953. godine u Podgoriji, opština Mrkonjić Grad, Republika Srpska, BiH. Mašinski fakultet Univerzitet u Novom Sadu, Odsek za proizvodno mašinstvo, upisao je 1972. godine, gde je i diplomirao 1977. godine. Magistrirao je na Fakultetu tehničkih nauka Univerziteta u Novom Sadu, na studijskoj grupi za Proizvodno mašinstvo, 1984. godine. Doktorsku disertaciju odbranio je na Fakultetu tehničkih nauka u Novom Sadu 26.11.1996. godine. Naziv doktorske disertacije je bio: "Sistem za automatizovano projektovanje i predikciju ponašanja sklopa glavnog vretena mašina alatki".

Po završetku studija, 1977. godine zaposlio se kao asistent u naučnom radu za oblast Procesi obrade metala, na Katedri za obradu metala skidanjem strugotine Fakulteta tehničkih nauka u Novom Sadu. Za asistenta je izabran 1984. godine u užoj naučnoj oblasti Mašine alatke, fleksibilni tehnološki sistemi i automatizacija postupka projektovanja. U zvanje docenta izabran je 1997. godine a u zvanje vanrednog profesora 2002. godine. Za redovnog profesora izabran je 2007. godine, za užu naučnu oblast Mašine alatke, tehnološki sistemi i automatizacija postupaka projektovanja.

Prof. dr Milan Zeljković je izvodio predavanja i učestvovao u razvoju preko 20 nastavnih predmeta na Fakultetu tehničkih nauka u Novom Sadu i odeljenju fakulteta u Kikindi. Na Mašinskom fakultetu u Istočnom Sarajevu izvodio je predavanja u okviru tri predmeta na diplomskim studijama.

Prof. dr Milan Zeljković je autor i koautor pet univerzitetskih udžbenika. Vodio je preko 200 diplomskih, bio mentor/komentor 11 magistarskih radova i 10 doktorskih disertacija. Učestvovao je u komisijama za odbranu 21-og magistarskog rada i 19 doktorskih disertacija, pored matičnog i na Mašinskom fakultetu u Beogradu, Banja Luci, Istočnom Sarajevu i Mašinskom fakultetu (sada Fakultetu inženjerskih nauka) u Kragujevcu. Bio je recenzent 9 univerzitetskih udžbenika. Realizovao je preko 50 naučno-istraživačkih projektata iz oblasti proizvodnog mašinstva od kojih je na 15 bio rukovodilac. Objavio je 8 naučnih publikacija monografskog karaktera, 40 tehničkih rešenja, 1 patent, 18 radova u međunarodnim časopisima sa SCI liste, 47 radova u domaćim časopisima, 185 radova na međunarodnim skupovima, 187 radova na domaćim naučno-stručnim skupovima (ukupno 437 publikovanih radova). Prof. dr Milan Zeljković bio je recenzent u časopisima sa SCI liste.

Prof. dr Milan Zeljković bio je član istraživačkog tima koji je početkom osamdesetih godina razvio originalno rešenje prvog jugoslovenskog softvera za automatizovano projektovanje tehnoloških procesa i nosioca informacija za NUMA-SAPOR-S sistem. Navedeni softver dobio je vrhunska priznanja na nizu specijalizovanih izložbi i sajmova u zemlji a primenjen je u nekoliko preduzeća u Vojvodini.

Obavljao je niz funkcija na Institutu, Fakultetu i Univerzitetu u Novom Sadu. Bio je Pomoćnik direktora Instituta za proizvodno mašinstvo (1998-2002. godine), šef Katedre za mašine alatke, fleksibilne tehnološke sisteme i računarom podržane procese projektovanja (2011-2012. godine), član Stručnog veća za mašinske nauke i poljoprivrednu tehniku Univerziteta u Novom Sadu (2002-2007. godine), član Nastavno - naučnog veća i član Saveta fakulteta tehničkih nauka.

Aktivno je učestvovao u velikom broju naučno-stručnih skupova i savetovanja u zemlji i inostranstvu. Član je naučnih, programskih i organizacionih odbora većeg broja domaćih (JUPITER konferencija) i međunarodnih skupova i konferencija (ICAMAT - Bukurešt, MSE - Sibiu, DEMI - Banja Luka, MMA - Fleksibilne tehnologije - Novi Sad, COMETA Istočno Sarajevo i dr.).

Održao je više uvodnih predavanja na skupovima u zemlji inostranstvu. Učestvovao je na 15 Savetovanja proizvodnog mašinstva. Bio je predsednik Organizacionog odbora 32. Savetovanja proizvodnog mašinstva Srbije održanog u Novom Sadu 2008. godine i bio je član Naučnog odbora nekoliko Savetovanja proizvodnog mašinstva. Dobitnik je većeg broja priznanja.

Prof. dr Miodrag MANIĆ

Dr Miodrag Manić, redovni profesor Mašinskog fakulteta Univerziteta u Nišu, rođen je 1.2.1957. godine u Beloj Palanci. Mašinski fakultet u Nišu upisao je 1975. godine gde je i diplomirao 1980. godine. Dobitnik je Povelje Univerziteta u Nišu kao najbolji student u svojoj generaciji. Magistarske studije, smer Proizvodno mašinstvo, upisao je 1981.godine na Mašinskom fakultetu u Nišu. Magistarski rad pod nazivom "Automatizacija projektovanja tehnoloških procesa izrade rotacionih delova na bazi metoda prepoznavanja" odbranio je1989. godine. Doktorsku disertaciju pod naslovom "Ekspertni sistem za projektovanje tehnoloških procesa pri rezanju u obradi rotacionih delova" odbranio je 1995. godine na Mašinskom fakultetu u Nišu pod mentorstvom prof. dr. Dragana Domazeta.

Posle diplomiranja, 1980. godine zasnovao je stalni radni odnos sa Mašinskim fakultetom u Nišu kao saradnik Instituta. Za asistenta-pripravnika na Katedri za proizvodno mašinstvo za predmet Tehnološki sistemi i kontrola izabran je 1981. godine. Reizabran je1986. godine u zvanje asistenta-pripravnika za isti predmet. U zvanje asistenta izabran je 1989. godine na Mašinskom fakultetu u Nišu na Katedri za proizvodno mašinstvo, za predmet Tehnološki sistemi i kontrola, u isto zvanje reizabran je 1993. godine. Od 1989. do 1994. godine, kao i u periodu od 1999. do 2001. godine bio je angažovan sa 1/3 radnog vremena u Višoj tehničkoj školi u Nišu, na Mašinskom odseku, kao predavač i viši predavač, za predmete Programiranje i numeričko upravljanje mašinama, Numeričke mašine i Proizvodni sistemi.

Kao stipendista vlade Republike Srbije, 1991. godine boravio je na usavršavanju u Mančesteru u Engleskoj na UMIST-u, na *Manufacturing and Machine Tools Engineering Division*. Osnivač je Laboratorije za inteligentne proizvodne sistema (LIPS) 1994. godine i njen dugogodišnji šef. U zvanje docenta izabran je 1995. godine na Katedri za proizvodno mašinstvo Mašinskog fakulteta u Nišu za predmet Tehnološki sistemi. Decembra 2000. godine izabran je za vanrednog profesora na istom fakultetu za predmet Tehnološki sistemi. Za redovnog profesora izabran je2006. godine za užu naučnu oblast Proizvodni sistemi i tehnologije. Kao nastavnik izvodio je nastavu na predmetima Tehnološki sistemi, Projektovanje proizvodnje primenom računara, Numerički upravljane mašine alatke i roboti, Programiranje numerički upravljanih mašina, CAPP/CAM sistemi, Proizvodni sistemi, Planiranje tehnoloških procesa, Elektronsko poslovanje, Tehnološko i poslovno predviđanje, Numerički upravljani obradni sistemi, Proizvodna sredstva, Osnovi biomedicinskog inženjerstva. Na doktorskim studijama, na studijskom programu “Mašinsko inženjerstvo” izvodio je nastavu na predmetima: Odabrana poglavlja iz proizvodno-informacionih tehnologija, Integralni razvoj proizvoda, Virtuelni razvoj proizvoda i tehnologija, Simulacija u razvoju proizvoda, Inteligentni proizvodni sistemi i Proizvodnja medicinskih uređaja i implantanata. Govori engleski i služi se francuskim jezikom. Bavi se istraživanjima u domenu proizvodnog mašinstva, pri čemu se izdvajaju sledeće oblasti: Projektovanje tehnoloških procesa, CNC tehnologije, Biomedicinski inženjering i Planiranje i sprovođenje eksperimenata.

Bio je mentor velikog broja diplomskih radova, šest doktorskih disertacije i dve magistarske teze. Bio je član više komisija za odbranu magistarskih i doktorskih disertacija na matičnom fakultetu i na fakultetima u Srbiji. Objavio je kao autor ili koautor tri udžbenika. Publikovao je više od 300 naučnih radova u domaćim i međunarodnim časopisima, kao i u zbornicima radova sa nacionalnih i međunarodnih naučnih konferencija. Od toga je 50 radova u međunarodnim časopisima (25 radova u časopisima sa SCI liste), 25 u nacionalnim časopisima i veliki broj u zbornicima radova sa međunarodnih konferencija. Kao rukovodilac i član timova radio je na realizaciji 15 nacionalnih naučno-istraživačkih projekata kao i 8 međunarodnih projekata. Više puta je biran za člana programskog/naučnog odbora nacionalnih i međunarodnih konferencija. Bio je recenzent nekoliko udžbenika i većeg broja naučnih radova za časopise.

Od 2008. do 2012. godine bio je pomoćnik gradonačelnika grada Niša, zadužen za oblast visoko obrazovanje i nauka. Od 2002. do 2004. godine bio je prodekan, a od 2006. do 2009. godine bio je Dekan Mašinskog Fakulteta Univerziteta u Nišu. Bio je i član Senata Univerziteta u Nišu. Od 2009. do 2018. godine bio je član Matičnog odbora za mašinstvo pri Ministarstvu nauke i tehnološkog razvoja Republike Srbije. Od 2016. godine se nalazi na funkciji Šefa Katedre za proizvodno-informacione tehnologije na Mašinskom fakultetu u Nišu.

dr Milica PETROVIĆ, vanr. prof.

Dr Milica M. Petrović, vanredni profesor Mašinskog fakulteta Univerziteta u Beogradu, rođena je 28.08.1986. godine u Gornjem Milanovcu, Republika Srbija. Osnovnu školu „Sava Kerković“ i gimnaziju „Hiljadu trista kaplara“ u Ljigu završila je sa odličnim uspehom, a za postignute rezultate je nagrađena diplomama „Vuk Stefanović Karadžić“. Na Mašinski fakultet Univerziteta u Beogradu upisala se školske 2005/2006. godine. Osnovne akademske studije završila je 2008. godine sa prosečnom ocenom 9,86 (devet i 86/100) i ocenom 10 (deset) na završnom (BSc) radu pod nazivom „Analiza mogućnosti primene robokolica u fleksibilnom tehnološkom sistemu za izradu limenki“ iz predmeta Tehnologija mašinske obrade (mentor prof. dr Zoran Miljković). Školske 2008/2009. godine upisala je Master akademske studije na Katedri za proizvodno mašinstvo, a iste je završila 28. septembra 2010. godine sa prosečnom ocenom 10 (deset), odbranivši diplomski-master rad (MSc) na temu „Prilog razvoju inteligentnog tehnološkog sistema u domenu unutrašnjeg transporta baziran na mašinskom učenju“ iz predmeta Inteligentni tehnološki sistemi (mentor prof. dr Zoran Miljković), sa ocenom 10 (deset). Ukupna prosečna ocena tokom studija je 9,93 (devet i 93/100). Doktorsku disertaciju pod nazivom „Veštačka inteligencija u projektovanju inteligentnih tehnoloških sistema“ odbranila je 24.06.2016. godine na Mašinskom fakultetu Univerziteta u Beogradu pred Komisijom u sastavu dr Zoran Miljković, redovni profesor (mentor), dr Bojan Babić, redovni profesor, dr Miloš Glavonjić, redovni profesor, dr Milan Zeljković, redovni profesor, dr Miodrag Manić, redovni profesor.

Nagrađivana je povodom Dana Mašinskog fakulteta za izvanredan uspeh postignut na svim godinama Osnovnih akademskih studija (šk. 2005/2006, 2006/2007. i 2007/2008. godina) i Master akademskih studija (šk. 2008/2009. i 2009/2010. godina). Dobila je nagradu za najboljeg studenta na trećoj godini Osnovnih studija, prvoj i drugoj godini Master akademskih studija, kao i za najboljeg studenta na Master akademskim studijama. Dobitnica je Godišnje nagrade Privredne komore Beograda za najbolji master rad studenata za školsku 2009/2010. godinu, kao i Priznanja na 34. Međunarodnom Savetovanju proizvodnog mašinstva održanom 2011. godine u Nišu za najbolju prezentaciju rada mladih istraživača (istraživači mlađi od 30 godina). Nagrada Zadužbine „Rodoljub Nićiforović“ za odbranjenu doktorsku disertaciju i uspeh postignut tokom studija dodeljena joj je 2016. godine. Udruženje studenata tehnike Evrope – BEST Beograd dodelilo joj je zahvalnicu za učešće (žiriranje) u lokalnom inženjerskom takmičenju EBEC Beograd, održanom od 9. do 13. marta 2017. godine. Dobitnica je Zahvalnice za učešće na školskom Festivalu nauka „Unaukuj se!“, u organizaciji Osnovne škole „Kralj Petar Prvi“. Nagrada Društva robotičara, naučnog i organizacionog odbora međunarodne konferencije „New Technologies, Development and Application“ NT-2019, Bosna i Hercegovina, Sarajevo, dodeljena joj je 2019. godine kao najmlađem docentu na konferenciji za ostvaren značajan doprinos transferu nauke i novih tehnologija u proizvodnom i tehnološkom razvoju. Takođe, primala je stipendije Ministarstva prosvete Republike Srbije (od 2001. do 2009. godine), Asocijacije „Seine et Sava“, Pariz, Francuska (od 2007. do 2011. godine), stipendije Fonda za mlade talente Ministarstva omladine i sporta Vlade Republike Srbije – najboljih 1000 studenata (šk. 2009/2010. godina), stipendije Saveza studenata Beograda (od 2011. do 2013. godine), kao i stipendiju Ministarstva prosvete, nauke i tehnološkog razvoja za postdoktorsko usavršavanje u Centru za automatizaciju i robotiku, Madrid, Španija (2019. godine).

Od 1. januara 2011. godine zaposlena je na Mašinskom fakultetu u Beogradu, prvo kao stručni saradnik na naučnoistraživačkom projektu tehnološkog razvoja „Inovativni pristup u primeni inteligentnih tehnoloških sistema za proizvodnju delova od lima zasnovan na ekološkim principima“, koji finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Vlade Republike Srbije (evid. br. TR-35004, rukovodilac projekta prof. dr Bojan Babić), a zatim, od 1. maja 2011. godine, i kao asistentkinja na Katedri za proizvodno mašinstvo. Nakon odbranjene doktorske disertacije, 27.12.2016. godine izabrana je u zvanje docenta za užu naučnu oblast Proizvodno mašinstvo. Trenutno ima zvanje vanredni profesor na Mašinskom fakultetu u Beogradu.

Kandidatkinja dr Milica Petrović koautor je jednog osnovnog udžbenika, 7 poglavlja u knjigama, monografijama i tematskim zbornicima međunarodnog značaja, 11 radova objavljenih u istaknutim, vodećim međunarodnim časopisima, 5 radova objavljenih u nacionalnim časopisima, kao i 28 radova u zbornicima međunarodnih i 11 radova u zbornicima nacionalnih naučnih skupova. Istovremeno, kao autor ili koautor, realizovala je 11 tehničkih rešenja, dva tehnička izveštaja i dva skupa podataka u okviru naučno-istraživačkih projekata na kojima je učestvovala. Ukupan broj citata naučnih radova kandidatkinje prema Scopus bazi je 306 (h-index = 8), prema bazi Research Gate je 427, dok je prema bazi Google Scholar 506 (h-index = 11, i10-index = 11).

U ZNAK SEĆANJA
IN MEMORIAM

Prof. dr RADOMIR V. SLAVKOVIĆ (1952-2021)

Dr Radomir V. Slavković, redovni profesor u penziji, dugogodišnji član kolektiva Fakulteta tehničkih nauka u Čačku rođen je 1952. godine u Guči. Posle osnovnog obrazovanja u rodnom selu Rti i Guči, profesor Slavković je završio Tehničku školu u Čačku. Diplomirao je 1976. godine na Mašinskom fakultetu u Beogradu. Na istom Fakultetu 1983. godine završio je magistarske studije na grupi za proizvodno mašinstvo i primenu kompjutera i podgrupi proizvodne tehnike odbranom magistarskog rada „Identifikacija dinamičkog ponašanja obradnog sistema za duboko bušenje“. Doktorsku disertaciju pod naslovom „Prilog problematici instalisanja mašina alatki“ odbranio je 1993. godine, takođe na Mašinskom fakultetu u Beogradu. Izuzetno vredan i radan, a nada sve pošten, o profesoru Slavkoviću njegovi drugovi sa studija jedinstveni su u mišljenju: -Bio je najbolji student u generaciji na proizvodnom mašinstvu.-

Kao stipendista Industrijskog kombinata „GUČA“ u Guči, po završetku studija u Kombinatu je počeo svoju profesionalnu karijeru. U toku dvadesetpetogodišnjeg rada u tom preduzeću bio je na pozicijama vodećeg tehnologa, vodećeg konstruktora, upravnika pogona, direktora službe za razvoj i tehničkog direktora preduzeća. Na nekadašnjem Tehničkom, a danas Fakultetu tehničkih nauka u Čačku dr Radomir Slavković izabran je za docenta 1994. godine, za predmet Proizvodne mašine i numeričko upravljanje mašinama. U februaru 2000. godine, izabran je za vanrednog profesora za predmete: Programsko upravljanje i Programsko upravljanje mašinama i procesima. Naučno zvanje redovnog profesora univerziteta stekao je 2005. godine za predmete iz naučne oblasti Proizvodne tehnologije.

Iz naučno-istraživačke aktivnosti, široj naučnoj javnosti prezentovao je brojne radove na nacionalnim i međunarodnim stručnim i naučnim skupovima i u časopisima. Lista referenci profesora dr Radomira Slavkovića broji 192 naslova, od kojih je 21 rad na SCI listi u kategorijama M21, M22 i M23.

Rukovodio je ili učestvovao u istraživačkim timovima u realizaciji više od 12 projekata koje je podržalo Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije. Brojne projekte realizovao je kao višedecenijski saradnik Istraživačko-razvojnog instituta „Lola“ u Beogradu i saradnik više industrijskih preduzeća među kojima su: Kolubara-Lazarevac, Termoelektrana-Kostolac, Industrijski kombinat „Guča“, Namenska industrija „Milan Blagojević“ Lučani. Realizator je više tehničkih rešenja, koja su našla primenu u metaloprerađivačkoj industriji, industriji papira i celuloze i elektroprivredi.

Napisao je monografiju nacionalnog značaja pod nazivom „Tehnologija fundiranja obradnih sistema“ i udžbenike: „Programsko upravljanje mašinama alatkama - sistemi i tehnike“ i „Programsko upravljanje mašinama alatkama - programiranje mašina alatki sa primerima“.

Na Fakultetu tehničkih nauka u Čačku rukovodio je i bio član tima koji je radio pripremu studijskog programa Mehatronika za akreditaciju 2009. i 2014. godine. Od 2009. godine bio je rukovodilac osnovnih i master akademskih studija Mehatronike, a od 2014. godine rukovodilac doktorskih akademskih studija Mehatronike. Takođe, na Fakultetu tehničkih nauka u Čačku, bio je šef katedre za Mehatroniku od 2014. godine do 2018. godine, predsednik Saveta Fakulteta tehničkih nauka u periodu 2006-2009. godine i prodekan za finansije od 2010. do 2012. godine. Na Univerzitetu u Kragujevcu, bio je član Suda časti Univerziteta od 2006. do 2009. godine i član Senata Univerziteta u Kragujevcu u dva mandata od 2013. do 2018. godine.

Održao je brojna predavanja po pozivu, u zemlji i u inostranstvu. Predsedavao je više puta sekcijama „NU-ROBOTI-FTS” i „CAD/CAM” na „JUPITER” konferencijama koje tradicionalno organizuje Mašinski fakultet u Beogradu. Od 2007-2011. godine bio je član Matičnog naučnog odbora za mašinstvo Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije, a od 2013- 2018. godine bio je član Izvršnog odbora Zajednice institucija proizvodnog mašinstva Srbije.

Rukovodio je ili bio član komisija za odbranu više od 150 diplomskih radova, mentor ili član komisija za odbranu preko 60 master radova, mentor magistarskog rada i mentor doktorske disertacije i član komisija za odbranu doktorskih disertacija i član komisija za izbor u sva saradnička i nastavnička zvanja na Fakultetu tehničkih nauka u Čačku, Fakultetu inženjerskih nauka u Kragujevcu i Fakultetu za mašinstvo i građevinarstvo u Kraljevu.

Za doprinos razvoju industrije i unapređenje privrednog ambijenta, prof. dr Radomir Slavković bio je nosilac brojnih priznanja i nagrada. Pogon „Kombinata“ kojim je rukovodio dobio je za postignute poslovne rezultate „Plaketu saveza sindikata” 1983. godine. Dobitnik je nagrade „Dan republike“ za 1987. godinu koju mu je dodelila Privredna komora Srbije. Iz oblasti neposrednog rada u industriji bio je dobitnik više fabričkih, mesnih i opštinskih nagrada.

Prof. dr Radomir Slavković bio je u penziji od 2018. godine. U sećanju kolega sa kojima je sarađivao i doprinosio da Fakultet tehničkih nauka postane važno i prepoznatljivo mesto na mapi visokoobrazovnih ustanova u Srbiji, ostaće upamćen kao vredan, pošten, precizan i disciplinovan čovek sa izuzetnim ljudskim osobinama. Njegovi najbliži saradnici pamtiće ga po posebnom odnosu, roditeljskoj brizi i spremnosti da im pomogne u svakom trenutku.

Prof. dr Radomir Slavković upokojio se na Božić, 7. januara 2021. godine u 69-oj godini.

Dr. Nedeljko Dučić
Dr. Ivan Milićević

Prof. dr JOKO P. STANIĆ (1930-2021)

Dr Joko P. Stanić, diplomirani mašinski inženjer, redovni profesor Mašinskog fakulteta Univerziteta u Beogradu, rođen je 1930. godine u Boanu, Bare, Crna Gora. Mašinski fakultet u Beogradu upisao je 1955. godine. Krajem 1960. godine odbranom diplomskog rada iz predmeta Mašinska obrada II, završio je studije na Mašinskom fakultetu u Beogradu. Početkom 1961. god. izabran je za asistenta za predmet Mašinska obrada na Mašinskom fakultetu u Beogradu. Poslediplomske studije na Mašinskom fakultetu u Beogradu upisao je 1963. godine a iste završio 1966. godine odbranom magistarskog rada sa temom „Ispitivanje reznih sposobnosti zavojnih burgija u zavisnosti od njihove geometrije".

Za docenta za predmet Mašinska obrada na Mašinskom fakultetu u Beogradu izabran je1968. godine. Više godina držao predavanja iz predmeta Tehnološki pribori i provera u Višoj tehničkoj školi u Čačku. Posle izbora u zvanje docenta 1968. držao je predavanja iz predmeta: Mašinska obrada na Mašinskom fakultetu i Tehnološki pribori i provera u Odeljenju Mašinskog fakulteta u Kragujevcu. Od 1969. god. Izvodio je nastavu iz novog predmeta Merenje i kvalitet obrade. Doktorsku disertaciju „Istraživanje optimalnih nivoa izlaznih karakteristika procesa bušenja konstrukcijskih čelika pri simetričnim i nesimetričnim formama alata" odbranio je juna 1974. godine na Mašinskom fakultetu u Beogradu. Za vanrednog profesora izabran je 1975. godine a unapređen u zvanje redovnog profesora 1980. godine za grupu predmeta proizvodnog mašinstva.

Kao redovni profesor predavao je više predmeta, kako na Mašinskom fakultetu u Beogradu tako i u odeljenjima Fakulteta u Užicu i Valjevu, i to: Mašinska obrada (Tehnologija mašinogradnje), Mašinska obrada II, Merenje i kvalitet obrade, Tehnološki merni sistemi, Teorija obrade metala, Upravljanje kvalitetom proizvodnje.

Bio je mentor pri izradi oko 100 diplomskih radova. Izvodio nastavu na poslediplomskim studijama iz više predmeta, i to na Mašinskom fakultetu u Beogradu: Metod inženjerskih merenja (deo predmeta), Nauka o rezanju (deo predmeta),Teorija mernih lanaca, Osnove tehnoekonomske optimizacije, kao i na drugim mašinskim fakultetima u tadašnjoj Jugoslaviji: Fakultet strojarstva i brodogradnje u Zagrebu (Optimizacija tehnoloških procesa), Fakultet tehničkih nauka u N. Sadu (Teorija tehnoekonomske optimizacije), Mašinski fakultet u Mostaru (Optimizacione metode), Mašinski fakultet Univerziteta u Nišu (Metod naučnoistraživačkog rada i planiranje eksperimenata), Mašinski fakultet u Kraljevu (Teorija mernih lanaca i Teorija tehnoekonomske optimizacije). Bio je mentor kod izrade preko 30 magistarskih teza i doktorskih disertacija. Napisao je samostalno oko 40 udžbenika i priručnika iz predmeta koje je predavao, koji su imali veliki broj dopunjenih i ponovljenih izdanja. Koautor je velikog broja udžbenika, priručnika i monografija.

Svoju veoma bogatu naučnoistraživačku delatnost obavljao je preko Zavoda za mašine alatke i Instituta za proizvodno mašinstvo i primenu kompjutera Mašinskog fakulteta kao i Instituta za alatne mašine i alate (IAMA) u Beogradu. Pri tome je sam izvodio određena ispitivanja i rukovodio istraživanjima u okviru velikog broja naučnih projekata, koji su finansirani od strane privrede i društvenih fondova. Rezultat projekta prof. J. Stanića „Ispitivanje obradljivosti pri obradi rezanjem domaćih konstrukcijskih materijala alatima domaće proizvodnje” u operacijama obrade struganjem, glodanjem, bušenjem, rezanjem navoja, brušenjem i provlačenjem, u čijem finansiranju je učestvovao vrlo veliki broj industrijskih preduzeća iz svih republika bivše Jugoslavije (železare, proizvođači alata, mašinska i automobilska industrija i drugi) su preko 200 objavljenih naučnih i stručnih radova štampanih u zemlji i u inostranstvu, oko 50 elaborata i studija i drugih radova ograničene cirkulacije. Sa svojim radovima učestvovao je na velikom broju održanih naučno-stručnih skupova i konferencija i većini održanih Savetovanja proizvodnog mašinstva.

Dobitnik je Ordena rada sa srebrenim vencem od strane Predsedništva SFRJ za dugogodišnji uspešan stručni, naučni i društveni rad, Povelje i Plakete „Prof. dr Pavle Stanković” 1994. od strane Zajednice institucija proizvodnog mašinstva SR Jugoslavije za ukupan doprinos razvoju proizvodnog mašinstva kao i veći broj Plaketa i Zahvalnica Mašinskog fakulteta u Beogradu i drugih mašinskih fakulteta u Srbiji.

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ZBORNIK BIOGRAFIJA
NASTAVNOG OSOBLJA MAŠINSKOG FAKULTETA

Sadržaj
Table of Contents

UVODNI RADOVI

PLENARY PRESENTATIONS

Society of Production Engineering

SPMS 2021

38. Savetovanje Proizvodnog mašinstva Srbije

ICPE-S 2021

38th International Conference on Production Engineering -Serbia

Faculty of technical sciences Čačak
University of Kragujevac

Čačak, Serbia, 14 – 15. October 2021

PROFESOR ŠOLAJA – OSNIVAČ SAVETOVANJA PROIZVODNOG MAŠINSTVA

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Abstrakt: *Profesor dr hc. dr Vladimir B. Šolaja je definisao proizvodno mašinstvo kao posebnu naučnu disciplinu u oblasti mašinskog inženjerstva, koja se pre njega izučavala samo kroz jedan predmet "Mašine alatke" na Mašinskom fakultetu u Beogradu. Osnovao je 1963. godine Institut za alatne mašine i alate (IAMA) u Beogradu, prvi i jedini samostalni institut za proizvodno mašinstvo na prostorima bivše Jugoslavije. Bio je direktor Instituta IAMA od osnivanja, a istovremeno je bio i šef Katedre za proizvodno mašinstvo Mašinskog fakulteta u Beogradu do odlaska u penziju 1985. godine. Izabran je za redovnog člana CIRP-a 1966. godine, kao prvi jugoslovenski profesor proizvodnog mašinstva. Dobitnik je počasnog doktorata, kao jedini doktor tehničkih nauka iz reda profesora Univerziteta u Beogradu. Osnovao je Savetovanje proizvodnog mašinstva Jugoslavije 1965. godine, kao najznačajniji naučni skup proizvodnih inženjera, koji se i danas održava. U okviru poslediplomskih studija uveo je novi predmet "Metod i organizacija naučno-istraživačkog rada – MONIR", koji je predavao ne samo na Mašinskom fakultetu u Beogradu, već i na mašinskim fakultetuma širom bivše Jugoslavije. Skoro svi magistranti i doktoranti profesora Šolaje su postali univerzitetski profesori, a njegovi studenti i diplomci su bili više decenija nosioci razvoja proizvoda i tehnologija naše metaloprerađivačke industrije. Do kraja života se bavio istorijom srpskog inženjerstva kroz nacionalni projekat PINUS. Zbog izuzetnog inženjerskog, naučno-istraživačkog i obrazovnog doprinosa, profesor Šolaja je svakako najznačajnija ličnost u istoriji proizvodnog mašinstva na našim prostorima.*

Keywords: *Profesor Šolaja, proizvodno mašinstvo.*

1. KRATAK ISTORIJAT PROIZVODNOG MAŠINSTVA

Planirani razvoj železnice u Srbiji, uticao je na uvođenje 1873. godine novog predmeta "Mehanika i nauka o mašinama" na Tehničkom fakultetu Velike škole u Beogradu, koga je predavao rudarski inženjer Ljubomir Klerić (1844-1910), kao prvi profesor mašinstva u Srbiji. Do razdvajanja ovog predmeta došlo je 1887. godine, pa je "Mehaniku" nastavio da predaje profesor Klerić, a "Nauku o mašinama" je predavao železnički inženjer Svetozar Zorić (1853-1931). Novi predmet "Mehanička tehnologija" je uveden 1895. godine, a za profesora je imenovan Todor Selesković (1856-1901), prvi srpski konstruktor mašina alatki. Prerastanjem Velike škole u Univerzitet u Beogradu 1905. godine i promenama na Tehničkom fakultetu je uveden prvi predmet iz oblasti proizvodnog mašinstva “Mašine alatljike”, koga je predavao železnički inženjer i prvi projektant srpskih hidroelektrana profesor Aćim Stevović (1866-1957). Po završetku Prvog svetskog rata, Tehnički fakultet Univerziteta u Beogradu je primio određen broj ruskih profesora, koji su emigrirali u Srbiju posle Oktobarske revolucije, među kojima je bio i Aleksandar Ivanovič Kosicki (1880-1954), specijalista za motore sa unutrašnjim sagorevanjem, parne kotlove i gasne generatore. Profesor Kosicki je predavao “Mašine alatke” u periodu 1922-1941. godine i objavio je prvi univerzitetski priručnik proizvodnog mašinstva “Mašine alatke” 1932. godine. Posle Drugog svetskog rata, formiran je samostalni Mašinski fakultet u Beogradu, a predmet “Mašine alatke” je predavao konstruktor aviona, vazduhoplovni inženjer profesor Pavle Stanković (1909-1969). Početkom 1949. godine Vladimir Šolaja je diplomirao na predmetu “Mašine alatke” i počeo da radi kao asistent i prvi saradnik profesora Stankovića na Mašinskom fakultetu u Beogradu. Vladimir Šolaja se intenzivno bavio naučno-istraživačkim radom u oblasti proizvodnog mašinstva i postao svetski poznat i priznat naučnik.

2. PROFESOR VLADIMIR B. ŠOLAJA, NAJZNAČAJNIJA LIČNOST PROIZVODNOG MAŠINSTVA NA NAŠIM PROSTORIMA

Vladimir B. Šolaja (sl. 1) je rođen 1920. godine u Zagrebu, gde je završio osnovnu školu, gimnaziju i četiri semestra na Strojarskom odseku Tehničkog fakulteta. Njegov otac prof. dr Bogdan Šolaja (1883-1956) je bio poznati profesor hemije na Poljoprivredno-šumarskom fakultetu Sveučilišta u Zagrebu. Prekinuo je studije početkom Drugog svetskog rata ulaskom nemačkih okupacionih snaga u Zagreb i sticajem srećnih okolnosti sa porodicom izbegao u Srbiju. Po oslobođenju Beograda 1944. godine pridružio se jedinicama narodnooslobodilačke vojske, a demobilisan je okrobra 1945. godine radi nastavka studija na Mašinskom fakultetu u Beogradu. Posle diplomiranja na opštemašinskom odseku, primljen je 1949. godine kao asistent za predmet “Mašine alatke”. U zvanje docenta za predmet “Mašinska obrada” izabran je 1958. godine, unapređen je u zvanje vanrednog profesora 1961., a 1969. godine je izabran za redovnog profesora Mašinskog fakulteta u Beogradu.

Posle specijalističkih boravaka u Velikoj Britaniji tokom 1952., posle naučno-istraživačkog rada u vreme 1956-58. godine u poznatom engleskom univerzitetskom centru Volverhempton u Birmingenu, obimnih eksperimentalnih istraživanja tehnološkog procesa završne obrade na strugu u Zavodu za mašine alatke Mašinskog fakulteta (sl. 2) i u Institutu za alatne mašine i alate u Beogradu, okončao je doktorsku disertaciju, koju je odbranio u zvanju redovnog profesora 1972. godine na Mašinskom fakultetu u Beogradu.

Slika 1. Profesor dr Vladimir B. Šolaja

Slika 2. Inž. Vladimir Šolaja izvodi eksperimente u Zavodu za mašine alatke Mašinskog fakulteta u Beogradu

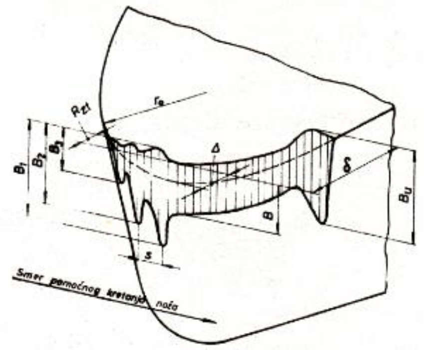
Kao istaknuti naučnik, profesor Vladimir Šolaja je primljen 1966. godine u najznačajniju naučnu organizaciju u svetu, internacionalnu akademiju za proizvodno mašinstvo CIRP (Collège International pour la Recherche en Productique) koja je osnovana 1950. godine sa sedištem u Parizu. Šolaja je prvi profesor proizvodnog mašinstva sa prostora bivše Jugoslavije koji je postao redovni član CIRP-a, a zahvaljujući njemu, članovi CIRP-a su postali i njegovi bliski saradnici profesori Mašinskog fakulteta u Beogradu prof. dr Vladimir Milačić i prof. dr Milisav Kalajdžić.

Za ostvarene naučnoistraživačke rezultate, dobio je 1962. godine najveće republičko priznanje Sedmojulsku nagradu, a dodeljen mu je počasni doktorat Univerziteta u Beogradu 1991. godine. Posle smrti prof. dr Pavla Stankovića 1969. godine je izabran za šefa Katedre za tehnologiju, da bi 1972. godine formirao Katedru za proizvodno mašinstvo Mašinskog fakulteta u Beogradu, kojom je rukovodio od osnivanja do odlaska u penziju 1985. godine.

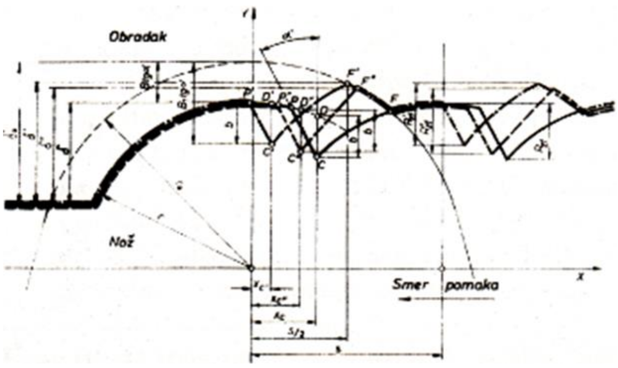
Proofesor Šolaja je kao prodekan za nastavu organizovao prve poslediplomske magistarske studije na Mašinskom fakultetu u Beogradu, da bi 1971. godine organizovao i prve poslediplomske studije u oblasti proizvodnog mašinstva. Bio je mentor preko 400 diplomskih radova, mentor 22 magistarska rada i 15 doktorskih disertacija. Spisak njegovih objavljenih radova, elaborata, monografija, priručnika i studija obuhvata 354 reference, koje su i danas veoma aktuelne.

3. KONCENTRISANO HABANJE ALATA

Profesor Šolaja je postao poznat u svetskim naučnim krugovima po svojim istraživanjima fenomena "koncentrisanog habanja alata" pri obradi metala rezanjem (sl. 3). Prvi u svetu je definisao funkcionalnu zavisnost između kvaliteta obrađene površine, geometrijskih parametara sečiva alata i elemenata režima rezanja pri završnoj obradi struganjem (sl. 4). To je bila i tema njegove doktorske disertacije, u okviru koje je čitavu deceniju izvodio eksperimente proveravajući svoj model i dokazujući njegovu praktičnu primenu. Koncentrisano habanje alata je bilo tema velikih rasprava na zasedanjima CIRP-a i diskusija na najznačajnijim naučnim skupovima u svetu, posle kojih je profesor Šolaja ušao u red najvećih svetskih naučnika u oblasti proizvodnog mašinstva Tajlora, Opica i Merčanta.



Slika 3. Karakteristične veličine koncentrisanog habanja sečiva alata



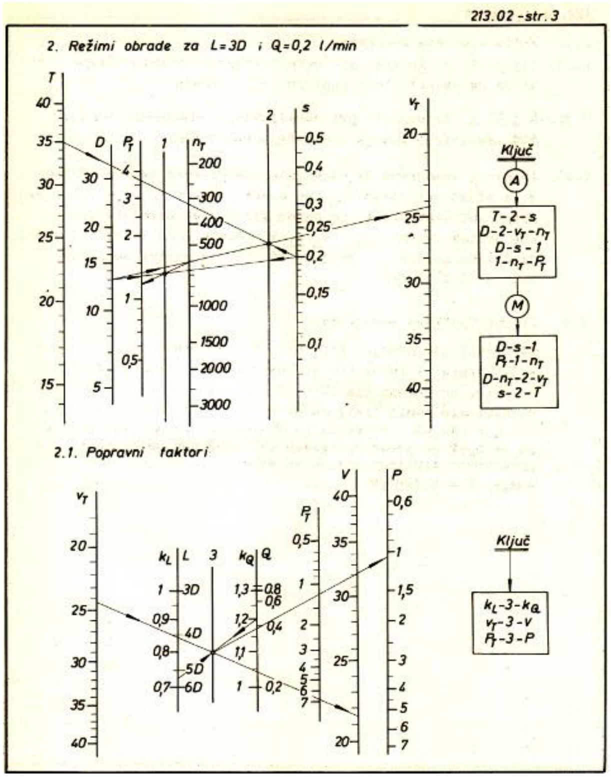
Slika 4. Model koncentrisanog habanja alata profesora Šolaje

Profesor Šolaja je prvi pokrenuo naučno-istraživačku delatnost u oblasti proizvodnog mašinstva u bivšoj Jugoslaviji. Svi njegovi prethodnici, profesori "Mašina alatki" su bili istaknuti inženjeri, projektanti i konstruktori, a on je radio na razvoju teorije obrade metala rezanjem, eksperimentalnim istraživanjima fenomenoloških pojava u obradnim procesima i razvijao primenjena istraživanja za praktičnu primenu u metaloprerađivačkoj industriji.

4. MISIJA PROFESORA ŠOLAJE

Profesor Šolaja se ceo život zalagao za razvoj nauke i istraživanja na univerzitetskom nivou i saradnju sa privredom. Smatrao je da su najznačajniji oni naučni rezultati koji se mogu primeniti u domaćoj industriji i doprineti privrednom i ekonomskom napretku zemlje. U tom cilju je 1963. godine osnovao Institut za alatne mašine i alate (IAMA) u Beogradu, prvi i jedini samostalni institut proizvodnog mašinstva u Jugoslaviji, poznat kao Šolajin institut. Institut IAMA je imao tri osnovne istraživačke oblasti: mašine alatke, alati sa ispitivanjem obradljivosti i grupna tehnologija sa organizacijom proizvodnje, na kojima je radilo oko tridesetak istaknutih istraživača. Profesor Šolaja je izdavao monografije IAMA, priručnike IAMA, časopis "Saopštenja IAMA", kasnije "LOLA Saopštenja", publikaciju Vesti IAMA&KAPROM i dostavljao privrednim organizacijama i naučno-stručnoj javnosti sa ciljem prezentacije rezultata istraživanja Instituta IAMA. Institut IAMA je imao laboratorije na Mašinskom fakultetu u Beogradu, a profesor Šolaja je bio direktor sve do odlaska u penziju 1985. godine, kada je Institut IAMA ušao u sastav Industrije Ivo Lola Ribar i nastavio sa radom pod imenom LOLA Institut. Profesor Šolaja je bio savetnik i predsednik Naučnog veća LOLA Instituta do kraja svog života.

"Rezna sposobnost zavojnih burgija", je prvi istraživački projekat u oblasti obrade metala rezanjem u našoj zemlji, koji je profesor Šolaja realizovao sa svojim saradnicima 1963. godine, za potrebe Industrije alata iz Trebinja. Naredne 1964. godine, organizovao je prvi naučni skup u oblasti proizvodnog mašinstva u Trebinju, na kome su saopšteni rezultati ovog projekta. Pokrenuo je 1965. godine makroprojekt SIO (Sistematsko ispitivanje obradljivosti pri obradi rezanjem domaćih konstrukcionih materijala domaćim alatima) najveći istraživački projekat u istoriji proizvodnog mašinstva, koji je okupljao sve naše železare, proizvođače alata i nekoliko desetina najvećih preduzeća industrije prerade metala iz svih republika bivše Jugoslavije. Projekat SIO se realizovao do 1979. godine, a profesor Šolaja je sve vreme bio rukovodilac ovog projekta. Rezultati sistematskog istraživanja obradljivosti preko 50 vrsta domaćih čelika u različitim termičkim stanjima, pri obradi struganjem (grubo i završno), glodanjem valjkastim, koturastim, vretenastim glodalima i glodačkim glavama, bušenjem, proširivanjem, razvrtanjem i urezivanjem navoja, zatim ravnim i kružnim brušenjem, su kontinualno objavljivani u okviru Priručnika IAMA "Režimi rezanja", poznatog kao "Šolajina crna knjiga" (sl. 5). U okviru projekta SIO je odbranjeno nekoliko stotina diplomskih radova, preko trideset magistarskih radova i preko dvadeset doktorskih disertacija.



Slika 5. Priručnik IAMA – Režimi obrade (nomogrami za određivanje režima rezanja i popravnih faktora pri bušenju)

U vreme pokretanja projekta SIO, profesor Šolaja je ostvario kontakte sa Institutom za alatne strojeve u Zagrebu, Institutom za strojništvo u Ljubljani i iste 1965. godine organizovao Prvo savetovanje proizvodnog mašinstva Jugoslavije u Beogradu. Nosilac organizacije je bio Šolajin Institut IAMA, a savetovanje je održano na Mašinskom fakultetu u Beogradu.

Profesor Šolaja je tada formirao i Zajednicu naučno-istraživačkih institucija proizvodnog mašinstva, pa su naredna savetovanja održana u Zagrebu, Ljubljani, Sarajevu, Kragujevcu, … . U organizaciji prvih pet savetovanja je direktno učestvovao profesor Šolaja, a Zbornike radova je štampao Institut IAMA. Pisao je uvodne referate za skoro svako Savetovanje proizvodnog mašinstva, a njegov uvodni referat napisan na preko stotinu strana za jubilarno X Savetovanje je najozbiljnija studija sveukupnog tadašnjeg stanja industrije prerade metala u našoj zemlji. Profesor Šolaja je visoko uvažavao svoje profesore, a iz poštovanja prema prof. dr Pavlu Stankoviću, predložio je 1983. godine dodelu povelje i plakete sa njegovim imenom, koja se od tada dodeljuje na Savetovanju proizvodnog mašinstva kao priznanje istaknutim naučno-istraživačkim radnicima za izuzetne doprinose razvoju proizvodnog mašinstva.

Drugi kapitalni makroprojekat ROPOS – Razvoj i optimizacija obradnih sistema, koji se realizovao u periodu 1970-1985. godine, predstavlja viziju razvoja proizvodnog mašinstva profesora Šolaje u narednih pola veka. Projektom je obuhvaćen razvoj novih metoda proračuna i projektovanja proizvoda, sistem modularno projektovanje mašina alatki, koncept grupne i tipske tehnologije, sistem upravljanja proizvodnjom, istraživanje tehnoloških procesa i nekonvencionalnih postupaka obrade metala, razvoj CNC mašina alatki, primena računara u projektovanju proizvoda i tehnologija, industrijska automatizacija i primena robotskih sistema u industrijskoj proizvodnji. Uporno je nastojao da realizuje ideju intenzivnijeg razvoja istraživanja na univerzitetu za potrebe privrede kroz pokušaj integracije Instituta IAMA sa Katedrom za proizvodno mašinstvo Mašinskog fakulteta u Beogradu. Posle tri neuspela referenduma za integraciju 1972. godine, shvatio je da njegova misija neće biti ispunjena. Posle toga je podržao ulazak Instituta IAMA u poslovni sistem industrije Ivo Lola Ribar, našeg najvećeg proizvođača mašina alatki i industrijske opreme i formiranje LOLA Instituta.

5. PROIZVODNO MAŠINSTVO – NAUČNA DISCIPLINA MAŠINSKOG INŽENJERSTVA

Četiri decenije je predmet “Mašine alatke” bio jedini u oblasti proizvodnog mašinstva koji se izučavao na Tehničkom fakultetu, a zatim na Mašinskom fakultetu Univerziteta u Beogradu. Školske 1945/46. godine uveden je novi predmet “Mašine alatke i industrijska proizvodnja mašina”, a kada su formirane katedre 1948. godine, nastava na ovom predmetu se odvijala u okviru Katedre za osnove mašinstva sve do 1956. godine. Profesor Šolaja se na početku svoje univerzitetske karijere zajedno sa prof. dr Pavlom Stankovićem angažovao na formiranju Zavoda za mašine alatke, a zatim na uvođenju novih predmeta proizvodnog mašinstva. Školske 1956/57. godine formirana je Katedra za industrijsku proizvodnju kojom je rukovodio prof. dr Pavle Stanković i uvedeni su novi predmeti “Radioničko upoznavanje” sa težištem na laboratorijskim vežbama osnovnih tehnoloških operacija obrade metala rezanjem i “Projektovanje mašina alatki” sa proračunima i obaveznim projektom podsklopova mašina alatki. Uvedeno je deset usmerenja 1957. godine, među kojima i Industrijsko-proizvodni smer sa predmetima “Mašine alatke”, “Mašinska obrada” i “Mašinska obrada II”. Ove premete je predavao prof. dr Pavle Stanković, a od 1958. godine predmet “Mašinska obrada II” je predavao docent Vladimir Šolaja. Uvođenjem stepenaste nastave 1960/61. godine formirana je Katedra za tehnologiju, koja je obuhvatala pored oblasti proizvodnog mašinstva i oblast mašinskih materijala. Tada su uvedeni predmeti “Mašine alatke i oprema”, “Tehnološki sistemi” i “Tehnološki pribori i provera”. U to vreme dekan Mašinskog fakulteta u Beogradu je bio prof. dr Pavle Stanković i šef Katedre za tehnologiju sve do svoje smrti 1969. godine, kada je rukovođenje katedrom preuzeo profesor Šolaja. Profesor Šolaja je 1961. godine primio svoje prve asistente (Vladimira Milačića, Joka Stanića, Milenka Jovičića i Ljiljanu Dimitrijević), koji su bili i njegovi prvi saradnici u Institutu IAMA. Stepenaste studije su ukinute školske 1966/67. godine, a novi program je obuhvatao niz novih predmeta proizvodnog mašinstva. Uvedene su poslediplomske studije u oblasti proizvodnog mašinstva, a organizacionim promenama 1972. godine formirana je Katedra za proizvodno mašinstvo na Mašinskom fakultetu u Beogradu. Do tada su naučne discipline proizvodnog mašinstva pripadale drugim katedrama, pa se može konstatovati da je profesor Šolaja osnivač i prvi šef Katedre za proiztvodno mašinstvo na Mašinskom fakultetu u Beogradu, koji je najviše doprineo da proizvodno mašinstvo postane jedna od glavnih naučnih disciplina mašinskog inženjerstva.

Počevši od 1960. godine, otvarani su drugi Mašinski fakulteti širom zemlje, a profesor Šolaja je dao ogroman doprinos razvoju proizvodnog mašinstva i na tim novootvorenim fakultetima. Uveo je novi predmet na treći stepen studija mašinstva "Metod i organizacija naučno-istraživačkog rada – MONIR" koji je predavao skoro do kraja života, ne samo na Mašinskom fakultetu u Beogradu, već i na mašinskim fakultetima u Kragujevcu, Kraljevu, Nišu, Skoplju, Titogradu, Mostaru, Sarajevu, Banja Luci, Zenici i Fakultetu tehničkih nauka u Novom Sadu. Njegov priručnik MONIR je štampan u više izdanja i danas je redovna literatura na doktorskim studijama svih Mašinskih fakulteta u Srbiji.

6. PROJEKAT PINUS PROFESORA ŠOLAJE

Profesor Šolaja se čitav radni vek bavio istorijom proizvodnog mašinstva, organizovao stručne skupove posvećene jubilejima obrazovanja proizvodnih inženjera, jubilejima Instituta IAMA i organizovao tematski skup "Dan proizvodnog mašinstva" u Beogradu. Po odlasku u penziju u potpunosti se posvetio istraživanju istorije srpskog inženjerstva, kroz projekat PINUS – Putevima inženjerstva u Srbiji (i u Srba), na kome je radio kao rukovodilac i koordinator do kraja života (sl. 6).

Slika 6. Izlaganje profesora Šolaje na temu istorije srpskog inženjerstva 1996. godine

Projekat PINUS je podržavalo Ministarstvo za nauku i tehnologiju, Zajednica tehničkih fakulteta Univerziteta u Beogradu, Muzej nauke i tehnike, a nosilac istraživanja je bio LOLA Institut. Profesor Šolaja je okupio preko stotinu saradnika na projektu, održao veliki broj stručnih skupova, organizovao više izložbi širom Srbije u saradnji sa Muzejom nauke i tehnike iz Beograda i objavio dvadesetak monografskih izdanja kroz ediciju Zapisi PINUS, kao i veliki broj drugih publikacija.

Posle smrti profesora Šolaje 1998. godine, projekat PINUS se ugasio, pošto nije pronađena adekvatna ličnost koja bi nastavila rukovođenje ovim nacionalnim projektom.

7. ZAKLJUČAK

Profesor Šolaja je imao veoma preciznu ličnu evidenciju svih inženjera proizvodnog mašinstva, koji su diplomirali na Mašinskom fakultetu u Beogradu, počevši od 24. maja 1948. godine. U vremenu kada nije postojao poseban smer proizvodnog mašinstva, on je smatrao da su proizvodni inženjeri svi oni koji su diplomirali na predmetu "Mašine alatke" i "Mašinska obrada". Inženjere koji su završili studije na smeru proizvodnog mašinstva, ali su diplomirali na drugim predmetima izvan proizvodnog mašinstva, profesor Šolaja nije svrstavao u inženjere proizvodnog mašinstva.

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38th International Conference on Production Engineering -Serbia

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Čačak, Serbia, 14 – 15. October 2021

DESIGN AND MANUFACTURING OF CUSTOMIZED ANATOMICALLY ADJUSTED PLAT IMPLANTS

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Abstract: *In the field of orthopedic surgery the main goal is to find the best treatment for the person with a bone fracture or other trauma. Personalization in medicine mainly refers to the use of treatments that are adjusted to a specific patient. The design and manufacturing of customized implants is a field that has been developed rapidly during recent years. This paper presents an originally developed method for designing a 3D model of customized anatomically adjusted implants for particular fractures. With this method, it is possible to design volumetric implants used to replace a part of the bone or a plate-type for the fixation of a bone part. It could be used as a guideline for modifying standard implants and/or for creating the personalized type of implant. Each of the stages of the creation of an implant should enable the possibility of adequate requirements, knowledge, and recommendations of the orthopedic, and thus, in addition to automation, to provide flexibility to the patient at all stages regarding design and manufacture.*

Keywords: *plate implant, 3D model, UDF, personalized medicine*

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WHICH WAYS FOR SERBIAN PRODUCTION ENGINEERING IN THE NEXT DECADES AFTER DESTRUCTION OF SERBIAN INDUSTRY ?

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Abstract: *The paper discusses possible ways for future developments of production engineering in Serbia. The motivation for such discussion is due to actual state of the production systems and enterprises in Serbia and due to expected industrial revolution by many named as Industry 4.0. The question of the Production engineering in Serbia or the Serbian production engineering is discussed. The quintuple model of interaction among of the beliefs and ideology, political and economic models, industry and academy are briefly discusses. Some insights in the approaches to the development of the Serbian production engineering are presented.*

Keywords: *Production engineering, strategy, re-industrialization, roadmap, scalability,*

1. INTRODUCTION

The objective of this paper is to discuss possible ways for future developments of production engineering in Serbia. The motivation for such discussion is due to actual state of the production systems and enterprises in Serbia and due to expected industrial revolution by many named as Industry 4.0.

The immediate connotation of production engineering is “production”. In the modern time “production”, when in the context of “production engineering”, is associated with industry. The common sense concludes that virtually the production engineering cannot exists without industry.

Recalling the fact that the Serbian industry (in the first place the manufacturing industry as the principal domain of the “classical” production engineering, but other industrial sectors as well) suffered practically total destruction after the political changes after dissolution of yugoslavia and after totally unsuccessful so-called “transition” (which, curiously, by some personalities is still on course !?) the questions, considering a phenomenological context, related to the “existential” and “identity” nature could be raised.

This characterization could be understood e.g. as follows:

1) concerning the “existential” question:
   could Serbian production engineering, or production engineering in Serbia, exists at all without a strong industrial environment and its continuous development ?

2) concerning the “identity” question: the production engineering in Serbia should be, or is, “Serbian production engineering ” or “production engineering in Serbia” ?[1] and following , which are the “identity” features of the production engineering ?

Obviously, the positive answers are possible for any alternative implied by the above mentioned questions. The proof is obvious. The production engineering in Serbia is in actual existence and operational.

However, by the title of this paper it is implicit that the aim of discussion is the issue of the Serbian production engineering and possible ways for its development.

The discussion will be structured through the following subsequent chapters.

The second chapter will present the production engineering existential, and development, framework, the third chapter will present some hypothesis on the Serbian production engineering development and re-the Serbian industrialization, and the fourth chapter will provide some recall on the big historical periods of the Serbian production engineering and some insights for the possible operationalization of the ways for the Serbian production engineering future development.

2. THE “ONION” OF THE PRODUCTION ENGINEERING DEVELOPMENT ENVIRONMENT, or THE HIERARCHY OF THE PRODUCTION ENGINEERING DEVELOPMENT DETERMINANTS

We are perfectly aware of a number of “development strategies” developed, proposed (or suggested) and assumed as different bodies within the Serbian society. Just to refer two, from the last two decades, e.g. [1] and [2]. Many others are published as well, by the national or international personalities and bodies, as well as mixed, e.g. [3]. However, unfortunately, we could not say that these very effective. Why ?

The objective of this paper will be not to prove rigorously why it has happened, but to hypothesize the explanation.

Virtually it has happened because of, in fact, reductionist’s approach to the methodology of defining the development strategy. Although technologically and economically correctly prescribed goals of the proposed strategies, the wider social contexts that in fact determine the success of a development strategy were not correctly addressed. By these “wider social contexts” are meant politics, i.e. the political models, and the underlying ideologies, that drive the political and macro-economic models, in fact instrumentalizing the development strategy models, in our case the models of production engineering.

In other words, a development strategy models not in accordance with the political model in effect, does not have chances to be successful. From the other side, implementing a desired development strategy model requires a political engagement.

Usual basic model of the development strategy for some are based on academy, as the production engineering is (as many others), is based on the university-industry-government interactions for innovation, called “triple helix model”. The basic model could be instantiated for three particular models, i.e. 1) a “’statist model’ of government controlling academia and industry”, 2) “a ‘*laissez-faire* model’ with industry, academic and government separate and apart from each other, interacting only modestly across strong boundaries”, and 3) ‘balanced helix model’ which “has largely arisen out of a dialectic between laissez-faire ideology and practical exigencies”, Figure 1 [4].

The basic “triple helix” model is further expanded to the “quadruple helix” and “quintuple helix”, see [5], extending the determinant factors to the contexts of society and natural environment for society, Figure 2.

[1] Of course, this question is alreqady well known for the public in general through a numerous discussions on the same question of identity for various institutions, including scientific, political and others.

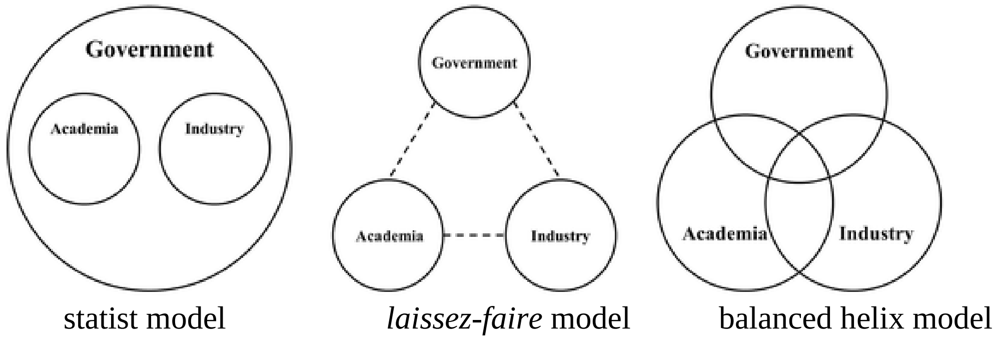


Figure 1. Three Triple Helix models [4]

All 5 determinants (from the quintuple helix) are also represented as the subsystems in the form of "onion"[2], Figure 3 [5].

We would like to present a similar hierarchy ("onion"). The differences are that on the model we propose on "top" the belief and ideology, instead of "natural environment" which (the natural environment) is obviously driven by the ecological reasons for "global" sustainability. Second level would be political system, which stems from the beliefs and ideology, then the economic policy, following by the industry and at the end the academy, which would form the "onion". The proposed hierarchy represents the proposed quintuple helix model for instantiation of the Serbian production engineering, Figure 4.

The reason for the model proposed is to facilitate perception that the all other "subsystems" are determined by our beliefs and the corresponding ideology. This determines our political model. From the other side the economic model is determined by the political model. The political model in effect that governed all subordinated policies could be characterized as neo-liberal, that

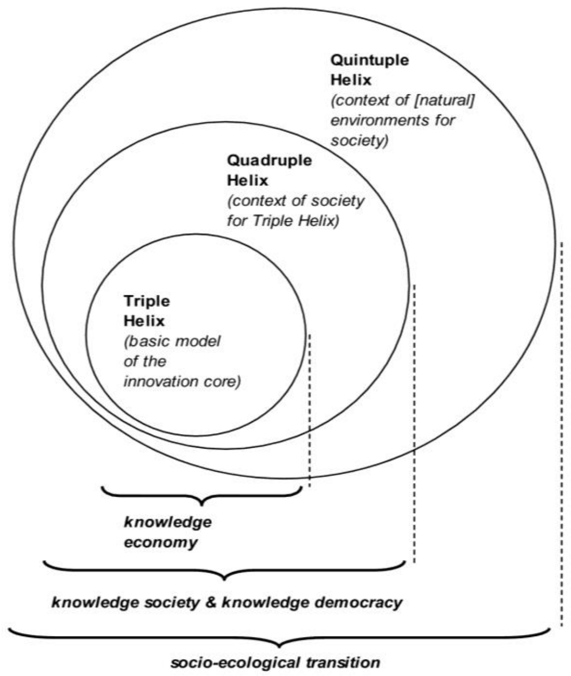


Figure 2. Triple- to quintuple- helix: Knowledge production and innovation [5]

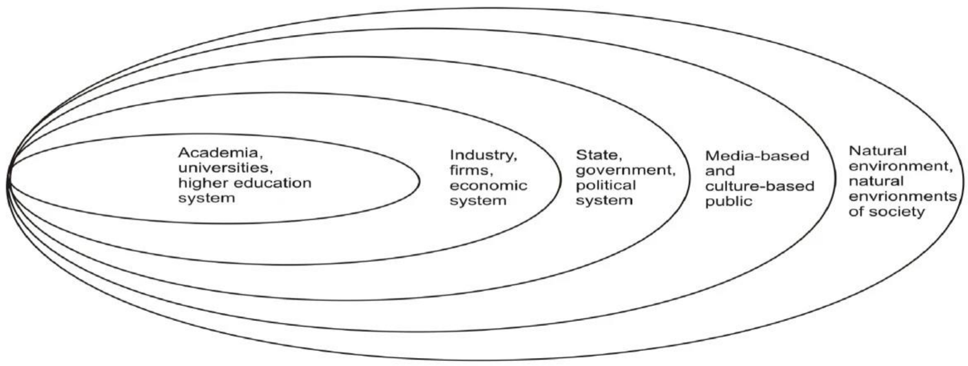


Figure 3. The subsystems of the Quintuple Helix model [5]

[2] The well known „onion" as a representation form is „Research onion", obvioously derived from Venn diagrams for logical relations between sets.

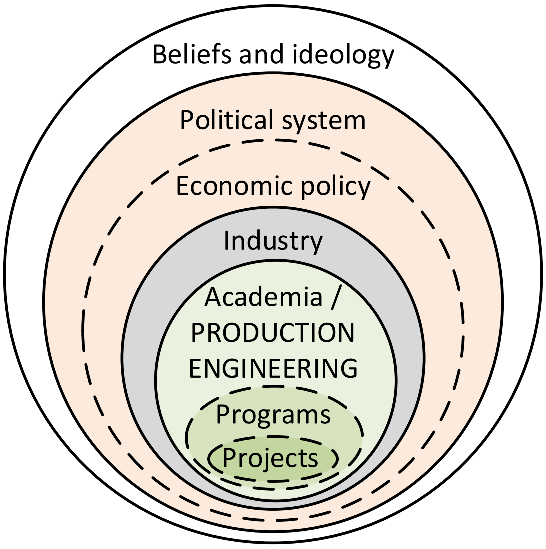


Figure 4. Proposed quintuple helix for instantiation of the Serbian production engineering

dictated overall privatization and the, so-called, exogenous economic development model, manifested by privatizing practically the totality of the industrial assets to the external (exogenous) capitals, so-called, and prised by the political groups as great "success". When saying "all industrial assets" it understood also the whole intellectual capital of the privatized industrial companies, which means the whole technological documentation and technological knowledge and related human capital, which have a number of elements of the technological culturecide.

Thus, is it possible for production engineering to exists in the environment with so reduced industry ?

Yes, it is. But, if there is no industry in Serbia (somebody will say this is not true, the Serbian industry exists), or better there is no manufacturing industry in Serbia that have existed, and that the production engineering must be associated with the industry, the question is: with which industry the production engineering is associated ?

The response could be very simple: to the European industry. This orientation is supported by the European funds and cooperation with European universities, industry and government. Is it negative for the production engineering in Serbia ? Not necessarily at all.

As the resources are mainly external, this model of development, of the production engineering, is typical exogenous model, which perfectly corresponds to the exogenous economic development model.

But, the question is could we call this model Serbian production engineering or Production engineering in Serbia ? which is the typical "identity question".

By the author of this paper, in this case the production engineering model would be called "Production engineering in Serbia".

However, somebody could claim that the model could be called also the "Serbian production engineering" which characteristic is orientation to the global free market and cooperation, i.e. following the philosophy of "globalization".

Obviously, the validity of the first or of second depends of the person's belief and ideology.

But, if the author of this paper think that it can not be called "Serbian production engineering" then what is the alternative to the above referred model ?

The alternative is characterized by the opposite concepts on the belief and ideology, political and economic models.

On the ideological and political level opposite to the neo-liberal and globalisation model is *souverainiste* (in French) or nationalist (in English).

On the level of economic development, opposite to the exogenous model is endogenous model. The question on endogenous growth vs. exogenous growth, the question on growth based on attracting foreign investment (virtually at any cost) or developing the internal potential.

This does not mean that the exogenous model is not desirable, but the question is of dominance of one of the models in the ideology and in policies, and it should be endogenous. This approach is recognized in document [2] where one of the conclusions were that "Conclusion #4: Industralization is not possible through the exogenous development model". Related to this model, an interesting question is on state-own companies, against privatization. Prof. Elinor Ostrom's research (Nobel prize in economics 2009) demonstrated that the state-owned and community-owned companies and institution could be successful as well. This means that virtually it was not necessary to privatize everything, in particular the capital manufacturing companies in Serbia, the environment and the objective of the Serbian production engineering.

On the level of academy/university, the opposition of two models could be manifested through the university networks, i.e. international networking against national networking.

Finally, on the programs level, the dominance should be nationally oriented programs against international agenda.

The summary is presented in the Table 1.

Table 1. Characterization of the "Production engineering in Serbia" and "Serbian production engineering" models

	Production engineering in Serbia	**Serbian production engineering**
Ideology and political model	Neo-liberal, globalism	Souverainiste, nationalist
Economic development dominant model	Exogenous	Endogenous
Industry	Foreign capital (in country or outside)	National capital
Academy (University) dominant networking	International	National
Programs	International	National

An example of the neo-liberal policy is given in Figure 5 [6].

Some examples of nationalist oriented policies are given in Figures 6 and 7, [6].

Figure 5. Privatization of all assets - from [6]

Figure 6. Protecting national industry - from [6]

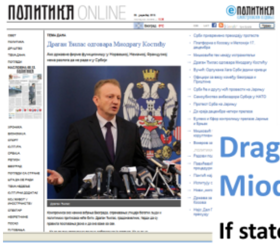
3. SOME HYPOTHESIS FOR SERBIAN RE-INDUSTRIALIZATION

One of the fundamental conditions for Serbian production engineering is Serbian industry.

If this industry is practically destroyed, then the task of the Serbian production engineering is to make all efforts to build a new Serbian industry. In other words, the task is to provide programs, models and tools for Serbian re-industrialization.

This is easy to say, but not so easy to realize.

There is a great number of difficulties. One of the most difficult condition is of the financial nature, i.e. the investments nature and sources. Following is lack of knowledge for strategic programs and projects management.



Dragan Djilas responds to Miodrag Kostic

If state-owned companies operating in Norway, Germany, France, there is no reason not to work in Serbia

Elinor Ostrom
From Wikipedia, the free encyclopedia

Elinor "Lin" Ostrom (born **Elinor Claire Awan**;[2] August 7, 1933 – June 12, 2012) was an American political economist.[3][4][5]

Nobel Prize in Economics

In 2009, Ostrom became the first woman to receive the prestigious Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, commonly known as the Nobel Prize in Economics. The Royal Swedish Academy of Sciences cited Ostrom "for her analysis of economic governance," saying her work had demonstrated how common property could be successfully managed by groups using it. Ostrom and Oliver E. Williamson shared the 10-million Swedish kronor (£910,000; $1.44 m) prize for their separate work in economic governance.[24]

The Royal Swedish Academy of Sciences said Ostrom's 'research brought this topic from the fringe to the forefront of scientific attention', "by showing how common resources — forests, fisheries, oil fields or grazing lands, can be managed successfully by the people who use them, rather than by governments or private companies". Ostrom's work in this regard challenged conventional wisdom, showing that common resources can be successfully managed without government regulation or privatization.[25]

Figure 7. State-owned and community owned companies can be successful as well - from [6]

Following some hypothesis for Serbian re-industrialization are presented.

At the first place, the investment model should be endogenous and not exogenous.

If endogenous investment when the state investments are either very low or not willing to invest in state-owned companies (due to the neo-liberal political model), then the only source are small private investors. The model should provide different and innovative business models for enabling a great number of small investors. These models are based on the following production system models:

- Large and complex production networks
- Co-production

Secondly, the new industrialization models should be scalable (see [7] for scalability of manufacturing systems), i.e. one of the characteristics should be:

- scalability

Thirdly, some non-classical and emergent concept could be considered as useful, if not necessary, instruments, such as collaborative economy rather than concurrent/competitive. Another one is Open source products. I.e.:

- Collaborative organizational forms for collaborative economy
- Open x (x: products, software, hardware, science, …)

The organizational, and technological as well, models of production enterprises that satisfied the above mentioned requirements are characterized as:

- Virtual and Ubiquitous Enterprises
- Community-based Manufacturing
- Social network-based Manufacturing
- Social Manufacturing
- …

"As common properties of these systems and architectures, … could be identified as: (1) all of them are networked systems, integrating large numbers of ''nodes'', from thousands to billions! (2) all of them have extremely high capacity of changing the way of work and doing business, whether for individuals or for companies, and (3) all of them are highly scalable systems simply because these systems ''are not bound to a predefined size, so that the underlying coordination mechanism has to be highly scalable'' [8]" [7].

Concerning the re-industralization model itself, the term "neo-industralization" is used as well.

There are basically two approaches to neo-industralization.

Neo-industralization 1.0:

"Neo-industrialization is carried out with the usage of state support realizable under the conditions of national projects and federal special-purpose programmes." [9], cited in [11].

"… projects are now nationally supported by the new state policy on urban revitalisation and national technology development." [10], cited in [11].

- Emphasize on the political approach (local and national)
- Concerning the Urban Forms, the new Industrialisation mainly addresses to the Urban Revitalisation (convert "old"

industries - buildings and places – in “new” industries)
- Only addressing Proprietary Models
- Top-Down Design [11]

Neo-industralization 2.0 (our proposal):

“… “neo-industrialization”, with its simultaneous processes of transformation and diversification of former industrial regions.” [12], cited in [11].

“Many makers are driven by social ideals of improving the lives of underprivileged people and caring for the natural environment, often subscribing to the sharing principles of the open source movement.” [13], cited in [11].

“People can build upon one another's best ideas without worrying about getting in trouble for infringing on someone's intellectual property.” [14], cited in [11].

- Emphasize in agents approach (individual, community and social)
- Concerning the Urban Form, it will require an Urban Transformation
- Open Models
- Down-Top Design [11]

Relation between Neo-Industrialisation 2.0 and Industry 4.0

In the context of Complexity Management, most of the Industry 4.0 approaches are oriented to “Old-Thinking New-Doing”, this means that this will not lead to a real novelty approach (for Complexity Management and “Old-Thinking New-Doing” characterization see e.g. [15]).

Industry 4.0 should not be considered an approach of Neo-Industrialisation (NI) 2.0 but as a possible element that will part of the NI 2.0, Figure 8.

An Example of evolution towards a Neo-Industrialization 2.0 is given in Figure 9 [16].

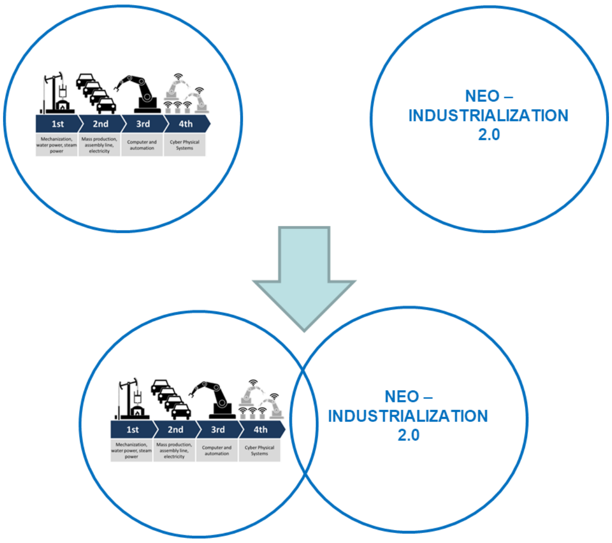


Figure 8. Neo-Industrialisation 2.0 and Industry 4.0

4. OPERATIONALIZATION

Operationalization implies a complex structure of actions and/or activities, especially considering the proposed model of quintuple helix for instantiation of the Serbian production engineering.

The term “implementation” could be used as well.

The commonly known dimensions of the production engineering development are:

Figure 9. An example of evolution towards a Neo-Industrialization 2.0 is given in Figure 9 [16].

- scientific domain
- organisational domain
- pedagogical domain

Fortunately, the Serbian production engineering has a rich history from which we could learn, and based on which the future development strategy could base.

4.1 Recalling 3 big historic programs of Serbian production engineering

The author of this paper recognize three big historic periods with three big and the most characterizing +rpgrams.

These are:

1st period and program –

The 1st period was the period in fifties and sixties years of the 20th century when the most fundamental discipline and curricula unit of Machine Tools was established as the regular and standard discipline (subject). The program was to establish the scientific and engineering basis for the machine tolls design and manufacturing in Serbia. The leader of this period and program was Prof. Pavle Stankovic.

2nd period and program -

The 2nd period and the corresponding program was characterized by a number of strategic programs, such as Development and optimization of machining systems, Systematic research of machinability of domestic materials by domestic tools (SIO), Development of methods for static and dynamic testing of machines and machine structures, and many others. Maybe the most representative was the program SIO that "produced" a very large number of MSc and DrSci projects and involved a large number of industries. Virtually, this period, in a way, "closed" the mechanical technological base for the Serbian production engineering. This period and programs were lead by Prof. Vladimir Solaja, the successor of Prof. Pavle Stankovic.

3rd period and program -

The 3rd period and corresponding programs was characterized by the introduction and development of the computerization of all processes and systems were established. These technologies are well known under the name of Computer Aided technologies, Information Systems, Computer Integrated Manufacturing and Intelligent Manufacturing systems. It could be said without any reserve that this period represented in fact the preparation for the upcoming I4.0. The leader of this period and program was Prof. Vladimir Milacic, the successor of Prof. Vladimir Solaja.

4.2 Some elements for the future Serbian production engineering

New programs, or Roadmaps, for the Serbian production engineering should follows the requirements referred in the Chapters 2 and 3.

In fact, the emphasis is on the emergent models of equipment and emergent organizational forms that would provide the possibility of organization and production of "low cost" and accessible resources. The fundamental conditions are large structures – networks, scalability and co-production.

In [7] the authors proposed a Roadmap for development of scalable manufacturing systems that contains many elements adequate for the Serbian production engineering in the context of actual environment and the referred requirements, and that could be an example serving as the initial suppositions.

Following, some elements from the Roadmap from [7] will be given.

There are identified 4 big challenges:

Challenge 1: Theory of scalability for Manufacturing Systems (MS

Challenge 2: Scalability for the actual MS paradigm

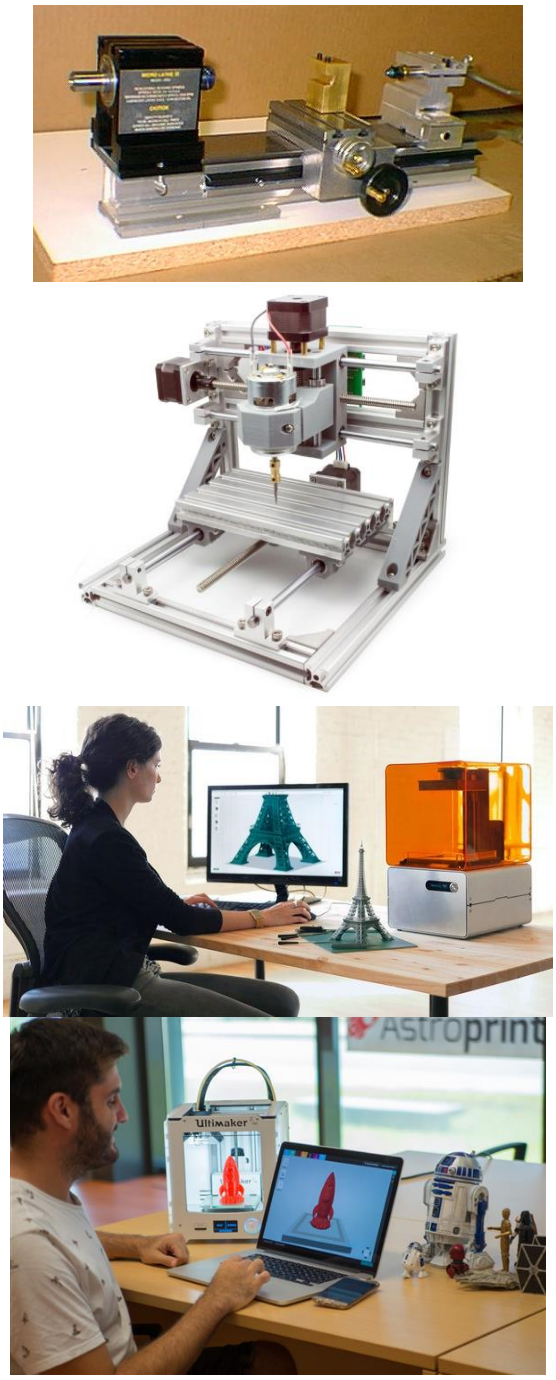
Challenge 3: Scalability for emergent MS paradigm(s)

Challenge 4: Business and social dimension of scalability

Each "Challenge" is detailed in a number of particular themes/projects to be developed.

One of the most interesting projects proposed that should provide rapid and economically efficient elements for the "Neo-industrialization 2.0" is:

- 2.7. Meso- and micro- MT of very low cost – target price 50 € - from reusable components, from wood and/or plastic (Challenge 2)
  i.e. desktop machine tools [Additive Manufacturing (AM) included], Figure 10.



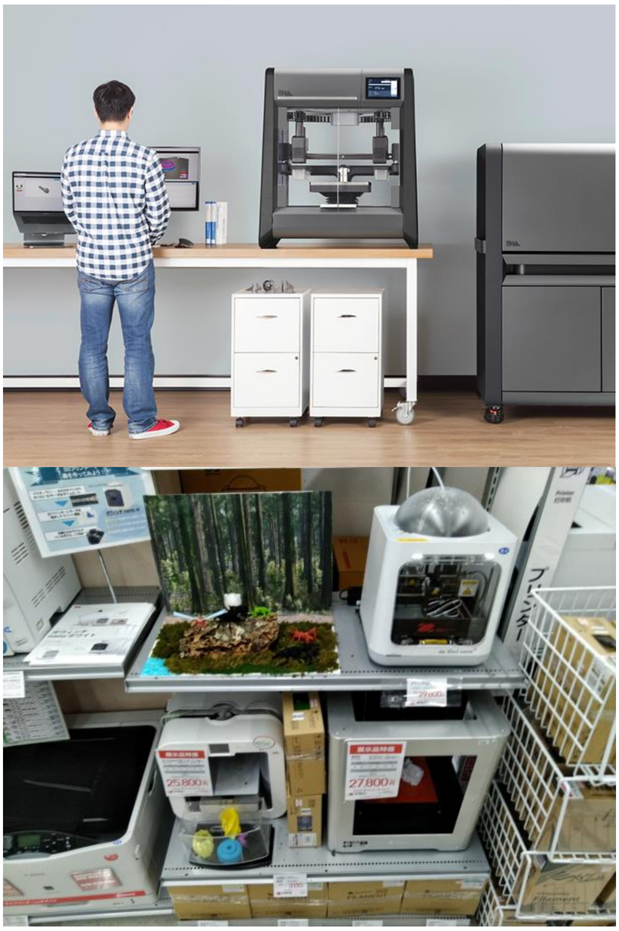


Figure 10. Desk-top machines for scalable large production networks [17]

5. CONCLUSIONS

The paper has presented a discussion on ways for the Serbian production engineering development in the next decade(s).

The discussion does not prescribe the “recipe” but aimed to provide an insight based on recent developments in organizational systems, equipment and control, as well as a number of implementations of new and emergent production systems and engineering technologies.

In fact, the main problem is not in the technological sphere but in “upper” levels of ideology, politics and macroeconomic policies. In fact, the definition of the Serbian production engineering (the “identity” problem) depends of the user’s belief and ideology.

So, the question is to chose. The choice is between a neo-liberal / “globalist” agenda and the *souverainiste* / nationalist agenda. The choice is not obvious but at least the choice should be informed.

The author is obviously oriented to the Serbian production engineering based on the *souverainiste* / nationalist view, but not only in the Serbian case but in general, including Portugal.

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APPLICATION OF PLACKETT-BURMAN EXPERIMENTAL DESIGN FOR SCREENING OF ULTRASONIC WELDING PROCESS

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Abstract: *Screening designs are important designs for identification of the most important factors with respect to a given performance characteristic of production processes. In this study, Plackett-Burman screening design was used to identify the factors that influence the pull-out force of relay contact created by ultrasonic welding of metal shaft and plastic part. The experiment had 8 experimental trials and was replicated three times and considered seven factors which were varied at two levels. Analysis of the results has shown that factors differently affect pull-out force and pull-out force variance. It was observed also that only two factors have statistically significant impact on the pull-out force. These results are only the first step in further experimental investigation of significant factors and their possible interactions effect.*

Keywords: *Ultrasonic welding, Design of experiments, Plackett-Burman design, quality.*

1. INTRODUCTION

Today, industry is oriented towards mass production of simple rather than complex parts. Individual simple parts are afterwards joined in order to get a complex part with required functionalities. Bearing this in mind, joining technologies became pervasive in modern production. As is the case with other production processes, efficient use of joining technologies, in terms of quality, cost, productivity, etc, requires good understanding of the psychical phenomena involved during the process and up to date knowledge. Today, with the development of a wide spectrum of engineering materials, there is often a need for joining dissimilar materials, since parts created from dissimilar materials have better properties and abilities to adapt to new production challenges.

One of the aims for the use of dissimilar joints is to enhance product design flexibility, allowing the differing materials to be utilized in an efficient and functional manner considering specific properties of each material [1]. The most widely used methods for joining dissimilar materials include: adhesive bonding, mechanical fastening and welding. Among these, ultrasonic welding (USW) is considered as a promising method [2, 3].

USW is an ultra-fast joining friction welding method in which the parts to be welded, i., adherends, are subjected to mechanical vibrations of high frequency (20 - 50 kHz) and low amplitude (10 - 250 μm) and a static welding force. The mechanical vibrations are generated by a piezoelectric converter and applied onto the adherends by means of a sonotrode, which is also responsible for exerting the welding force. A booster and the sonotrode itself are responsible for amplifying the vibrations [4].

With respect to the orientation of the mechanical vibrations to the welding interface, a distinction is made between plastic ultrasonic welding, in which the vibrations are introduced transverse to the welding interface, and metal ultrasonic welding, in which the vibrations are introduced parallel to the welding interface [5].

USW is a very efficient process, especially in the case of welding polymeric materials, due to the fact that it does not cause degradation of their properties [2]. Being a cleaner process, as compared to others, as there is no contamination, USW is preferred in medical applications, packaging industries, electronic industries, etc. [6].

Considering the complexity of USW process and large amount of input parameters which affect larger number of process performances, in order to achieve better understanding of USW process and achieve desired joint quality, different analytical, experimental and empirical modelling and optimization approaches are used. The first step in researching of complex production processes (or systems) involves the application of screening experimental designs. These designs are used to identify a small number of factors that significantly affect the considered outputs and to eliminate those that are not important for further experimentation and analysis.

Plackett-Burman design (PBD) is one of the most frequently used screening designs because of its ability to estimate main effects with the same precision. It is a fractional factorial design with the advantage of minimizing the experimental runs from large number of variables to smaller most significant factors. Using this design, N factors can be screened with N + 1 experimental runs [7].

Previously, PBD was applied for screening of different production processes such as electro-discharge machining (EDM) [8], plasma cutting process [9], stir casting [10], micro dry wire electrical discharge machining process (μDWEDM) [11] and laser assisted machining (LAM) [12].

In order to get better acquainted with the process of USW of dissimilar materials (metal and polymeric materials), this study uses PBD with 8 trials and three replicates for assessment of seven factors with respect to selected ultrasonic welding performance characteristic i.e., pull-out force of the relay contact and its variation.

2. EXPERIMENTAL SETUP

For joining plastic top part (made of latamid) and metal shaft, an ultrasonic servo press MS sonxTOP FUSION with frequency of 20 kHz was used (Figure 1).

Figure 1. Experimental setup

The same ultrasonic servo press was used to measure the pull-out force of the relay contact which was selected as the observed process output (ultrasonic weld quality characteristic). The entire experimental setup and data acquisition was performed in real manufacturing conditions.

Based on the recommendations of the machine manufacturer and acquired experience and knowledge of engineers from quality and production departments, a set of factors and their values that will vary have been determined. Factors with their names, labels and values on low level (-1) and high level (+1) are shown in Table 1.

The PBD enables the development of the first order model which can be represented by the following equation [8]:

$$Y = \beta_0 + \sum \beta_i \cdot X_i \quad (1)$$

where Y represents the response, β_0 is the model intercept, i represent the variable number, β_i are unknown coefficients and X_i correspond to independent variables.

The main effect of each of the factors is determined as [7]:

$$E_{(x_i)} = \frac{(\sum M_{+1} - \sum M_{-1})}{n} \quad (2)$$

where $E_{(x_i)}$ is the response value effect of the factor, $\sum M_{+1}$ is the summation of the response value at high level, $\sum M_{-1}$ is the summation of the response value at low level, and n is the number of trials.

All plastic parts were from the same production series. The geometrical PBD matrix for 7 factors and 8 trials in coded form, real factor values and measured pull-out force of the relay contact is shown in Table 2. In order to assess the process variation, experiment was replicated 3 times. There was no change of machine or operator during the production and testing of ultrasonically welded joints.

The order of conducting of experimental runs is obtained by randomization process and it is given in first column of Table 2 (in brackets).

Table 1. Factors and levels

Factor	Label	Low level (-1)	High level (+1)
Amplitude (%)	A	95	100
Trigger force (N)	B	100	200
Trigger speed (mm/s)	C	10	12
Speed 1 (mm/s)	D	10	16
Speed 2 (mm/s)	E	5	9
Travel distance for speed 2 (mm)	F	0,2	0,7
Holding force (N)	G	50	200

3. RESULTS AND DISSCUSION

Conducting statistical analysis based on the application of screening designs may help in determining the main effects of individual factors on pull-out force and pull-out force variance. Main effects of factors are shown in Figure 2.

Table 2. PBD matrix in coded form and real factor values with measured responses

Run	A (%)	B (N)	C (mm/s)	D (mm/s)	E (mm/s)	F (mm)	G (N)	Y_1 (N)	Y_2 (N)	Y_3 (N)
1(7)	+1 (100)	-1 (100)	-1 (10)	+1 (16)	-1 (5)	+1 (0.7)	+1 (200)	451,40	488,30	461,70
2(3)	+1 (100)	+1 (200)	-1 (10)	-1 (10)	+1 (9)	-1 (0.2)	+1 (200)	472,30	430,50	449,40
3(1)	+1 (100)	+1 (200)	+1 (12)	-1 (10)	-1 (5)	+1 (0.7)	-1 (50)	473,50	460,40	440,30
4(6)	-1	+1	+1	+1	-1	-1	+1	492,80	517,80	495,70

	(95)	(200)	(12)	(16)	(5)	(0.2)	(200)			
5(2)	+1 (100)	-1 (100)	+1 (12)	+1 (16)	+1 (9)	-1 (0.2)	-1 (50)	467,80	526,40	476,00
6(4)	-1 (95)	+1 (200)	-1 (10)	+1 (16)	+1 (9)	+1 (0.7)	-1 (50)	498,60	502,70	446,90
7(5)	-1 (95)	-1 (100)	+1 (12)	-1 (10)	+1 (9)	+1 (0.7)	+1 (200)	419,00	455,90	442,40
8(8)	-1 (95)	-1 (100)	-1 (10)	-1 (10)	-1 (5)	-1 (0.2)	-1 (50)	500,60	455,10	464,10

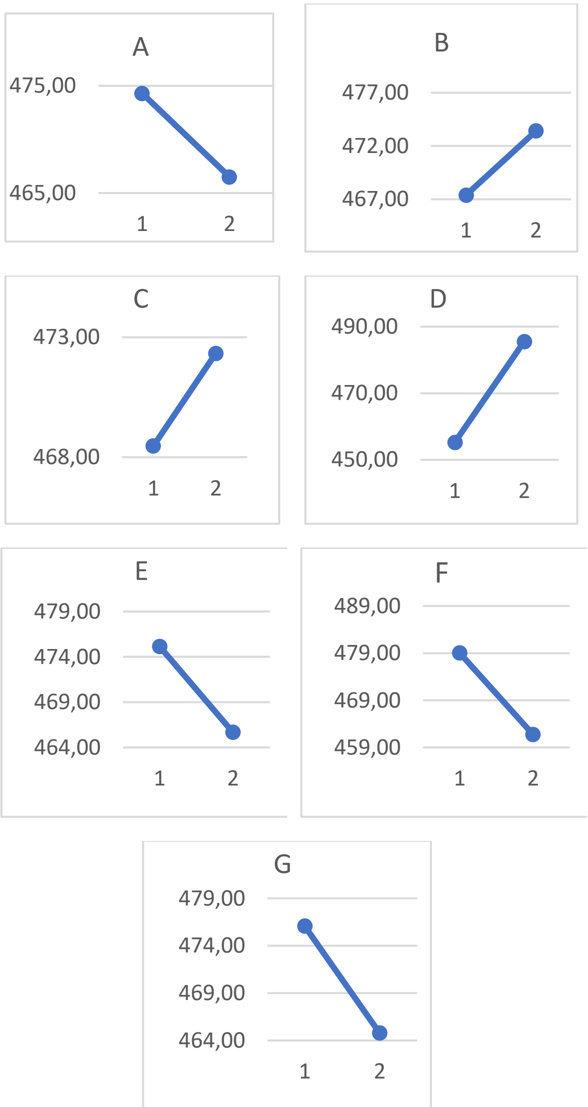

Figure 2. Main factors effects on pull-out force

From Figure 2 it can be concluded that factors A, E, F and G have a negative correlation with the output (pull-out force), i.e., their reduction increases the value of the pull-out force and vice versa. On the other hand, factors B, C and D have a positive correlation with the output (pull-out force), i.e., with an increase in their value, an increase in pull-out force can be expected.

Looking at the absolute values of the main effects it can be concluded that the factor with coded name D (Speed 1), has the greatest main effect on the pull-out force, while the smallest main effect on the pull-out force has a factor with coded name C (Trigger force).

The ranking order of factors, based on the values of the main effects, in descending order is shown in Figure 3.

D F G E A B C

Figure 3. Factors arranged in descending order by absolute value of main effect on pull-out force

In addition to the value of output (pull-out force), variation of output, i.e., variation of the pull-out force, can be of great importance for the observed production process. The high value of the variation tells us that the process is not well tuned and can be further optimized in order to minimize variation. Main effects of individual factors on pull-out force variance, determined by calculating the standard deviation of pull-out force for each experimental trial, are shown in Figure 4.

Figure 4. Main factors effects on pull-out force variation

By analysing factor main effects plots given in Figure 4, it can be concluded that factors B, C, F and G have a negative correlation with the output (pull-out force variation), i.e., their reduction increases the value of the pull-out force variation and vice versa. On the other hand, factors A, D and E have a positive correlation with the output (pull-out force variation).

Looking at the absolute values of the main effects it can be concluded that the factor with coded name G (Holding force), has the greatest main effect on the pull-out force variation, while the smallest main effect on the pull-out force variation has a factor with coded name A (Amplitude).

The ranking order of factors, based on the values of the main effects, in descending order is shown in Figure 5.

G E D C B F A

Figure 5. Factors arranged in descending order by absolute value of main effect on pull-out force variation

By comparing with the tabular value of Fisher's statistics for the degrees of freedom of factor and error, and for the selected significance level of 0.1, it was observed that factors D and F are of statistical significance.

Based on a comprehensive analysis of the main effects of factors on the pull-out force, as well as the main effects of factors on the variation of pull-out force, as a basis for further study of USW process of considered dissimilar materials, a combination of process factor levels can be recommended as follows:

D (+1) - because Speed 1 has the greatest influence on the pull-out force, despite the fact that Speed 1 has a positive correlation with the variation of the pull-out force (but its main effect in that case is ranked third).

E (-1) - because Speed 2 has the second largest influence on the variation of the pull-out force, despite the fact that Speed 2 has a negative correlation with the pull-out force (but its main effect in that case is ranked four).

F (-1) - because the travel distance for speed 2 2 has the second biggest influence on the pull-out force. Its influence on the variation of the pull-out force is ranked only in place 6.

G (+1) - because the Holding force has the greatest main effect on the variation of the pull-out force, despite the fact that the Holding force has a negative correlation with the pull-out force (but its influence in that case is ranked third).

As shown in the previous analysis, factors A, B and C (Amplitude, Trigger force and Trigger speed) have the least influence on the pull-out force and its variation, so their levels can be adjusted to further ensure that the minimum value of the pull-out force of 420N or more robust process conditions. A combination of factor levels can be suggested as a final recommendation:

A (-1) B (+1) C (+1) D (+1) E (-1) F (-1) G (+1).

The final recommendation of the combination of factor levels is already included in the initial experimental matrix, i.e., experimental trial 4 has the recommended combination of factor levels. It could be observed that this experimental trial yielded the highest average value of the pull-out force (502.1 N). Also, from it can be seen that the value of variation is the lowest for experiment number 4.

4. CONCLUSION

Based on the experimental results of measuring the pull-out force of the relay contact, as well as the performed qualitative-quantitative analysis, it can be clearly seen that the significance of the factors changes depending on which output performance of the USW process is observed. It is therefore necessary to adjust factor values in accordance with the considered output parameter (process performance or quality characteristic).

Statistical analysis of the experimentally obtained results showed that only two factors are statistically significant for the observed process of USW in relation to one process performance, namely the pulling force of the relay contact. Speed 1 and travel distance for speed 2 are the most statistically significant factors. It was also determined that in order to.

Achieve the highest possible pulling force, speed 1 should have a higher value (16 mm / s), while travel distance for speed 2 should have a lower value (0.2 mm).

In addition to random noise factors, the variation of the pulling force is mostly influenced by the factors G (holding force) and E (speed 2). It was also determined that in order to achieve the smallest possible variation of the pulling force, the holding force should have a higher value (200 N), while the speed 2 should have a lower value (5 mm / s).

After the screening experiment, it is necessary to implement the subsequent experimental plans of higher resolution in order to perform a more detailed analysis of the process and possibly reveal the existence of significant parameter interactions in this process. For this purpose, could the scope of future research be towards more detailed analysis of the factors identified as statistically significant in order to find the best settings of the parameters of the USW process of dissimilar materials in relation to achieving the desired process performance characteristics.

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DEFINING PARAMETERS FOR LASER CUTTING PARTS MADE OF AISI 4140

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Abstract: *The advantages of laser cutting over conventional cutting methods are reflected in the high-speed processing capability, narrow width of the cut, straight cut edges, low roughness of cut surfaces and the possibility of creating complex profiles. The process of laser cutting and cut quality depends on proper selection of cutting parameters. A set of cutting parameters is supplied with each laser and they are optimized for cutting certain materials. The paper presents the process of defining new parameters for cutting parts made of steel AISI 4140. Adequate accuracy of the quality and shape of the cut has been reached. Therefore, the obtained parameters are reliable and are further used in the production process.*

Keywords: *fiber laser, CO2 laser, cutting parameters, surface roughness*

1. FIBER LASER TECHNOLOGY

The application of fiber laser technology provides a wide range of possibilities in industrial unconventional metal processing. Fiber lasers are competing with the traditional CO2 laser, plasma and water jet technology [1].

Over a relatively short period of time it can be seen exponential advances in fiber laser technology used for flat sheet metal cutting. In just five years, fiber lasers achieved the 4kW cutting threshold that took CO2 lasers approximately four times as long to reach. After ten years, fiber lasers have achieved the 15kW power level for cutting. In all fairness, fiber lasers – some exceeding 20kW – have been used by other industries for many years in applications other than sheet metal cutting. [2].

The high-quality laser beam that the Fiber laser provides at high power creates the possibility of cutting thicker materials, which in previous years was the field of application of exclusively CO2 lasers.

Fiber lasers belong to the group of solid-state lasers. With a wavelength of 1,064 micrometers, fiber lasers produce an extremely small focal diameter; as a result, their intensity is up to 100 times higher than with CO2 lasers with the same emitted average power. These lasers have a long lifespan of at least 25,000 operating hours.

Fiber lasers consist of active optical fibers and a semiconductor diode. Optical fiber is a thin glass thread made of silicon. The laser beam emission is contained in the optical fibers and travels through an insulated flexible cable. Light travels through glass fibers thanks to a phenomenon called total internal reflection. In this way, a large output power is created with a high quality of the output air. Fiber lasers are characterized by easy maintenance, high power utilization and quality laser beam, regardless of the power of the laser. They are available in the power range from 500 W to 50 kW with an energy efficiency of more than 30%. The high total energy delivered to the material is optimally used only when the dynamics of the positioning of the cutting head meets the technological requirement for a given type and thickness of the material. In thin materials, the technological optimum at high energies requires movement at high speeds.

To ensure high dynamics with optimal energy use, Messer has developed a mechanical system with two local axes that provides cutting head acceleration while keeping energy and labor costs low. The primary advantages of cutting flat sheet metal with Fiber laser technology are derived from its monolithic, Fiber-to-Fiber, compact solid state design configuration that is maintenance free and provides a lower cost of operation than can be achieved with comparable CO2 lasers. Fiber laser beam characteristics also provide much faster cutting speeds than CO2. The focused beam of even a 2kW Fiber laser demonstrates a 5X greater power density at the focal point when compared with a 4kW CO2 laser [2].

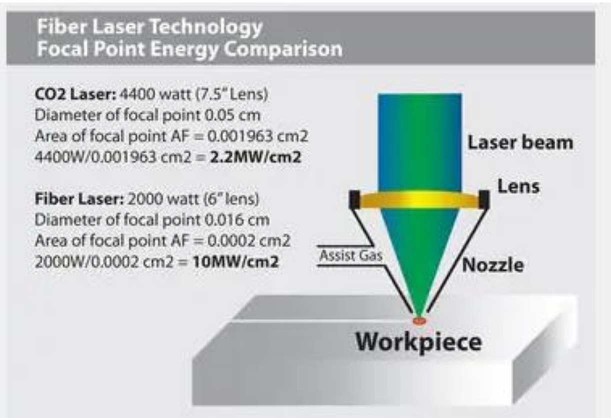

Figure 1. Powder density comparison of Fiber and CO2 lasers at the focal point

2. EXPERIMENTAL INVESTIGATIONS

The experiment of cutting metal with laser beam was realized in real production conditions in the company Atenic commerce d.o.o. Cacak, by implementing CNC Fiber laser technology. The aim of the experiment is to find the optimal cutting parameters for AISI 4140 steel, 6 mm thick.

Experimental research was conducted on Messer Fiber laser 2.4 kW (Fig. 2), a product of Messer Cutting Systems from USA [3], whose technical data are shown in Table 1.

The user environment is supported by the OmniWin Nest software package, which is also manufactured by Messer Cutting Systems and runs on Windows XP.

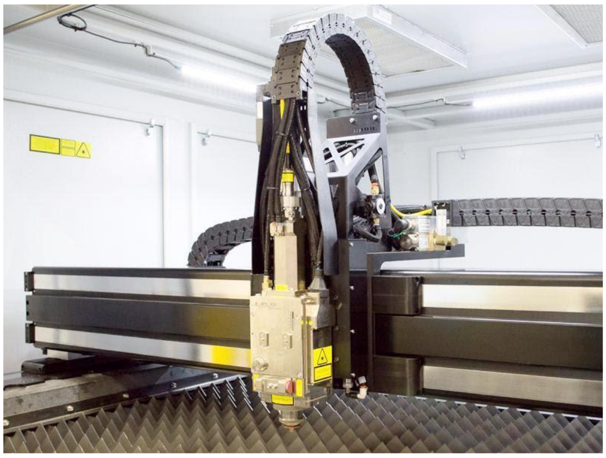

Figure 2. Messer fiber laser

The recommended values of cutting parameters for materials of specific type and thickness were given by the laser manufacturer.

Table 1. Messer fiber laser tehnical data

Messer Fiber laser 2.4 kW	
Working Area	y = 2000 mm; x = 8000 mm
Max. positioning speed	35000 mm/min
Max. cutting speed	7000 mm/min
Positioning accuracy	± 0.1 mm
Repeatability	± 0.05 mm
Cutting precision	± 0.1 mm
Cutting kerf	0.3 ÷ 0.5 mm
Max. cutting sheet thickness	
Steel	15 mm
Stainless steel	10 mm
Aluminum	8 mm
Max. workpiece weight	1440 kg
Laser power source (resonator)	
Resonator designation / type	IPG YLS 2400
Resonator power	2400 W
Wavelength	1.07 ± 0.01 µm
Fiber diameter	150 µm
Fiber length	20 m
Polarization	Circular
Frequency	1 ÷ 2500 Hz

The recommended processing parameters for AISI 4140, sheet thickness 6 mm are shown in Table 2.

Table 2. Recommended processing parameters

Workpiece material: AISI 4140 Sheet thickness: s=6 mm	
RECOMMENDED PROCESSING PARAMETERS	
Description	Value
Nozzle Type	SL 4_1.0
Nozzle Hole Diameter	1 mm
Focus Position	274
Pierce Height	8 mm
Pierce Gas Pressure	1.2 bar
Pierce Time	0.6 s
Pierce Start Laser Power	2000 W
Pierce Start Frequency	300 Hz
Pierce Start Duty Cycle	100
Pierce End Laser Power	2000 W
Pierce End Frequency	300 Hz
Cut Height	0.6 mm
Cut Gas Pressure	0.9 bar
Cut Speed	3000 mm/mm
Kerf	0.4 mm

3. CUTTING PARAMETERS OPTIMIZATION

Cutting parameters are scalar values that have a direct effect on the process of cutting. In order to properly modify the cutting parameters, it is important to know how the path for the part has been programmed and which cutting technology is used [4]. Processing parameters include the characteristics of the laser cutting process that can be modified to improve the quality of the cutting process and achieve the required results of cutting [5].

Having in mind that a large number of parameters affect the laser cutting process, experimental tests were performed to determine the degree of influence of the processing parameters on the quality of the cut. During the experiment of the laser cutting process, the following parameters were identified that significantly affect the cutting process: laser power, cutting speed, gas pressure and focus position. It was found that by varying the values of the parameters, the characteristics of the cut quality change significantly. When choosing the values of the parameters, the manufacturer's recommendations, technical and technological limitations of the machine and the characteristics of the workpiece material were taken into account.

Also, one of the pre-set goals was to achieve a complete cut in each combination of parameters in the experimental optimums, while covering a relatively wide domain of parameters variation. As part of the experimental tests, all experiments were performed on the same machine, under the same conditions and with the participation of the same operator.

The experimental processing parameters for AISI 4140, sheet thickness 6 mm are shown in Tabel 3.

Table 3. Experimental processing parameters

Workpiece material: AISI 4140 Sheet thickness: s=6 mm	
EXPERIMENTAL PROCESSING PARAMETERS	
Description	Value
Nozzle Type	SL 4_1.2
Nozzle Hole Diameter	1.2 mm
Focus Position	274
Pierce Height	2 mm
Pierce Gas Pressure	1.0 bar
Pierce Time	6 s
Pierce Start Laser Power	1500 W
Pierce Start Frequency	50 Hz
Pierce Start Duty Cycle	20
Pierce End Laser Power	2200 W
Pierce End Frequency	110 Hz
Cut Height	0.4 mm
Cut Gas Pressure	1.10 bar
Cut Speed	2400 mm/mm
Kerf	0.4 mm

4. MEASUREMENT AND ANALYSIS OF SURFACE ROUGHNESS

For quality evaluation of the cut in the experimental procedure, the roughness of the cut surface was measured on two experimental samples. The roughness of the cut surface was estimated via the arithmetic mean deviation of the profile (Ra).

Experimental measurements of surface roughness were performed in the Laboratory for Production Metrology and Total Quality Management (TQM) - Department of Production Engineering, Faculty of Mechanical Engineering, University of Belgrade. The measurements of the surface roughness was performed on the MarSurf PS 10 surface roughness measuring device, which is characterized by high technical performance.

Surface roughness measurements were performed along the depth of cut in three layers at a reference length of l = 15 mm. The samples were cut according to the parameters shown in Table 3. Figure 3 shows the laboratory reports of surface roughness.

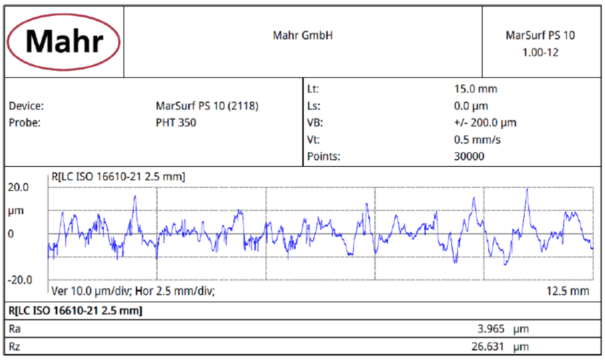

Figure 3. Laboratory reports of surface roughness

The microscopic appearance of the surfaces on which the surface roughness was measured is shown in Figure 4 for the I sample, and in Figure 5 for the II sample. The surfaces are marked with I-1, I-2 and I-3 for the sample cut with the recommended parameters (Table2), and II-1, II-2 and II-3 for the sample cut with the experimental parameters (Table3).

The presented figures show the influence of the applied processing mode parameters on the achieved cut quality. Lower gas pressure during punching and cutting, with the use of smaller diameter nozzles, with shorter heating and punching time of the workpiece material, as well as excessive cutting speed and greater distance of the nozzle from the workpiece during punching and during the cutting process, lead to surface defects and irregularities cut (Figure 4).

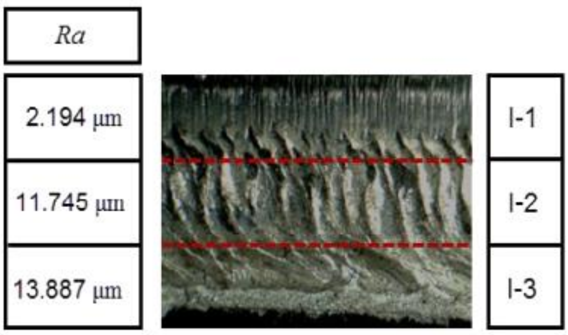

Figure 4. Microscopic appearance of the surfaces for the I sample

From the laboratory maesurements, after the conducted analyzes, it can be concluded that, with the application of empirically established parameters of the processing regime, a better quality of processing is achieved.

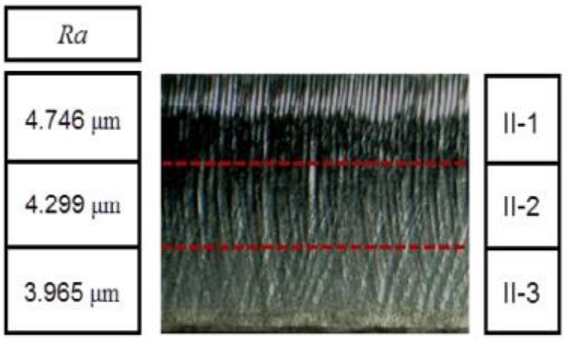

Figure 5. Microscopic appearance of the surfaces for the II sample

5. CONCLUSION

The paper presents the results of experimental research with the aim of optimizing the laser cutting process and evaluating the influence of process parameters on the performance of the cut quality, in order to increase the cut quality when cutting AISI4140 steel.

The planning and execution of experimental tests of laser cutting in real industrial conditions were carried out in order to establish the dependence between process parameters and cut quality characteristics.

Based on previous research, the greatest influence on the output characteristics of the laser cutting process with optimal parameters and processing conditions has the processing material itself with its physico-chemical and thermomechanical characteristics.

By varying the values of the process parameters, the characteristics of the cut quality change significantly. Too slow and too fast cutting speed gives unfavorable results in terms of characteristics and quality of the cut (increased roughness and slag formation from the bottom of the sample) which requires additional processing and additional operational processing costs.

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THE DEVELOPMENT OF THE “IN-LINE” MEASUREMENT OF THE SURFACE TEXTURE

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Abstract: *Surface metrology "on-machine" and "in-process" is important for quality control in the production of precision surfaces. Classifications, requirements, and tasks of surface metrology "on the machine" and "in-progress" are processed. The most modern measuring systems "on-machine" and "in-process" and sensor technology are presented. Debugging algorithms for machine debugging, which are especially needed in surface metrology "on-machine" and "in-process", are reviewed, followed by a discussion of calibration and traceability. Then advanced techniques in sampling strategies, the interface of measuring systems-machine tools, data flow, and analysis, as well as feedback for compensation production are demonstrated. Future challenges and development trends are also discussed.*

Keywords: *surface topography, wear tools, in-line measurement, CNC milling, monitoring*

1. INTRODUCTION

Surface metrology is an important discipline in the field of production metrology. It is defined as the deviation of the workpiece from the intended shape specified in the project drawing [1]. Surface metrology implies measuring the topography of the surface and surface defects, such as roundness, flatness, etc. The workpiece can be considered an integral element of the machine or mechanical system. Therefore, surface metrology plays an important role as an area because the surface topography of the workpiece affects its function and performance in the production process.

A large number of commercially available workpiece surface testing instruments and software can be used to obtain cross-sectional or surface topography data. Examples of mentioned instruments are mechanical pencil profiles [1, 11], non-contact instruments [2, 12], probe scanning microscopes [3], etc.

Surface metrology is an important part of the post-production inspection of the produced workpiece. This type of test is usually performed in a metrologically well-controlled room to determine whether the workpiece surface parameters meet the design requirements. Maximum efficiency of quality control is achieved when the measurement is performed at the nearest possible point of the production process [4].

Surface metrology is, also, effective for control of manufacture (on-machine and in-process) through optimizing the manufacturing process and the machine tool settings. The surface texture of the workpiece represents the characteristics of the process. Disadvantages of machine tools, vibrations, movements of geometric errors, and thermal distortions are reflected through surface form errors [1]. In recent years, an indispensable part of the chain of traditional production processes (cutting, grinding and polishing for precise workpieces of complex shapes and / or extremely narrow tolerances) is metrology on the machine and during the process [5, 7, 11]. Similar trends were noticed in manufacturing processes such as additive manufacturing [6] and nano-manufacturing [8].

This paper presents the tasks, classifications, and requirements of the surface metrology on the machine and during the process for precise production, appropriate measuring instruments, and sensor technologies as a supplement to previous CIRP papers on surface measurement.

2. ACTIVITY OF THE MEASUREMENT IN THE MANUFACTURING

In addition to the terms "on-machine" and "in-process", terms such as "in-situ" and "in-line/on-line" are often used to describe thestate of measurement activities in production metrology, Figure 1 [9]. One of the motives of this paper is to classify these terms in order to distinguish and use them correctly in the manufacturing engineering community [10].

In order to avoid possible ambiguities in the use of the term "process", we would note that this term refers to the fundamental process of the production, and not to the entire process chain or to the iterative process cycles.

Figure 2 shows a production line that is based on a production chain in a factory where environmental conditions cannot be strictly controlled, such as temperature, vibration, and humidity. Instruments for measuring the topography of the surface on the workpiece are placed in different places inside the factory. There is an ecologically isolated metrology room in many factories. In these rooms, it is possible to better control the measurement conditions and the influence of the environment on the measurement. From the environmental conditions point of view, it is possible to classify measuring instruments into two groups, namely: those that are located in the metrology room and those that are not [9].

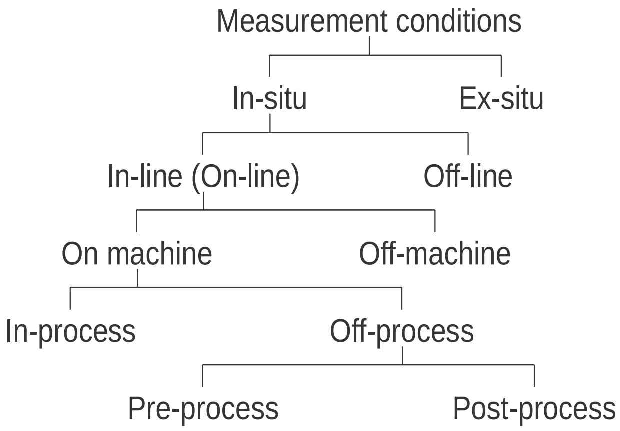

Figure 1. Conditions for precision manufacturing [9, 10]

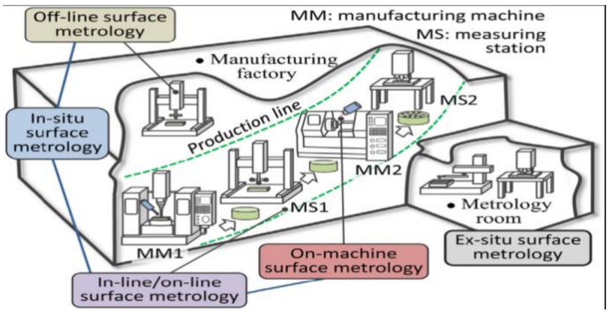

Figure 2. Scheme of the surface metrology in a factory with a production line [9]

Depending on the method of the workpiece surface measuring, there are "ex-situ" surface metrology and "in-situ" surface metrology. The "ex-situ" surface metrology means that the measurements were performed in the different conditions from a production process, while the "In-situ" surface metrology: a measurement of a part surface that is carried out inside the same manufacturing floor/shop floor without isolating the measurement process outside the manufacturing line.

Measuring instruments outside the metrology room can be, also, classified into two groups depending on their location in relation to the production line. Some of them are placed outside the production line. In some cases, the workpiece needs to be taken out of the production line and measured (with one or more instruments), and then returned to the line if it is necessary for further production. This measurement can be classified with the term "off-line" surface metrology. It is possible to use the terms "In-line/on-line" surface metrology: a measurement of a part surface that is carried out in a production or manufacturing line either inside (on-machine) or outside (off-machine) a production machine. Off-line is the measurement is carried out outside the production or manufacturing line, but still inside the same manufacturing floor.

When surface metrology is performed on a production line, the workpiece can be measured either when it is mounted on the machine or when it is taking out of the machine. When the workpiece is moved from the machine and measurements are made, such measurement can be classified according to the term "non-machine" surface metrology. "On-machine" surface metrology: a measurement of a part surface that is carried out inside a production machine that manufactures the part. The measurement can be carried out in-process (during the process) or off-process (before or after the process).

The above-mentioned classifications are made on the basis of the place where the workpiece surface measurement is carried out. The term "on-machine" surface metrology relates to the measurement carried out on the manufacturing machine. Because of that, it is necessary to identify this term according to the manufacturing process on the machine.

As shown in fig. 3, "on-machine" surface metrology can be performed before the production process, which can be classified as "pre-process on-machine" surface metrology. Also, "on-machine" surface metrology can be performed after the production process. In that case, the term "post-process on-machine" surface metrology can be used. These two can be grouped as "off-process" on-machine or simply "off-process" surface metrology. The corresponding "in-process" surface metrology, which is classified as another subcategory of on-machine surface metrology, can then be referred to as: "In-process" surface metrology: the on-machine measurement of workpiece surface carried out while the manufacturing process is taking place.

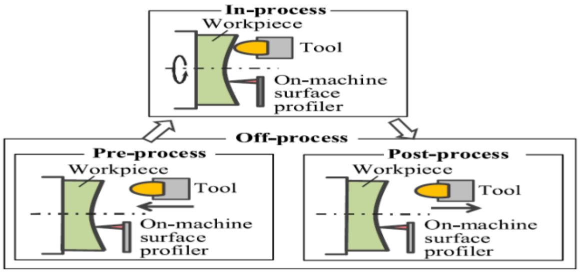

Figure 3. Classification of the "on-machine" surface metrology [9]

Fig. 4 represents a schematic of an "on-machine" surface metrology system. The most straightforward task of the "on-machine" surface metrology is to replace conventional post-manufacturing surface inspection of the workpiece made on a stand-alone surface measuring instrument. The "on-machine" inspection is performed soon after the production process and without taking off the workpiece from the machine. Therefore, the time interval from the end of the production process to the beginning of the inspection can be shortened in order to improve the efficiency of the inspection. The first step in this task is to set up the surface measuring instrument on the machine. Taking into consideration the limited space of the machine and the accessibility of the workpiece surface, the measuring instrument usually needs to be compact.

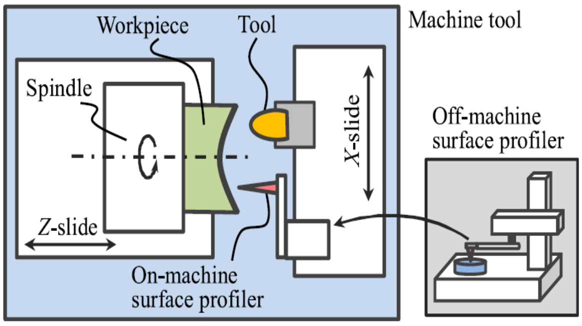

Figure 4. Schematic example of an “on-machine” surface metrology system [9]

In the case of the surface profile with probe scanning, only the instrument height sensor (Z) is mounted usually. Scanning movement relative to the workpiece surface, in the XY plane, is provided by the slider and by the spindle of the machine or by the transmission inside the probe measuring device. In order to construct topographic data of the surface workpiece, it is necessary to use data related to the position of the sliders and of the spindle from the machine NC controller, or directly from the output of the rotary and linear sensors of the spindle and sliders.

A significant difference can be noticed between "on-machine" and "off-machine" surface metrology by using a stand-alone surface measuring instrument. That difference is the result of the machine errors (including spindle/slide motion errors), thermal deformations, and/or vibrations. A sensor head alignment error on the machine tool is also an additional source of error. The reduction and separation of such errors from the "machine" surface measurement results, as well as related calibration and traceability issues must also be considered.

3. EXPERIMENTAL RESEARCH

The present research shows a part of the research results of the development an in -line measuring system for measuring machined surface topography and tool wear. Aluminum alloy workpiece AlMg4.5Mn (EN AW 5083) is mounted on a dynamometer "Kistler - Typ 9265A1".

Figure 5 shows measuring device positions used to measure the parameters of the topography (surface roughness) and the microscope of the camera used to measure tool wear.

Figure 5. Position of the measuring devices

The measuring device *ISR-C002 INSIZE* used to measure parameters of the surface roughness is mounted in a special bracket and attached to the main spindle carrier of the machine. In this way, it was possible to bring the measuring probe to the measuring position after milling using a predefined path in the NC code.

Figure 6 shows videos with microscope cameras and part of the measuring results of the roughness of the treated surface.

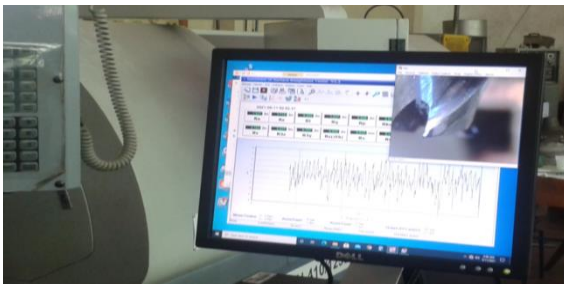

Figure 6. Video of the milling teeth and measured surface roughness

End milling cutter (10mm in diameter), HSS.E, with three teeth was used for the experiment. Aluminium processing was performed. Processing parameters were:

- milling width: 0.5 mm,

- milling depth: 10 mm,
- rpm: 1000 o/min,
- speed of the auxiliary movement: 100 mm/min,
- processing length: 100 mm.

The 10mm wide groove was made with 20 passes. The NC program was created in a way that the tool after processing is brought to a position that allows automatic placement of the probe of the roughness measuring device in a horizontal measuring position. At that moment execution of the NC program stops and waits for the adequate command to continue, fig. 7. During the program execution pause, the device for measuring surface roughness activates. By continuing to execute the NC program, the tool is automatically brought in front of the microscope camera to record the level of the cutter teeth wear.

Figure 7. Measurements of the roughness parameters after the first milling pass

Figure 8 shows the worn tooth of the used tool after the last processing pass and the removal of the deposits that occur during the machining of this aluminium alloy. The maximum width of the worn belt of the one tooth is 0.18mm.

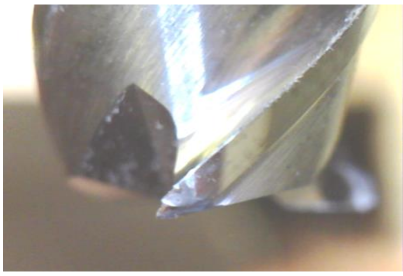

Figure 8. A worn tooth of the tool

Table 1 shows the results of measuring the wear width of the tooth (h) and the surface roughness parameters for machining with a new and worn milling cutter.

Table 1.

	h mm	Ra µm	Rz µm	Rmax µm
1	0	1.227	7.715	9.286
2	0,18	1.662	9.821	13.557

Table 1 shows that there has been an increase in the surface roughness or that there have been deterioration in the quality of treatment with tool wear.

4. CONCLUSION

In modern industry that does not suffer from downtime, errors and time losses, it is very important to ensure the correct method of monitoring the accuracy of machining (accuracy of measurements and quality of the machined surface) and the process of wear of the cutting tool. This is especially important in large-scale and mass production, such as in the automotive industry and others. For these reasons, the development of CNC machines is accompanied by the development of various monitoring methods. Monitoring the accuracy of the machining and the wear is becoming increasingly important, so that the new machines with factory-integrated monitoring systems are emerging, such as special cameras, dynamometers, acoustic devices, etc. In this way, the possibility of downtime or damage is minimized.

This paper presents experimental research that shows that measuring systems can be installed on a CNC machine, which provides online information on the roughness of the machined surface and the wear of the tool. Further research is directed towards the development of automated systems with integrated systems for monitoring the quality of the processed surface using laser non-contact measuring systems and recognizing the level of tool wear.

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SOFTWARE UPGRADE FOR AUTOMATIC ROUGH MILLING TECHNOLOGY DESIGN FOR PARTS WITH FREE FORM SURFACES

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Abstract: *Use of free form surfaces is present in almost all area of everyday living. In mechanical engineering such products are usually called parts with free form surfaces. Today is very easy to design such parts using some of commercial CAD software package. Unlike designing, production of those parts are more difficult. There are many strategies to machine parts with free form surfaces. The most used is milling method with ball mill cutter. In previous, at the Department for Production Engineering at the Faculty of Mechanical Engineering at Belgrade many research were conducted in the field of free form surface milling. Recently, the software for automatic technology design for parts with free form surfaces was developed. In this paper is presented developed procedure for software upgrade with new procedure for rough machining with milling head and ball end mill cutter.*

Keywords: *CAD/CAM systems, Computer Graphic, Free form surfaces, Ball end mill cutter, Milling.*

1. INTRODUCTION

In almost all commercial CAD software, free form surfaces are usually described in parametric form using parametric equations [1]. Parametric form allows tool path generation in an easy way to calculate CL (Cutter Locations) points across all surface which should be machined. Tool path generation include two segments and it is [2]:

- Tool path topology,
- Tool path parameters.

Generally, the milling with ball end mill cutter is the most used in machining of free form surfaces on 3, 4 and 5 axes milling machines. Machining with ball end mill include surface approximation with line segments. Until today three machining methods are developed, iso-parametric, iso-planar and iso-scallop machining method. Many years ago it was started research in the field of tool path optimization. One of the common use is federate scheduling optimization method. It can be based on specific production (MRR – **M**aterial **R**emoval **R**ate) [3, 4]. Second optimization method is based on cutting force prediction also called TWE – **T**ool **W**orkpiece **E**ngagement [5, 6]. It is also used models with Z map, workpiece discretization and similar.

In this paper is presented procedure and software upgrade for automatic technology design for free form surface machining, previously developed at the Faculty of Mechanical Engineering in Belgrade.

2. DEVELOPED SOFTWARE

In previous research CAD/CAM software for automatic technology design for free form surface machining is developed [7]. Software allows work with CAD model of free form surface in STL file format, figure 1.

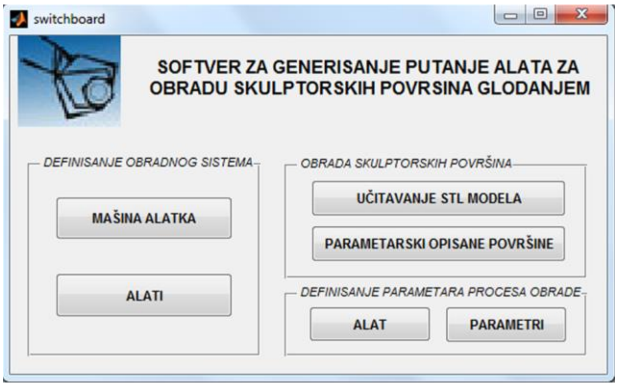


Figure 1. Developed CAD/CAM software [7]

After loading of CAD part file, it is possible to obtain NC code for machining with ball end mill cutter with multi criteria optimization method described in [8-10].

In cases when it is not possible to obtain NC code for machining with ball end mill cutter it was developed procedure for pre-machining with end mill cutter descripted in [11-14].

Tool path parameters (number of tool revolution and feedrate) are calculated from literature based on recommended values from [15, 16]. It is also possible to calculate cutting force so it can be machined with chosen machine.

Previous descripted procedure is presented on figure 2 [16].

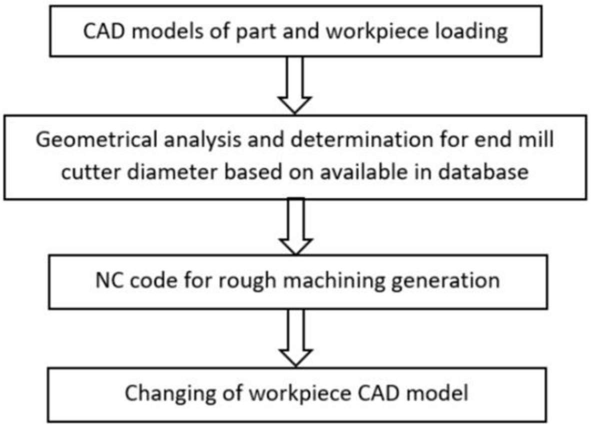


Figure 2. Developed CAD/CAM software [16]

Developed machining procedure is allowed by formed tool database which is included in system, figure 3. Entering this form is allowed from button “ALAT” from on figure 1.

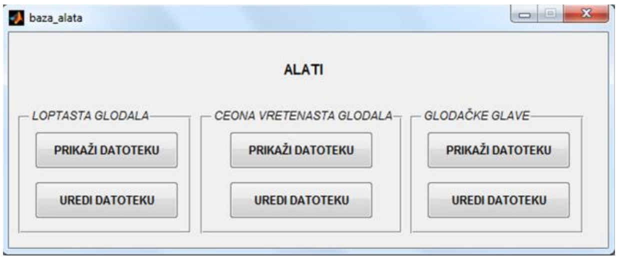


Figure 3. Form for toll database entering [7]

Using generated NC code for rough machining with ball end mill it is possible to get approximate shape of the surface (figure 4) which should be machined with ball end mill cutter which is also allowed with developed system.

Figure 4. Workpiece after rough machining [7]

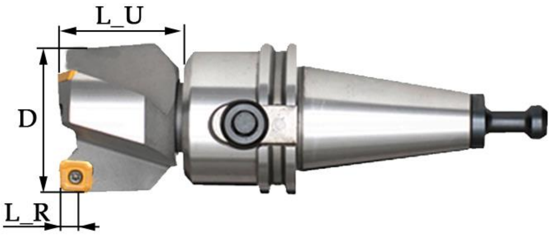
3. SOFTWARE UPGRADE

The next step in software development was to extend tool database with milling head and implement new procedure for rough pre-machining with milling head.

Usage of this machining procedure is justified in cases where is needed to cut as much as possible material in short time of period in order to minimize machining time and according to that final product price.

Generally speaking, description of milling head is similar to end mill cutter, but in developed system it is used few attributes to describe this kind of tool: Tool ID (ID), Tool

Diameter (D), Length of the cutting edge (*L_R*), Total Length (*L_U*), Number of teeth (z), Tool material (mat), Length correction mark (H). All described atributes are showen on figure 5.



ID	D	L_R	L_U	z	mat	H

Figure 5. Milling head file [7]

Current database is extended on this way to allow software to automatically chose machining with this tool in cases where that is possible.

In this state, software allows input of three types of tools and it is also possible to update database with new tools and eventually erasing some of existing in database according to procedure showed on picture 6.

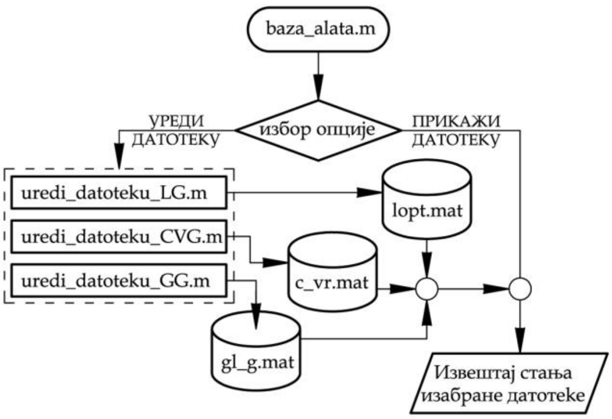


Figure 6. Tool database upgrade procedure [7]

Also, in any time it is possible to get current state of tool database with button "PRIKAZI DATOTEKU" from figure 3.

In cases where software recognize that it is possible to cut extra workpiece material with milling head it is allowed to input stock allow value for finish machining (δ_{GG}), figure 7. This stock allow will be machined in next machining step with ball end mill cutter in one or few passes depending on conducted geometrical analysis which is descripted in [7]. If software user don't want to machine with stock allow it is possible to input value equal to 0.

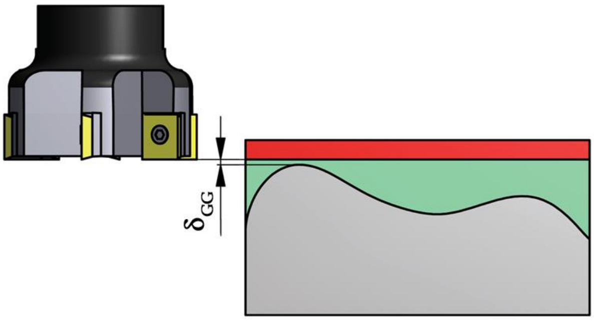


Figure 7. Stoch allow definition [7]

4. EXPERIMENTAL VERIFICATION

Using developed software, it was generated NC code for rough and finish machining of part with free form surface previously designed in commercial CAD software and saved in STL file format, figure 8.

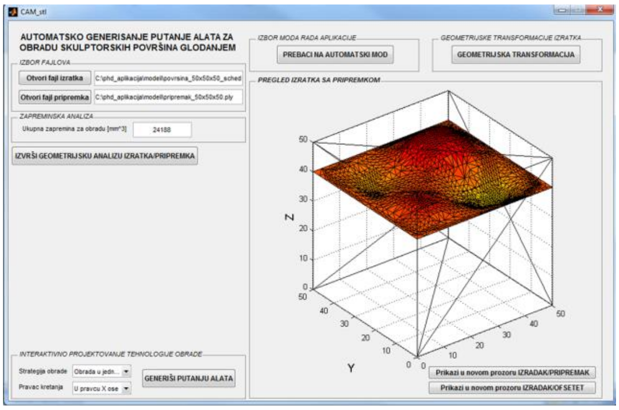


Figure 8. Stoch allow definition [7]

After machining on ILR HMC 500 working cente, measuring of part was conducted and point cloud was generated. Using Matlab software map of deviation was generated based on CAD model and generated point cloud, figure 9.

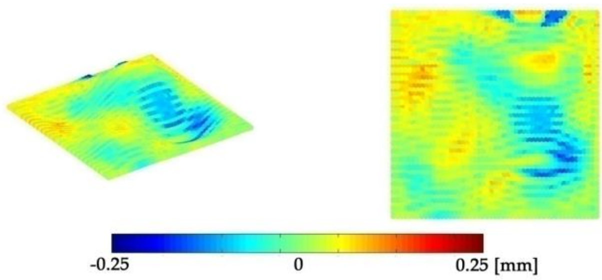


Figure 9. Map of deviation [7]

Based on analysis it was concluded that machining was performed in defined tolerances and surface roughness.

5. CONCLUSION

In this paper is descripted developed procedure for rough machining with milling head and its implementation in previously developed software. It was experimentally verified usage of developed software based on conducted machining and analysis from generated map of deviation.

ACKNOWLEDGEMENT

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THE ADVANCED DESIGN AND MANUFACTURE OF THE PLASTIC PART

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Abstract: *Injection molding technology is an important tool in producing complex-shaped plastic parts. Injection molding is one of the most common manufacturing process used today. It is able to produce parts with good quality and accuracy. The paper proposes an approach for design of the saltshaker and its manufacture. Based on the geometric product specifications and mathematical conditions of moldability, a collection of feasible injection parameters is formed using CAD and CAE tools.*

Keywords: *injection molding, plastic part, numerical simulation.*

1. INTRODUCTION

Today, the time-to-market for plastic products is becoming shorter, thus the lead-time available for making the injection mold is decreasing. There is potential for time saving in the injection cycle because a design process that is repeatable for every mold design can be standardized [1,2]. Due to its ability to produce complex-shape plastic parts with good dimensional accuracy and very short cycle times, injection molding has become the most important process for manufacturing plastic parts in the plastic industry today. However, the current plastics industry is under great pressure, due to the globalization of the market, the short life cycle of product development, increasing product multiplicity, high demand of product quality. To meet such requirements, it is important for this trade to adopt various advanced technologies, which include CAD/CAE/CAM integration technology, concurrent engineering, artificial intelligence, and so on, to effectively aid the development of injection molded product. In injection molding, the molding parameters are critical importance for product quality and efficient processing. In most cases, quality of mold is responsible for the economics of the entire process. Injection molding process involves extensive empirical knowledge (heuristic knowledge) about the material structure and material flows. Mold designers are required to possess thorough and wide experience, because detailed decisions require the knowledge of the interaction among various injection molding parameters. Unfortunately, it is presently impossible to cover the growing demand for such experienced designers. Therefore, CAD and CAE tools that can assist in the various tasks of injection molding process and mold design that are important to the productivity [3].

A number of research activities have been carried out on simulation of the injection molding and its related scientific area over the years using computer-aided techniques. These research activities range from studying particular areas of plastic simulation to investigating mold design as a completely CAD/CAE system.

To injection mold polymers, designing mold is key task involving several critical decisions with direct implications to yield quality, productivity and cost savings. One main decision among them is specifying injection molding parameters. Intuitively designers decide it wisely and then exasperate by optimizing or manipulating injection molding parameters [4].

The determinate of the injection molding process, whether by the improvement of product's quality or injection cycle time reduction is highly dependent on the mold design. Concerning the injection cycle, the cooling stage is the more significant component of the overall cycle time. Furthermore, it has a strong influence on plastic part's final properties and, therefore, cooling should be as efficient as possible. The cooling system design is, therefore, highly dependent on the compromise between temperature uniformity and the duration of the injection molding cycle [5,6]. Numerical simulations for the injection molding process provided excellent prospects concerning the use of conformal channels as the driver for defects minimization or even elimination as well as productivity gains, due to increased injection process efficiency [7].

This paper presents a methodology for designing the mold by determining the geometrical and critical injection molding parameters using a CAD/CAE tools. The authors propose integrated method using Creo Parametric and Moldflow software to simulate the injection molding process so that the product shrinkage can be considered at the early design stage and the quality of the part can be ensured with less molding cycle time. A real industrial case study will be provided to show the procedure and its validation. The method integrates PTC Creo Parametric and Moldflow simulation results as the intermediate state data set into PTC Creo Mold Design software. The available commercial CAE software for numerical simulation such as Pro/Plasic Adviser, Moldflow and Moldex3D can accurately simulate the injection molding process at different molding stages so that engineers can understand how the plastic melt flows into the mold and evaluate the product warpage effect. If the parts do not meet their quality requirements, potential reasons can be identified and the mold design can be updated on computers until high quality plastic parts can be manufactured. Therefore, the accuracy of the CAE simulation is vital for the product quality and the final cost. However, the available technology still has some limitations, as the real injection molding production process is very complicated and hard to control precisely. It has been the claim of Moldflow that product deformation due to the injection molding process can be simulated. At the end of the in mold cooling stage, the molded part is usually still warm and the quantity of molten plastic remains significant, especially for thick wall product ejected early. After ejection, these materials will continue to cool to room temperature in air, with in evitable shrinkage.

Certain plastic parts may have unevenly distributed wall thicknesses and mechanical properties so that the air-cooling process might cause complex, uneven deformations, which will account for a large portion of the whole product deformation [8]. Some researchers are trying to integrate Moldflow TM and Ansys to obtain a more accurate picture of the injection molded plastic product's mechanical performance [9-11]. Kulkarni et al. [9] proposed a integrated method to facilitate the design of a plastic injection molded product by using Autodesk Moldflow structural Alliance (AMSA).

2. MATERAILS AND METHODOLOGY

Usually, the initial plastic CAD model of the part is provided by the customers to meet their specific requirements, such as dimensions. Then the CAE numerical simulation is carried out to investigate how the manufacturing process will influence the part dimensions and identify shrinkage rates. After that, design updates are carried out by incorporating the manufacturing induced shrinkage rates to the initial part design, so that the updated design will satisfy the dimension requirements after going through the injection molding process. Usually, shrinkage rates induced by the injection molding process are small and the shrinkage pattern for the updated design is similar to the initial product design. The part material used in case study is Polypropylene PP001, that has a crystaline structure. There are tree dominant P-V-T viscosity models that are used in the numerical simulation of injection molding.

2.1 The 2-domain Tait P-V-T model

The modified 2-domain Tait P-V-T model is the model that Moldflow uses to account for material compressibility during a flow simulation. The compressibility of a material affects the volume of plastic required. The 2-domain Tait P-V-T [8,13,14,15,16,17,18] model is given by the following equations (1-7):

$$V(T,P) = V_0(T)(1 - C\ln(1 + \frac{P}{B(T)} + V_t(T,P)) \quad (1)$$

- $V(T,P)$ is the specific volume at temperature T and pressure P,
- V_0 is the specific volume at zero gauge pressure,
- T is the temperature [K],
- P is the pressure [Pa],
- C is a constant, 0.0894, and
- B accounts for the pressure sensitivity of the material and is defined below.

The upper temperature region $(T > T_t)$ can be described by the equations (2,3):

$$V_0 = b_{1m} + b_{2m}(T - b_5) \quad (2)$$

$$B(T) = b_{3m}\exp(-b_{4m}(T - b_5)) \quad (3)$$

Where:

- $b_{1m}, b_{2m}, b_{3m}, b_{4m}$, and b_5 (which represent the volumetric transition temperature, T_t, at zero gauge pressure) are data-fitted coefficients.

The lower temperature region $(T < T_t)$ can be described by the equations (4-6):

$$V_0 = b_{1s} + b_{2s}(T - b_5) \quad (4)$$

$$B(T) = b_{3s}\exp(-b_{4s}(T - b_5)) \quad (5)$$

$$V_t(T,P) = b_7\exp((b_8(T - b_5) - (b_9\mathrm{P})) \quad (6)$$

Where:

- $b_{1s}, b_{2s}, b_{3s}, b_{4s}$, $b_5, b_{7,} b_8$ and b_9 are data-fitted coefficients.

The dependence of T_t on pressure can be described by the equation (7):

$$T_t(P) = b_5 + b_6 P \quad (7)$$

Where:

- b_5 and b_6 are data-fitted coefficients.

2.2 The Cross Williams-Landel-Ferry (W-L-F) viscosity model

The Cross W-L-F viscosity model is given by the following equations (8-11) [13,14,15,16]:

$$\eta = \frac{\eta_0}{1 + (\frac{\eta_0 \dot{\gamma}}{T^*})^{(1-n)}} \quad (8)$$

$$\eta_0 = D_1\exp(\frac{-A_1(T - T^*)}{A_2 + (T - T^*)}) \quad (9)$$

Where:

- η is the viscosity [Pas],
- $\dot{\gamma}$ is the shear rate [1/s],
- T is the temperature [K].

$$T^* = D_2 + D_3 P \quad (10)$$

$$A_2 = A_2 + D_3 P \quad (11)$$

Where:

$n, T^*, D_1, D_2, D_3, A_1, A_2$ are data-fitted coefficients and P is pressure [Pa].

2.3 Moldflow viscosity model

The second order viscosity model is given by the following equation (12):

$$\ln(\eta) = A + B\ln(\dot{\gamma}) + CT + D(\ln(\dot{\gamma}))^2 E(\ln(\dot{\gamma})) + FT^2 \quad (12)$$

Where:

- η is the viscosity [Pas],
- $\dot{\gamma}$ is the shear rate [1/s],
- T is the temperature [^{0}C], and
- A, B, C, D, E, F are data-fitted coefficients.

The previously mentioned viscosity model is verified on the holder of saltshaker assembly, as will be described in the following section.

3. RESULTS AND ANALYSIS

A CAD assembly model of the saltshaker, is shown in Figure 1. The assembly is consists of following parts holder and stand.

Figure 1. Saltshaker assembly

The holder is used in the following case study. The technical drawing of the holder is presented in Figure 2.

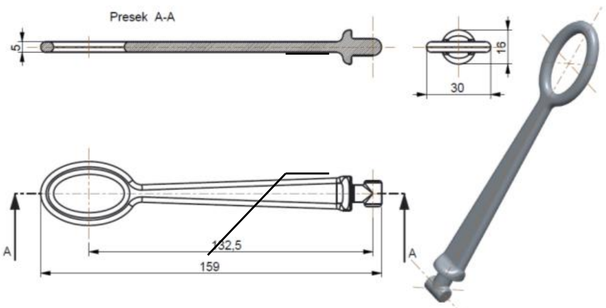

Figure 2. Draft with overall dimensions of the holder

The injection molding parameters of the holder are determined by using the MoldFlow software. The injection molding parameters are presented in Table 1.

Table 1. The injection molding parameters

Material Grade and Material Supplier	Polypropylenes PP 001 (KMT 6100)
Max Injection Pressure	180 [MPa]
Injection Pressure	13.85 [MPa]
Maximal melt temperature	280 [°C]
Mold Temperature	45 [°C]
Melt Temperature	245 [°C]
Transition temperature	130 [°C]
Injection Time	4.8 [s]
Structure	Crystaline
Calculated cycle time	22 [s]
Recommended ejection temperature	110 [°C]
Shear modulus	488 [MPa]
Maximal estimated shear stress	0,25 [MPa]
Max sink marks estimate	0,09 [mm]
Environmental temperature	20 [°C]
IMM name and manufacturer	270s ARBURG
Specific heat	2731 [J/kg°C]
Surface temperature variance range	-1.9 to 1.6 [°C]
Melt density	0.7344 [g/cm^3]
Solid density	0.8986 [g/cm^3]

General properties of the plastic material are presented using (η - T - $\dot{\gamma}$) chart in Figure 3.

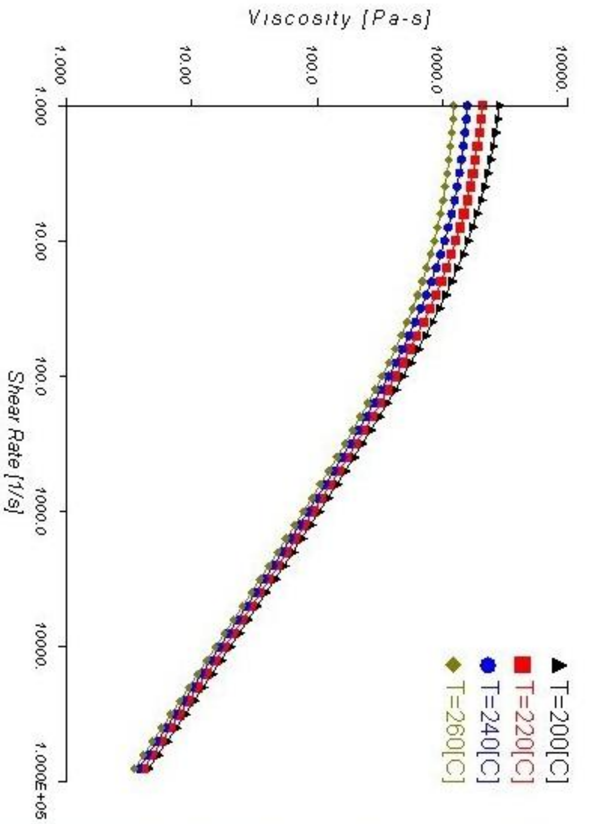

Figure 3. Rheological properties (η - T - $\dot{\gamma}$)

General material properties is presented using (P-V-T) chart in Figure 4.

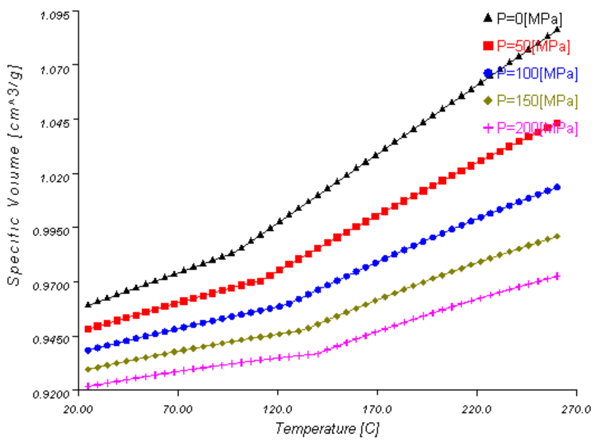

Figure 4. Rheological properties (P-V-T)

The Simulation model is generated using CAD system Creo, MoldFlow software for numerical simulation and PTC Mold Design. The appropriate simulation model consists of the gate subsystem and four plastic parts, as is shown in Figure 5.

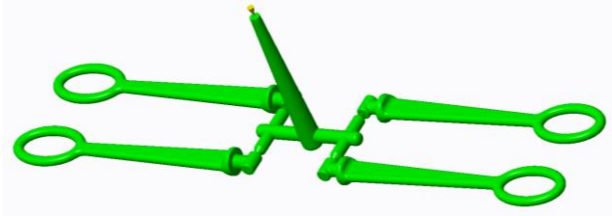

Figure 5. Simulation model

The quality test result measures the expected quality of the model's appearance and its mechanical properties. The quality is derived from combinations of the following five results: flow front temperature, pressure drop, cooling time, shear rate and shear stress. Only if all five results in an area are acceptable, the area is green and the simulation model has a high quality, as indicated in Figure 5.

The cooling quality analyze is presented in Figure 6.

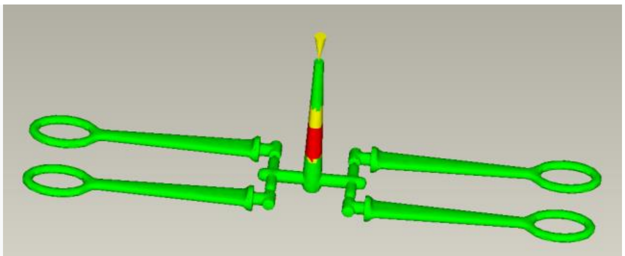

Figure 6. The cooling quality of the simulation model

There are three colors zones on the simulation model. The red zone cools five times longer than the green zone. The results is very important because cooling time is the most significant role in the calculated cycle time. The calculated cycle time includes the injection time, packing time, cooling time, holding time and the clamp opening time. The calculated cycle time is primarily based on cavity geometry. The cooling time is time for 90% of simulation model thickness frozen.

4. CONCUSIONS

Although there are some limitations, the authors expect that the method described in this paper will provide feasible foundations for full automation design process. Through illustrative example part, the approach is proven powerful and adaptable for use with current CAD/CAE systems and applications in industry. It will help in reducing the cycling time.

The proposed method achieves high accuracy and high performance. Example of industrially simulation model is used to demonstrate the performance and simplicity of the proposed method. The approach is generic in nature, allowing its application to be extended to any complex geometry in part and mold design.

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THE CUTTING SPEED INFLUENCE ON WIDTH AND TAPER OF KERF IN ABRASIVE WATER JET CUTTING

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Abstract: *The aim of this paper is analysis of the influence of cutting speed on the geometry of the kerf after machining with an abrasive water jet. The paper presents the results obtained by varying the cutting speed at constant pressure, abrasive flow rate and constant distance of the cutting head from the workpiece. Special attention was paid to monitoring the width of the kerf at the inlet and outlet of the abrasive water jet from the workpiece, in order to provide data on the deviation of the kerf taper. This is especially important, because based on the obtained results, it can be determined whether the additional machining is required. Also, AWJ machining with cutting speeds that are not optimal for certain machining conditions and modes can lead to the formation of pronounced irregularities on the machined surface. Therefore, it is important to find the appropriate cutting speed value for the given machining conditions.*

Keywords: *abrasive water jet cutting, kerf width, kerf taper*

1. INTRODUCTION

Advances in metallurgy have set new requirements in the fields of improving the quality of the material machining process, which will also lead to better quality of the final product. Abrasive water jet machining is one of the unconventional technologies that enables material processing, during which there are no thermal changes in the cutting zone,ie in the contact zone between the tool and the workpiece. This is one of the main advantages of this process.Thanks to this fact, it is classified as superior to other cutting processes. The application of this type of machining is especially useful in cutting 2D profiles of any shape and any material.The main feature of this processing is the use of a water jet that transmits kinetic energy to the abrasive particles, increasing their speed so that in contact with the workpiece, at the point of impact, the eroding effect of the jet on the material itself occurs. Abrasive water jet cutting with selected machining parameters will not always provide satisfactory surface quality. Therefore, it is necessary to pay special attention to certain characteristics such as tolerances and surface roughness, as well as the kerf taper. For the mentioned reasons, it is necessary to control the kerf taper, which will show whether additional machining of the cutted surface is necessary.

2. ABRASIVE WATER JET MACHINING

The high-pressure pump achieves the required water pressure, which is further directed to the orifice (Figure 1).In the orifice, the potential energy of the water is converted into the kinetic energy of the water jet.The water in the form of a small diameter jet passes through the orifice at high speed and reaches the mixing chamber where it mixes with the previously supplied abrasive particles, which improves the process efficiency. In the mixing chamber, the kinetic energy of the water jet is transferred to the abrasive particles after which a mixture of water and abrasive particles is sent to the nozzle where an abrasive water jet is formed ready for machining of the material.

An abrasive water jet is a mixture of abrasive particles, water and air.As the high-velocity jet hits the workpiece, the kinetic energy of the jet is converted into compressive energy which further causes high stresses in the material being machined.

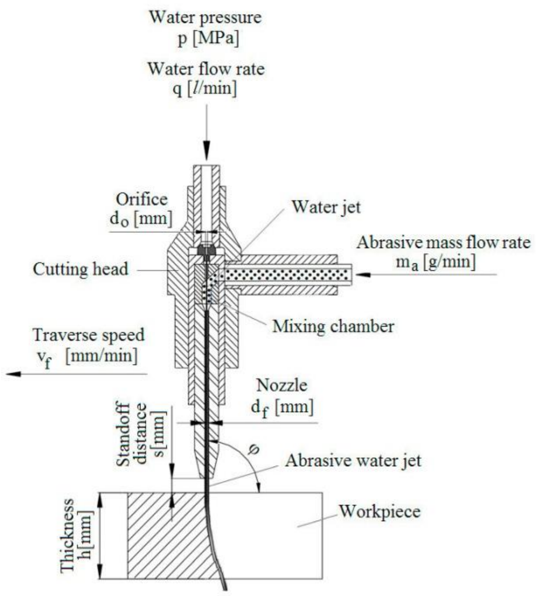

Figure 1. Scheme of abrasive water jet cutting [1]

3. CHARACTERISTICS OF THE SURFACE MACHINED WITH ABRASIVE WATER JET

Due to the fact that high-energy beam is used during the abrasive water jet machining, striation appears on the surfaces of the kerf. These striations can be more or less pronounced. Also, there is a change in the width of the kerf. This phenomenonssignificantly affects the accuracy of dimensions and quality of the treated surface.

On the kerf surface, obtained by AWJ machining, three characteristic zones are distinguished:

- Initial damage zone (initial erosion zone),
- Mid-kerf smooth cutting zone (middle zone the fine processing),
- Rough cutting zone adjacent to the jet exit (the roughing zone at the outlet of the jet from the material).

The appearance of each of these zones varies depending on the choice of machining parameters [2].

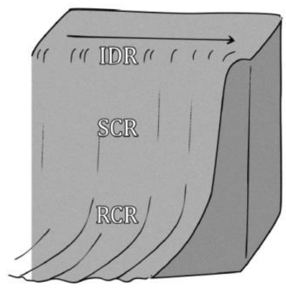

Figure2. Appearance of three characteristic zones obtained by cutting with an abrasive water jet [3]

The initial damage zone is characterized by a rounded profile and occurs due to the spread of the jet before it hits the workpiece (Figure 3) [4]. This zone is characterized by DIDR depth and WIDR width, which are used to obtain data on the roundness of the profile in theIDR.

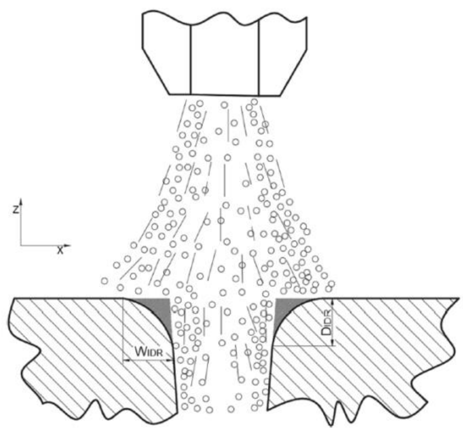

Figure3. Initial damage region, showing its width and depth [5]

The distance of the cutting head from the workpiece, the cutting speed, the pressure and the granulation of the abrasive sand significantly influence on this phenomenon. Reducing the pressure and increasing the distance of the cutting head from the workpiece will lead to greater roundness of the corners at the inlet. In order to achieve a better quality of the machined surface, it is necessary to strive to reduce the values of DIDR and WIDR [5].

The shapes of the kerf profile formed by AWJ machining can be different. The most common case is the appearance of a V-profile (Figure 5.a). The penetration of the water jet into the material leads to a continuous loss of its kinetic energy, which leads to a decrease in the diameter of the water jet and decrease of the width of the kerf from the inlet to the outlet of the jet from the workpiece (Figure 4). The V-shaped cross section is usually associated with a high cutting speed. The higher the cutting speed, the more pronounced the kerf taper from the inlet to the outlet of the jet from the material will be. As a consequence of this phenomenon, an irregular geometry is obtained, which is most often characterized by the following parameters:

-width at the inlet of the jet into the material (Wt),

-width at the outlet of the jet from the material (Wb),

- angle of the kerf taper (θ).

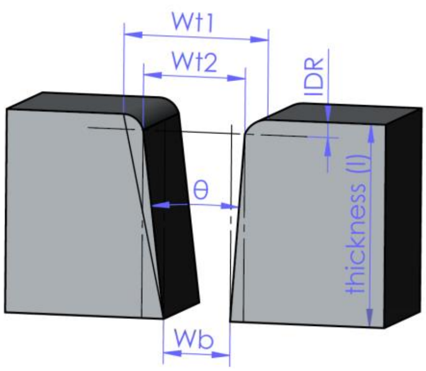

Figure4. Cut geometry in AWJ machining

Lower cutting speeds can result in the appearance of inverted kerf characteristics, ie an increase in the width of the cut can occur, ie the removal of a larger layer of material from the inlet to the outlet of the jet from the treated surface (Figure 5.b).This phenomenon is characteristic for the processing of ductile materials.The third shape of the cutting profile is such that the width of the cut in the middle of the kerf is greater than the width at the inlet and/or outlet of the jet from the material (Figure 5.c).Such a profile is characteristic for machining materials of large thicknesses.

The choice of machining parameters and machining mode directly affects the quality of the treated surface and the previously described geometric elements-kerf.

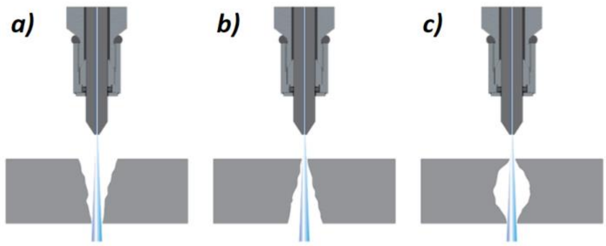

Figure5. The different types of kerf taper [6]

The parameters that have the greatest influence on the kerf geometry, and which can be easily changed and adjusted are the mass flow of the abrasive m_a, the operating pressure p, the distance of the nozzle from the workpiece x_o.Depending on the change in the value of these parameters, the kerf geometry processing alchanges.The most favorable case would be when the kerf surfaces are approximately parallel and perpendicular to the plane of the work table, while the most unfavorable case is the one where the slope of the cutting surface is most pronounced.There are several ways in which the resulting geometry can be calculated and defined.One refers to the observation of the ratio of the width of the kerf at the inlet of the abrasive water jet into the material and the width of the cut at the exit of the abrasive from the material (this ratio is denoted by K).

$$K=\frac{Wt}{Wb} \quad (1)$$

Of course, the more this ratio weighs the number 1 the geometry of the cut will be more favorable, and the quality of the treated surface better.

Another way to calculate the obtained kerf geometry is to find the angle θ that characterizes the kerf and the kerf taper obtained by AWJ machining.This angle can be obtained by using the following equation, where s represents the thickness of the material being processed.

$$\theta[rad] = 2\cdot arctan\left(\frac{\frac{W_t - W_b}{2}}{s}\right) \quad (2)$$

Since abrasive particles have a higher hardness than the machined material, the removal of the material will take place by a cyclic, stochastic erosion process. The abrasive water jet shows stochastic properties and instabilities in the interaction with the workpiece, which explains the appearance of waviness on the surface profile (Figure 6.c).The cause of such behavior can be pressure fluctuations, changes in particle distribution, the appearance of vibrations in the equipment as well as the inhomogeneity of the workpiece material [2].Cyclic movements of the jet lead to the formation of the characteristic profile-striations, shown in Figure 6.b, which corresponds to the width of the jet.The appearance of surface roughness is shown on Figure 6.a.

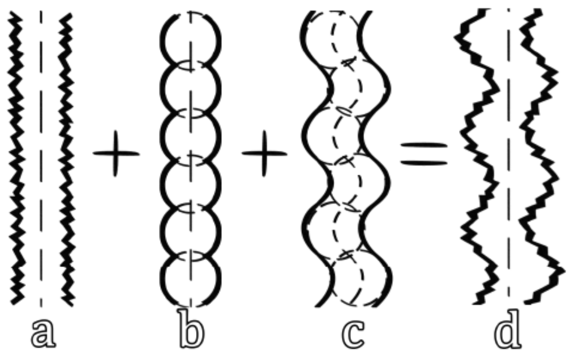

Figure6. Characteristic surface profile and its components in abrasive water jet cutting, a) roughness, b) cyclic pattern of jet movement, c) waves derived from jet instability and d) surface profile formed [3]

Considering all the mentionedcomponents and the previously described phenomena, the appearance of the formed surface profile is given in Figure 5.d.

4. EXPERIMENTAL PROCEDURE

Experimental investigations were performed on C45 steel.The chemical composition and tensile strength of this material are given in Tables 1 and 2.

Table 1. Material composition C45 (SRPS EN standard) expressed as a percentage (%)

	C	Si	S	P
[%]	0.37089	0.23707	0.00179	0.00732
	Mn	Ni	Cr	Mo
[%]	0.56557	0.06974	0.16295	0.03965

Table 2. The tensile strength of C45

Tensile strength	Rm	[N/mm^2]	650

During the experiment, the cutting speed was varied, while the pressure was constant and its value was 4130 bar.The abrasive was garnet mesh size 80, the abrasive mass flow ratewas 350 g/min, the distance of the cutting head from the workpiece –$x_0$was 3 mm.

Table 3. Machining parameters

Pressure	*p*	*bar*	*4130*
Garnet	*mesh*	*≠*	*80*
Abrasive mass flow rate	*m_a*	*[g/min]*	*350*
Distance of the cutting head	*X_o*	*[mm]*	*3*
Thickness	*s*	*[mm]*	*15*

During the experiment, 10 samples with different cutting speeds were cut, Table 4.

Table4. Cutting speed for different samples

Sample number	*Cutting speed Vc [mm/min]*	*Sample number*	*Cutting speed Vc [mm/min]*
1	100	6	220
2	120	7	240
3	140	8	260
4	160	9	280
5	180	10	180

The experiment was performed on a PTV - 3.8/60 machine.Figure 8 shows the machine during the experiment.

Figure 8. Machine PTV-3.8/60 during the experiment

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

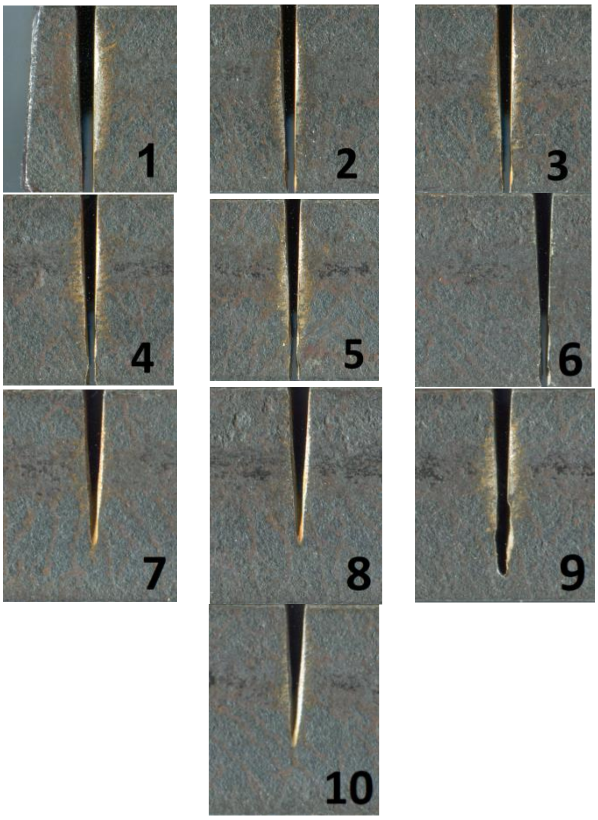

Figure9. Kerfs obtained at different cutting speeds

Figure 9 shows the samples obtained by cutting with abrasive water jet at different cutting speeds. Samples 8, 9, 10 and 11 were not taken into account when interpreting the obtained results, because no complete cut occurred during machining. The kerf widths at the inlet-Wt and outlet-Wb of the jet from the material of the workpiece were measured.Measurements were performed using an optical microscope with an accuracy of 0.01 mm.The measured results are given in Table 5. Based on the measured values, the kerf taper was calculated for each sample.

Table 5. Measured values of Wt and Wb

Sample number	*Cutting speed Vc*	*Wt*	*Wb*
	[mm/min]	*[mm]*	*[mm]*
1	100	1.66	0.98
2	120	1.33	0.98
3	140	1.4	0.67
4	160	1.13	0.69
5	180	1.38	0.84
6	200	1.51	0.89

The previously defined relation (2) was used to calculate the kerf taper. Values obtained by the calculation are given in Table 6.

Table 6. Kerf taper for samples

Sample number	*Cutting speed*	*Kerf taper Θ*
	[mm/min]	[°]
1	100	2.59
2	120	1.34
3	140	2.79
4	160	1.68
5	180	2.06
6	200	4.24

Figure 10 shows the effect of the change in cutting speed on the kerf widths at the inlet-Wt and outlet-Wb of the jet from the material of the workpiece.It can be noticed thatas the cutting speed increases, the cutting width decreases, both Wt and Wb.

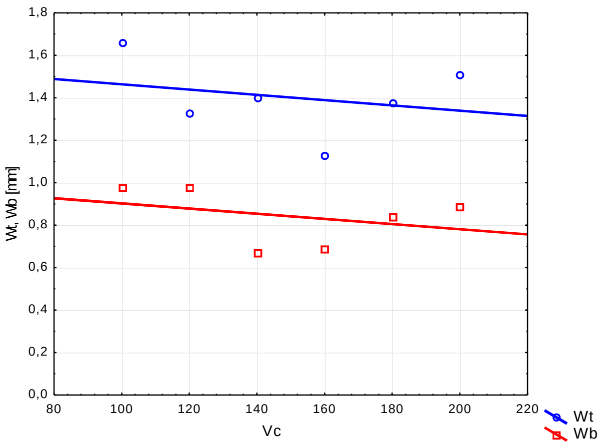

Figure 10. Diagram of the dependence of the kerf width on the cutting speed

Figure 11 shows the effect of the cutting speed on the kerf taper. It can be noticed thatas the cutting speed increases, so does the kerf taper.

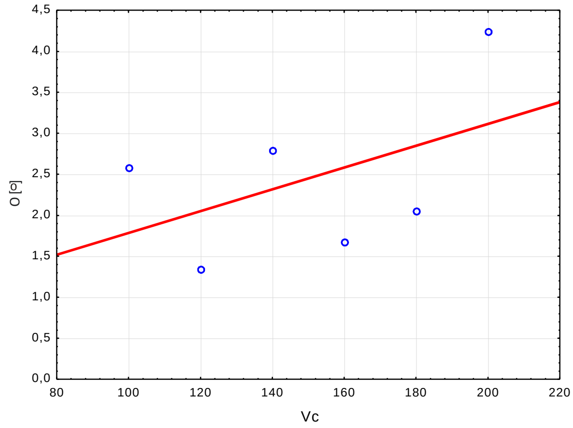

Figure 11. Diagram kerf taper depending on cutting speed

Increase in kerf taper means that the difference in the width of the kerf at the inlet of the AWJ in the material of the workpiece-Wt and the width at the exit of the AWJ from the workpiece-Wb increases.

6. CONCLUSIONS

The basicgoal of anymachining processismoreaccurateworkpiece. When machining with abrasive waterjet, the accuracy of workpiece is achieved by reducingthe width of the kerf and kerf taper. This can beachieved byproper combination of the abrasive water jet cutting parameters. Special attention should begiven to theselection of the operating pressure and traverse speed becausetheyhave the mostsignificant influence on the kerf geometry. The best combination is processing with high values of operating pressure and low traverse speed. On the machine on which the experiments were performed, it is possible to perform machining only with a operating pressure of 4130 and 3 500 bar, so that the optimal cutting width can be achieved only by changing the cutting speed. Based on the performed measurements, it can be concluded that with the increase of the cutting speed, the kerf width decreases and the kerf taper increases. When choosing the cutting speed, one should take into account the purpose of the workpiece, ie whether it is necessary to further process the workpiece due to the kerf taper. If the kerf taper does not affect the functionality of the part, it can be cutwith higher values of the cutting speed.

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METHODOLOGY FOR TOPOLOGICAL OPTIMIZATION AND 3D PRINTING OF A PERSONALISED WRIST ORTHOSIS FOR FRACTURES AND REHABILITATION

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Abstract: *Distal radius fractures are a common orthopaedic injury, which is treated by immobilisation of the wrist area using a plaster cast or an orthosis. A methodology for design of a personalized orthosis that can be flexible or fully stiff has already been presented by the authors. Further steps are presented here by expending the methodology to include the optimisation and production of the orthosis. In order to produce a personalised orthosis, additive manufacturing was chosen because of design freedom that it offers. A Fused Filament Fabrication machine was used for the creation of the orthosis. The body of the orthosis was made of a flexible material and additional reinforcing plates were produced to fully immobilise the fracture region. Additionally, topological optimisation was used to create ventilation holes in the orthosis, while having stiffness maximisation as a goal of optimisation.*

Keywords: *Biomedical Engineering, Additive Manufacturing, Topological Optimisation, Wrist Fracture, Orthosis*

1. INTRODUCTION

Distal radius fractures (DRF) are commonly treated with a plaster cast, but due to the discomforts it causes in terms of weight, hygiene, etc. multiple researchers have tried to find a better solution. In our previous paper, a methodology for designing a personalised wrist orthosis for fractures and rehabilitation is proposed. [1] The orthosis was developed through the application of an optical 3D scanner and Reverse Engineering (RE). This orthosis is designed in such a way that it can be stiff or flexible depending on whether it is used for the healing or rehabilitation process. Now this methodology is further developed through the application of Topology Optimisation (TO) and Additive Manufacturing (AM).

As already stated, several research teams have been dealing with the topics of Topology Optimisation (TO) and Additive Manufacturing (AM) of orthosis, and naturally different approaches can be observed in their work. When discussing the creation of ventilation openings on the orthosis, some researchers applied patterns of wholes (circular, diamond, etc. with the goal of minimal supports during 3D printing), which were checked using the Finite Element Method (FEM) [2]–[4]. Others have used Topological Optimisation (TO) in order to create optimal openings with respect to the structural characteristics of the model [5], [6]. Some have used 3D models for topological optimisation [5], while others used a 2D surface model in order to decrease the needed computing time [6]. There are orthosis design methodologies that employ an automated design process [2], [3], but as of now, we have not found any papers that have been able to automate the Topology Optimisation process for the orthosis, as confirmed by [7]. It is important to note that, to perform the analysis, most researchers used a model comprised only of the orthosis [2], [3], [5]–[7]. A more precise approach has been presented by Yanjun Chen et al [4], where the orthosis is attached to a model of hand tissue and bone.

Most approaches apply 3D printing (specifically FDM - Fused Deposition Modelling machines) as the means of manufacturing the orthosis [2]–[5], [7], [8], due to design freedom that it offers. It should be emphasized that FDM also has some drawbacks; in particular, production time can be a problem. This can be overcome by making the larger outer structure by injection molding (standard part), and the part that comes in contact with the skin (personalised part) by 3D printing. [9] The employed materials for orthosis 3D printing range from ABS [2], [3], to PLA [5], [6] and TPU [8].

2. TOPOLOGICAL OPTIMISATION OF ORTHOSIS

Topological optimisation was done using the Fusion 360 software in order to achieve maximal stiffness of the model while making the needed ventilation holes. The orthosis model was transferred from CATIA to the Shape Optimization module of Fusion 360 via STEP format. First, the material characteristics of Ninja Flex (Table 1) were defined as per the specifications given by the manufacturer Ninja Tek. [10]

Table 1. Ninja Flex mechanical properties

Property:	Value:
Young's Modulus	12MPa
Yield Strength	4 MPa (65%)
Tensile Strength	26 MPa
Density	1.19g/cm3

In this case a force of 100 N [2] was applied to the front face of the orthosis in a vertical direction and fixed support was added to the back face of the orthosis (Fig 1). This was a simple way to simulate the predominantly bending loads that in reality act on the orthosis.

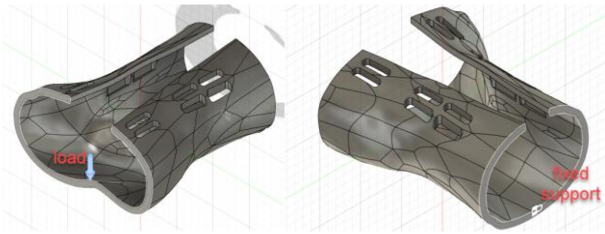

Figure 1. Topological optimisation setup: boundary conditions

The Preserve Region tool was used in order to define the regions of the model that were not to be changed during the optimisation (Fig 2.). The wrist joint area was defined as a region where no material should be removed (in addition to the position of holes for Velcro strips and the outermost edges of the orthosis (Fig 2.)).

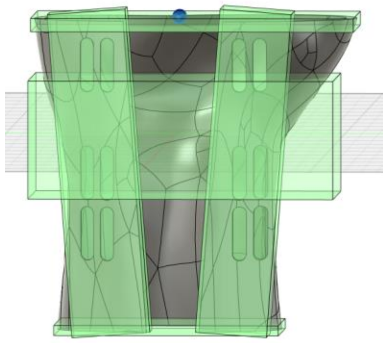

Figure 2. Topological optimisation setup: geometry regions that cannot change

For the optimisation goal stiffness maximisation was chosen with the constraint that the mass of the orthosis must be decreased by 20%. This was set to create ventilation holes in the position of minimal stresses on the orthosis in such a way that the overall mass of the remaining orthosis is equal to 80% of the original mass (Fig 3.).

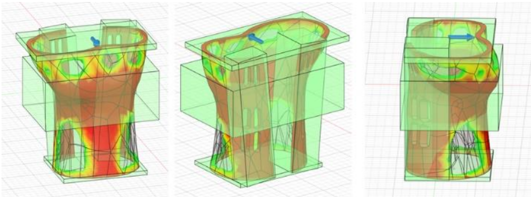

Figure 3. Topologically optimised orthosis

The model that has been created through the topological optimisation was defined by the mesh created for the purposes of the finite element method needed for the optimisation. In order to get a better geometrical model, the mesh model was placed over the original solid model using the Promote tool (Fig 4.).

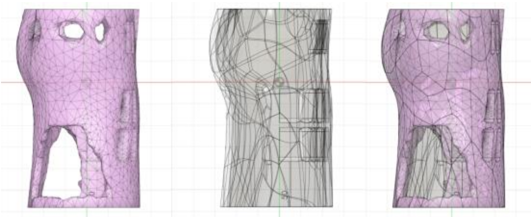

Figure 4. Mesh placed over solid model of the orthosis

Next sketch contours were made that correspond to the holes in the mesh model, and then the contours are cut from the solid model. By doing so the final solid model of the orthosis is created, which is then exported in the STL format needed for 3D printing (Fig 5.).

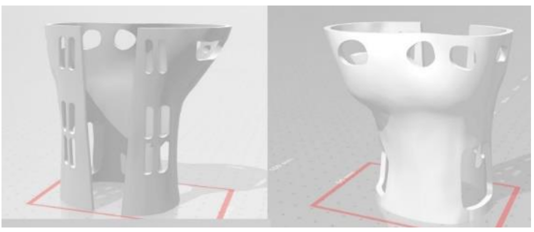

Figure 5. Solid model of the orthosis with ventilation holes

3. ADDITIVE MANUFACTURING OF ORTHOSIS

Additive manufacturing offers an array of benefits when compared to conventional methods of production. This is especially obvious for custom products (such as a personalised orthosis) where AM offers: freedom of design, minimal human interaction with the machine, minimal material waist and process with no specialised tools. In this case a Fused Filament Fabrication (FFF, also referred to as Fused Deposition Modelling - FDM) machine was used, because they are currently the most widely available additive manufacturing machines. FFF machines made up 75% of all additive manufacturing machines in 2018. [11] We used a Wanhao Duplicator i3 Plus FFF machine, which is a fairly inexpensive AM machine. This was done in order to ensure that the practical application of this methodology in medical clinics was possible without large investments.

The orthosis itself was printed out of a flexible material called Ninja Flex, a thermoplastic polyurethane (TPU). Retraction was not enabled, because it could cause inconsistent extrusion for TPU materials. A layer height of 0.25 mm was used (the first layer height was set to 0.375 mm to ensure better adhesion). The extruder temperature was set to 235°C, while the build plate was heated up to 60°C. The printing speed was set to 5mm/s. Higher speeds were not applicable because they caused inconsistent material flow. The clearance between the hot end and cold end of the extruder was minimized using a replacement component in order to prevent material flexing during the extrusion process (Fig 6.).

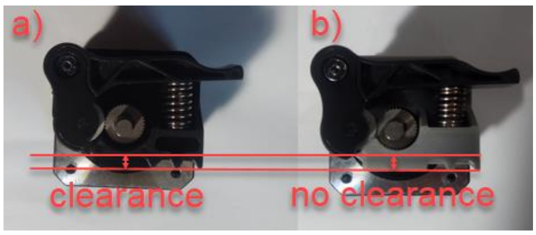

Figure 6. Wanhao Duplicator i3 Plus extruder cold end: (a) with clearance; (b) without clearance

The manufacturing process of the orthosis lasted 26 hours and 41 grams of material where used. Plates on the other hand were produced out of polylactic acid (PLA). Manufacturing the plates took 2 hour and 19 grams of material. The postprocessing of the orthosis included removing the supports and using send paper to make the internal surface of the orthosis finer (Fig 7.).

Figure 7. Orthosis and plates

4. CONCLUSION

When applied with reinforcing plates, the orthosis offers complete immobilisation of the fracture (Fig 8). Taking off the plates allows for a dorsiflexion and plantarflexion of 15^{o} to 20^{o}. While evaluating the orthosis the user described it as comfortable and had full functionality of the fingers.

Figure 8. In use orthosis with plates

A major flaw in the presented methodology is the 28 hours manufacturing time. In order to overcome this issue, the methodology could be repeated on different kinds of AM machines or on FFF machines which could handle the TPU material at higher speeds.

Further research may include the clinical application of the orthosis. In order for the clinical application to be practical, a parametric model of the orthosis should be considered (parameters would be defined for the wrist girth, arm length, etc.). This would decrease the design time and make it possible for medical technicians to easily apply the methodology.

Currently the time needed for data acquisition and the design process of an orthosis model is less than 4 hours. Further research in this area should strive to shorten these activities. Also, an orthosis for other body parts could be designed and produced using the same methodology.

ACKNOWLEDGEMENT

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DEVELOPMENT OF NOVEL SPRUE GEOMETRIES THAT MAXIMIZE COMPARATIVE ADVANTAGES OF ADDITIVELY MANUFACTURED SAND MOLDS FOR CASTING ALUMINUM ALLOYS

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Abstract: *One of the most important stages in the production of high-quality aluminum alloy castings is the mold filling process. Aluminum has a high affinity for oxygen and even the shortest contact between the melt and surrounding atmosphere causes the creation of the surface oxide film. In the presence of surface turbulence, these surface films are entrained inside the melt and create bifilm defects. Numerous studies performed in recent years have shown that bifilm defects cause severe deterioration of the reliability of the aluminum alloy castings. Current results indicate that to achieve high reliability and maximum mechanical properties, initial ingate velocities should be limited to a maximum of 0.5 m/s. I order to achieve these values numerous elaborate surge control systems and gating designs were recently developed. The most successful of them, namely the so-called trident gate, necessitate the use of several ceramic filters to minimize the priming problems. New technologies of additive mold production by 3d sand printing enable the use of complex gating designs that do not have to comply with many of the mold manufacturing constraints, i.e. the ease of pattern removal from the mold. Thus, novel geometries that minimize melt velocities are now possible to implement, and hopefully reduce the need for several filters that increase manufacturing costs. In this study, two sprue geometries were evaluated using numerical simulations. Obtained simulation results show that optimized sprue geometries have the potential to notably reduce melt velocities and thus increase mechanical properties of castings produced in additively manufactured sand molds.*

Keywords: *sand casting, 3D sand printing, gating system, casting simulation, numerical modeling.*

1. INTRODUCTION

In recent decades, there was a notable and steady rise in demand for reliable aluminum alloy castings. According to the available data from IKB Deutsche Industriebank AG, the global cast aluminum production steadily increased from 8 million tons in the year 2000 [1] to almost 19 million tons in the year 2018 [2]. More recent reliable data is still not published, but preliminary reports suggest that the approximate 20% production decrease in 2019-2020 caused by COVID-19 pandemic will probably be erased as early as the end of this year [3]. The aluminum alloy castings production will probably continue to increase and will reach more than 21 million tons in the 2025 [2]. This increase will mostly come from the automotive sector, but also from the trends related to lightweight construction in mechanical engineering sector. However, to reach these goals aluminum casting industry must increase reliability and mechanical properties their products. To achieve lighter products, design engineers need to decrease factor of safety during load bearing calculations. Thus, they need to be confident in the constant quality of the foundry sector.

1.1 Reliability of aluminum alloy castings

Recent research suggests that the main cause of reliability problems in aluminum alloy castings is the high melt velocity during the mold filling stage of the production process [4]. Aluminum has a high affinity for oxygen and even the shortest contact between the melt and surrounding atmosphere causes the creation of the surface oxide film. Current results indicate that aluminum melt velocities should be kept below 0.5 m/s. Higher velocities lead to increased probability in surface turbulence that causes entrainment of surface films inside the melt and creation of so-called bifilm defects. Numerous studies performed in recent years have shown that such defects cause severe deterioration of the reliability of the aluminum alloy castings. In one such study Green and Campbell [5] have shown that the type of the gating system and maximum metal velocity during mold filling have notable effect on distribution of mechanical properties of sand cast aluminum alloy castings, Fig. 1. Maximal ultimate tensile strength that can be achieved by using different gating systems is very similar. However, minimal values vary greatly. When using turbulent-free bottom filling system, not a single tensile specimen machined from the castings has failed below 270 MPa. However, for highly turbulent filling systems, specimen could fail when subjected to stresses lower than 190 MPa. Data clearly indicates that by using castings produced with low melt velocities one can subject them to 40% higher working loads. Such parts consume less material and offer possibilities for lighter products.

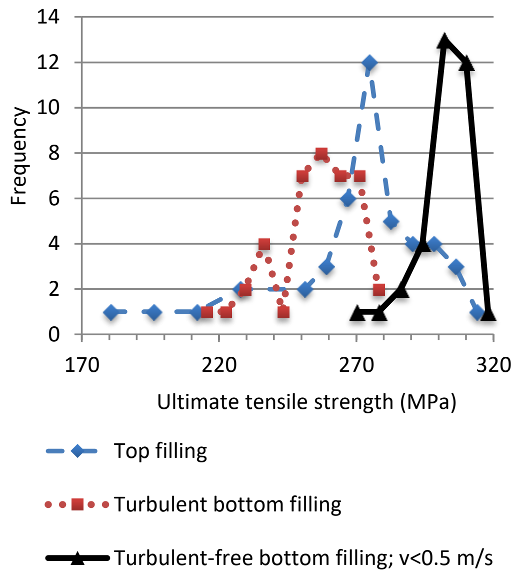

Figure 1. Influence of mold filling on reliability of mechanical properties of LM25 aluminum alloy castings. Data taken from reference [5].

In order to achieve low melt velocities during gravity sand casting, numerous elaborate surge control systems and gating designs were recently developed. The most successful of them, namely the so-called trident gate, necessitate the use of several ceramic filters to minimize the priming problems, Fig. 2. Therefore, achieving products that have high reliability and high mechanical properties comes at a price of increased production complexities and costs.

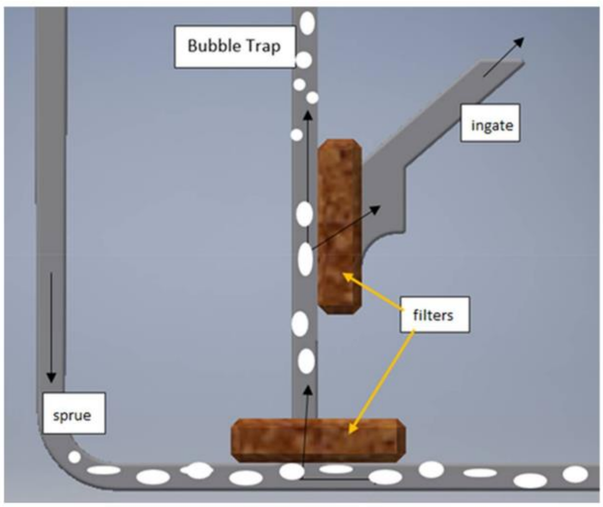

Figure 2. The trident gate system [6].

1.2 Additive manufacturing in the foundry industry

Additive manufacturing is generally considered as a competing technology to metalcasting, i.e. as a technology that can, in the long-term, take significant market-share in producing complex metal parts. However, in its current form, additive manufacturing and casting compete for completely different markets. Additive manufacturing specializes in one-off and small-scale production of parts with limited selection of available material compositions, while casting often caters to customers that require larger number of parts where material chemistry can be easily tailored to specific needs. In the niche markets where the target groups of these two industries intersect, they have found a way to augment each other. Many foundries are incorporating additive manufacturing techniques. At first, foundries started to cost-effectively produce sand casting or investment casting patterns from low melting materials by fused deposition modeling techniques. Although, this technology did not offer significant advantages over classical approaches, it did offer shorter lead times. However, the development of sand 3D printing technology (S3DP) has revolutionized the field of producing complex castings in low volumes [7]. S3DP offers the unique ability to fabricate molds and cores without any tooling requirements, i.e. patterns and core boxes [8]. For complex geometries and small production volumes, tooling costs are substantial and make up most significant share of total production costs. Therefore, initial benefits were clear. Since its first introduction into the regular manufacturing production of many foundries, additional benefits were observed. Parts produced by S3DP route can be made with undercuts and without drafts. This benefit enables increased design complexity and development of nonstandard geometries, including possibility to implement complex topology optimization algorithms [9].

The purpose of presented preliminary study is to investigate potential of novel sprue geometries, namely spiral sprue geometry, as a tool to minimize melt velocities and thus improve mechanical properties of aluminum alloy castings produced by S3DP route.

2. METHODOLOGY

To investigate performance of the spiral sprue, a simulation experiment was conducted based on two sprue geometries. First, a standard naturally pressurized gating system with a straight sprue was designed, Fig. 3. This gating system was used as a benchmark to adequately assess the benefits of the spiral sprue. Calculation was performed following recommendations given by prof. Campbell [4]. To make simulations computationally efficient and isolate the effect of sprue geometry and casting shape on melt velocities, models did not include a pouring basin and the filling was performed directly from the runner into the top of the cuboid-shaped casting geometry.

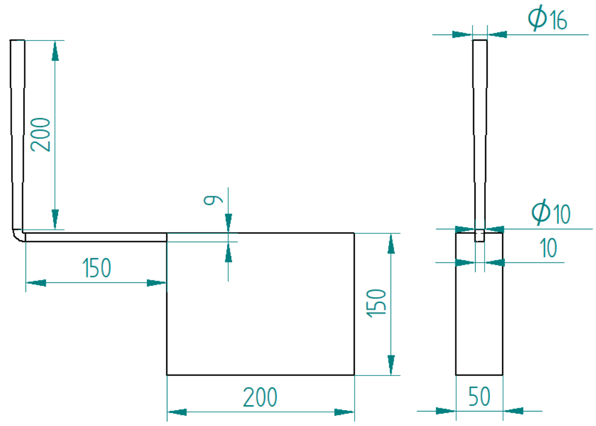

Figure 3. Dimensions of the straight sprue gating system in relation to the casting.

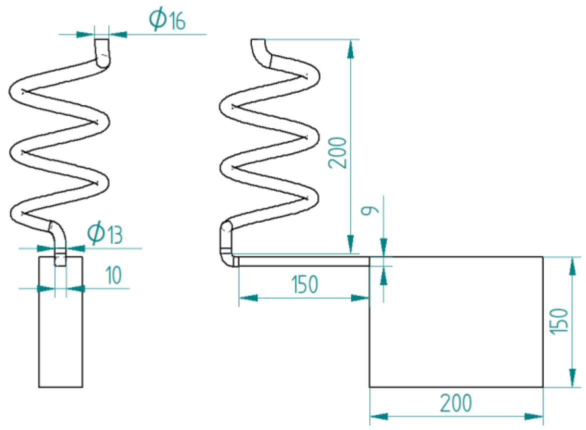

Figure 4. Dimensions of the spiral sprue gating system in relation to the casting.

The second gating system that was analyzed had a spiral sprue geometry, Fig. 4. Since the friction factor is still not known for this kind of sprue geometry, the sprue exit was arbitrarily increased from Ø10 mm to Ø13 mm. All other dimensions were kept the same.

The 3D geometries were modeled in Siemens Solid Edge and then imported into the simulation software through STEP interface. The simulations were carried out using Magma5 v5.3 from MAGMA Giessereitechnologie GmbH, Germany. In all simulations the pouring temperature was selected to be 650°C, and the pouring rate was defined through pressure curve boundary condition. One of the most common aluminum alloys, AlSi12 was selected as a casting material for all simulations. The mold material was green sand, and the initial mold temperature was set as 40°C. Values of material properties and heat transfer conditions were selected from internal database of the Magma5.

3. RESULTS AND DISCUSSION

As it is currently understood, one of the most important goals when designing gating system is that it should be filled with metal as fast as possible [4]. This means that as soon as the melt reaches certain cross section, the cross section should only contain molten metal and any air should be absent. Every air pocket that is left behind the melt front is a potential casting defect that reduces mechanical properties. In reality, this goal can never be achieved since the velocity field is not completely uniform. However, one should strive to minimize the time during which the gating system has air pockets in it. One way to objectively compare different gating systems from this aspect is to determine the time between the moment when the molten metal first reaches the casting cavity and the moment when the gating system is completely filled with metal. Simulation results for two investigated geometries are given in table 1.

Table 1. Critical timesteps during mold filling of analyzed gating geometries.

Sprue geometry	Time from start of the filling [s]	
	First melt reaches the casting	Gating system is completely filled
Straight	0.209	2.035
Spiral	1.227	1.629

Gating system with straight sprue geometry is filling the casting for 1.8 seconds until all air pockets are evacuated. For small to medium castings where filling times are approximately 5 seconds, this is unacceptably large timeframe. Casings produced with filling systems that have such priming problems usually have lower mechanical properties [4].

Since the spiral sprue is more voluminous than the straight sprue and metal needs to travel greater length, it takes 1 second longer for melt front to reach the reach the casting cavity. However, it then takes only 0.4 seconds until the gating system is fully filed with molten metal. Therefore, from priming perspective, the spiral sprue geometry can be regarded as more successful. However, closer analysis of the filling pattern reveals that there is still more areas for improvement.

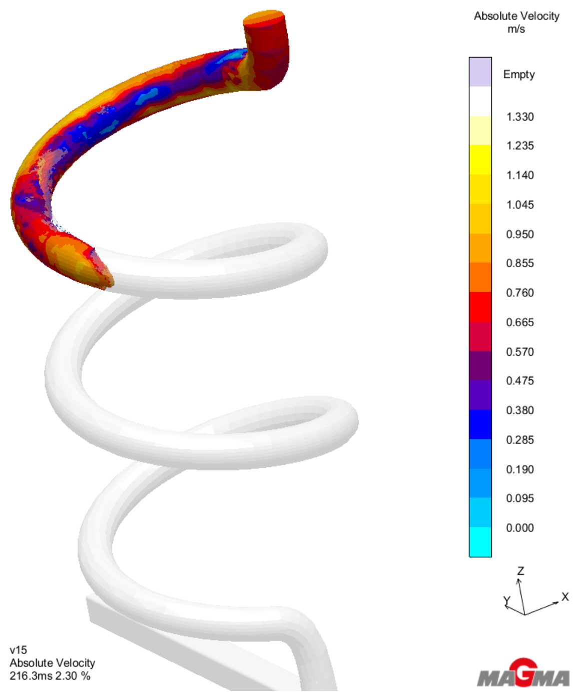

Figure 5. Simulated velocity fields at the start of the filling process.

As can be seen on Fig. 5, during initial stages of mold filling the inside radius of the sprue curvature remains unfilled. At this point it is unknown whether the air pocket is a simulation artefact, or would indeed be present during the actual casting process. To achieve computational efficiency, default settings in the software do not include complete physics. For example, surface tension is excluded from the calculation. However, it is reasonable to expect that future research on this topic should include optimization of the curvature of the spiral with regards to the melt velocity to prevent formation of such air pockets.

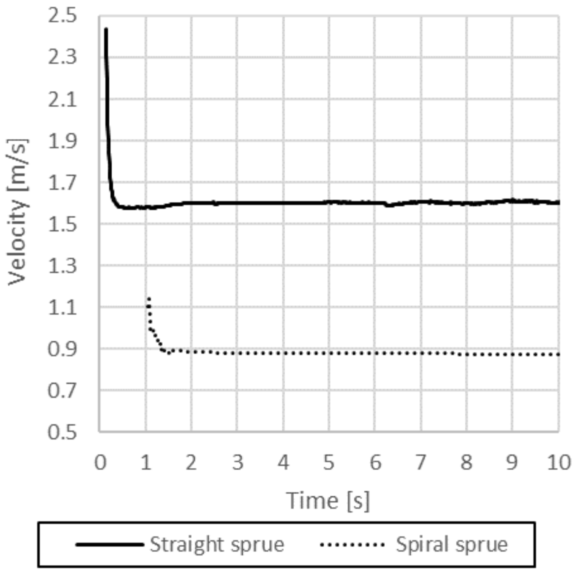

Figure 6. Simulated velocities at the end of the sprue.

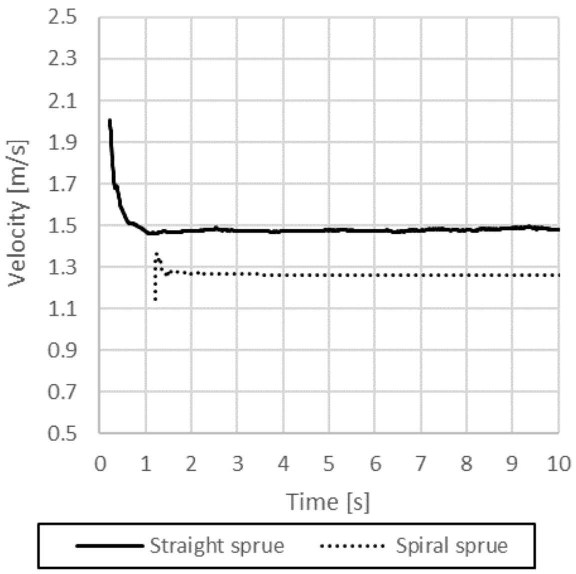

Figure 7. Simulated velocities at the end of the runner.

Simulated velocities for both gating systems at the critical cross sections, namely the end of the sprue and the end of the runner, are given on Figs. 6 and 7. In both cross sections melt velocities of the spiral geometry were lower. Likewise, in both cases the melt velocity increased between the time it exited the sprue and the moment it reached the casting cavity at the end of the runner. Such trend indicates that the runner had a smaller-than-optimal cross section and was acting like a convergent nozzle [4]. Therefore, energy losses were not adequately considered. This line of thought is substantiated by the fact that the rise in the melt velocity was much more pronounced for spiral sprue. Beneficial effects of the energy losses due to the spiral motion inside the sprue would have been utilized much better by adequately increasing the size of the cross section of the runner. Therefore, in order to be able to adequately calculate and design gating systems that use spiral sprue geometries much more work is needed to correctly determine friction energy losses.

4. CONCLUSIONS

Based on presented results, following conclusions can be drawn:

- Priming of the gating system with spiral sprue was considerably faster than the priming of the system with the straight sprue.
- Inside radius of the spiral sprue has a tendency to form pockets of reduced pressure where air entrainment could occur. Future research should address this issue and find optimum curvatures for various melt velocities and sprue heights.
- As expected, the spiral sprue geometry was able to significantly lower the melt velocities.
- Melt velocities increased between end of the sprue and end of the runner. This increase was notably larger for the spiral sprue geometry, indicating necessity to adequately predict melt losses in order to optimize the runner cross sections during the initial design stage.

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CONCEPTUAL MODEL OF AN INFORMATION SYSTEM FOR MEASURING CUTTING FLUID TEMPERATURE ON CNC MACHINES

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Abstract: *Cutting fluids are an important component of the cutting process due to their positive effects on tool life, surface quality and productivity. At the same time, cutting fluids have negative effects on human health and the environment, which makes it necessary to reduce their use. By monitoring and analyzing the cutting process, use of cutting fluids could be minimized and cleaner production achieved while maintaining the required processing quality and productivity. This paper proposes a conceptual model of a smart information system to optimize the use of cutting fluids. This system includes collecting, filtering and storing data obtained from temperature and flow sensors, and this information is then used to determine the relationship between process parameters and sensor data. In line with Industry 4.0, this monitoring system would be based on the Internet of Things and cloud service.*

Keywords: *cutting fluids (CF), manufacturing engineering, environmental, Internet of Things (IoT), smart information system.*

1. INTRODUCTION

The Fourth Industrial Revolution with the latest achievements in information and communication technology (ICT) has enabled a transition from traditional to advanced manufacturing processes and has promoted the idea of the smart factory [1].

The smart factory is now leading the whole change in the way of production [2]. In order to protect resources, reduce energy consumption, waste and toxic emissions (thus achieving cleaner and sustainable production), there is a need to achieve optimized technological improvements and process planning [3].

The smart factory model plays a crucial role in reducing environmental impacts and achieving cleaner production [4].

An important component of the cutting process are cutting fluids (coolants and lubricants).

Although lubricants and coolants improve surface quality and prolong tool life, due to the presence of toxic chemicals, they have harmful effects on the environment and human health.

Organized and regulated management of cutting fluids (CF) is one of the starting points for establishing a quality system and ensuring the humane aspect of quality aimed at environmental protection [5].

Current technologies such as Internet of Things (IoT)-based sensors can be considered a solution for efficient monitoring and management of the manufacturing process [6]. The use of CF can be optimized by processing and analyzing data collected from cutting process temperature sensors and the CF flow sensors.

In order to regulate improper treatment and disposal of CF the EU has introduced legal requirements for the application of all types of CF in manufacturing as well as their treatment and disposal [7].

World use of CF approximates 2.2 billion liters, 54% of which is used during the cutting process. This worrying data shows that mechanical industry is a serious environmental polluter [8]. Compliance with regulations and limiting values of the use of CF is not enough. We need to work towards their maximum possible reduction in order to achieve cleaner production.

To achieve zero (or at least reduced) levels of pollution and toxicity, care should be taken to select the appropriate type of CF and process analysis [5]. The optimal amount of CF is actually the minimum amount that should be used at certain given process parameters, so as to satisfy the required quality and maintain productivity.

The processing temperature is directly related to the amount and flow of CF [9]. Through monitoring process parameters and analyzing the data obtained from the sensors, a model of a smart information system of the cutting process can be established.

The main tasks of CF are shown in figure 1.

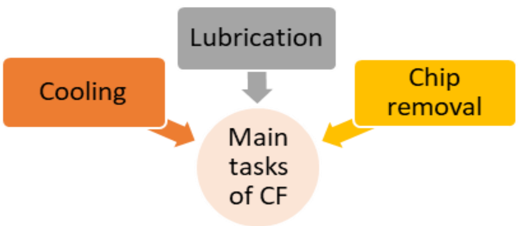

Figure 1. Main tasks of CF

The secondary function of CF is to extend tool life, increase productivity, provide better surface quality, prevent corrosion, and clean tools and workpieces. The appropriate CF is selected depending on the machining process, workpiece and tool material. Inappropriate application of CF poses a significant problem. In addition to the use of degraded CF as well as unsuitable type of CF for the requirements of the metalworking process, the biggest problem in the application of CF is excessive amounts. The optimal amount of CF is selected taking into account the following factors: tool condition, type and shape of tool, machine conditions, specific processing parameters (depth of cut, cutting speed, chip cross section) [5].

When a connection is established between predefined process parameters and data obtained from the temperature and flow rate sensors, a model is obtained that serves to minimize the use of CF while maintaining process productivity and the required processing quality.

2. TYPE AND CHARACTERISTICS OF CUTTING FLUIDS

CF can be divided into pure cutting oils and emulsions.

Pure cutting oils such as mineral, vegetable, animal, synthetic or mixtures of these oils are more used in operations that primarily require lubrication at low speeds where the increase in temperature is not significant, and there are high resistances to cutting. Biodegradable oils are environmentally friendly and a good alternative to mineral oils.

Pure cutting oils can be inactive and active. The main difference is that inactive pure cutting oils do not have a corrosive effect on non-ferrous metals and their alloys. The additives in active cutting oils react chemically at low temperatures, which is why they are most often used in the processing of steel and its alloys.

Emulsions consist of oil, water and an emulsifier that keeps the oil in fine droplets in water. They are used in operations that primarily require cooling and chip removal (at high cutting speeds where lower cutting resistances occur, but there is a significant increase in temperature).

Types of CF in relation to the content of mineral oil and synthetic components are shown in the figure 2 [5].

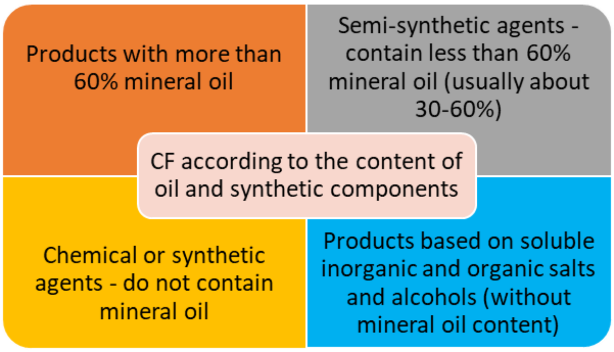

Figure 2. Types of CF

Additives like corrosion inhibitors, antifoams, stabilizers, extreme pressure (EP) additives, surfactants and emulsifiers, additives for prolongation of tool life and bactericides are added to achieve the required physicochemical characteristics. The use of additives that contain chlorine is not recommended, and some are even prohibited [10].

There are some global recommendations when it comes to the choice of CF depending on the metalworking process. Thus, depending on the working conditions, semi-synthetic and synthetic emulsions or pure cutting oils with increased content of EP additives are used in the milling process.

Emulsions with improved lubricating properties are mainly used during the turning process. If there is a danger of mixing with other oils (hydraulic), then pure inactive cutting oils are used [11]. CF with an increased cooling effect are used when high temperatures occur in the cutting zone as in the case of high-strength metal cutting [12].

3. NEGATIVE IMPACTS OF CUTTING FLUIDS

Adequate maintenance and regular cleaning of the entire plant prevents the degradation of CF which in turn contributes to their longer and more eco-friendly use. Use of degraded CF causes the increase of in microorganisms and metal particles, as well as the appearance of chemical imbalances, all of which lead to increased friction, inaccurate metalworking, corrosion, unpleasant odours, tool wear, sticking, clogging, etc.

Loss of CF through evaporation, leakage, splashing, spillage and residue left on the workpiece and chips is a big problem. In order to prevent CF evaporation (harmful vapours), it is necessary to carefully choose the type of CF with evaporation point appropriate for the workpiece and temperature that occur in the cutting zone. Losses can also be reduced by using the optimal amount of CF.

The actions aimed at achieving clean production are shown in figure 3.

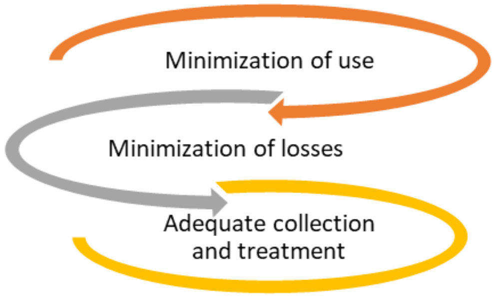

Figure 3. Actions aimed at achieving clean production

Since CF is one of the most complex types of chemical waste with a large amount of potentially hazardous substances, necessary measures for a proper treatment (incineration, filtration, distillation, flotation, centrifugation and electrolysis) need to be implemented [13]. CF pose a great risk to the health of machine operators through their exposure to the liquid, vapor or mist, all of which have carcinogenic and toxic properties. This can lead to occupational diseases such as lung cancer, asthma, genetic disorders, etc [14]. This risk can be reduced by an adequate choice of eco-friendly CF with less harmful additives and optimal use.

When selecting the type of CF used, hazardous properties such as flammability, explosiveness etc, should be taken into account. The data showing that 1.2 million operators are exposed to CF negative impacts highlights the importance of reducing the use of CF [15].

Figure 4 shows four ways in which CF can enter the human body: dermally, by inhalation, orally and through wounds [16].

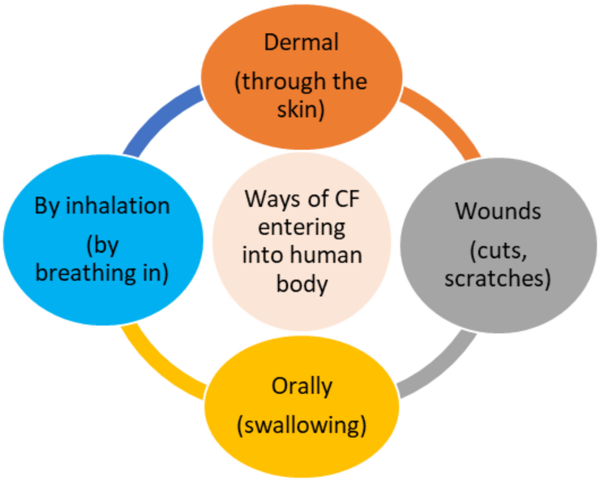

Figure 4. Ways of CF entering into human body [16]

Given the many proven negative effects that CF and their vapors have on human health, it is not enough to just comply with regulations, but do everything to minimize the use of CF.

By optimizing the use of CF, financial savings are also achieved, since most of the material costs are directly related to uneconomical use of CF.

4. IOT SENSORS

Use of the Internet of Things (IoT) is expanding and improving, which drives Computer Numerical Control (CNC) processing towards higher revenues and wider usability. The use of IoT in cutting processes has an impact on reducing consumption, creating optimized processes and higher quality products, all with consideration and in accordance with environmental protection and the creation of cleaner production. IoT actually represents a revolution in many manufacturing practices as it further connects and digitizes our factories. Constant monitoring of the process enables timely response, which leads to maximum productivity. The major benefits that IoT brings to cutting processes are product quality control, preventive maintenance and automated operation [17]. IoT sensors can detect defects in tools and materials as well as errors in the cutting process, and remote monitoring of both the machines and the products can be done in real time. The sensors ensure optimization and automation of the CNC machine, constantly monitoring the cutting process with the possibility of warning of any problems and deviations. Based on the sensor feedback, the necessary changes are made to solve the problem or improve the cutting process itself. IoT cutting process automation reduces process costs, prevents workplace injuries, and reduces negative environmental effects.

An outstanding feature of sensors is their ability to convert information obtained in the outside world into data for analysis. The sensors monitor certain physical phenomena that are further converted from analog to digital data. Digitized data is sent to data collection systems, where it can be further processed and analyzed [18]. The information from analyzed data is returned to the physical world. This most often implies sending orders to actuators to perform some actions, thus achieving a complete system of control and management [19].

Monitoring and measuring very simple parameters in the cutting process can extend the life of tools and other components, increase productivity, reduce downtime while optimizing the use of CF, which can have positive outcome on reducing environmental pollution and other negative effects of CF.

Thermal phenomena (cutting temperature, generated heat, etc.), which occur in the narrower and wider area of the cutting zone, are directly and very closely correlated with the tool wear rate, the machinability rate of the workpiece material, tool durability and so on.

The heat generated in the cutting zone is transferred to the chips, tools, workpiece and the environment. The distribution of this heat depends on the workpiece and tool materials (mechanical and chemical properties), cutting speed, feed rate, depth of cut, tool geometry, CF (coolants and lubricants) and a number of other factors. Under the influence of the heat that passes to the tool, the hardness of the material decreases, which leads to a gradual plastic deformation of the cutting blades, loss of the cutting ability of the tool and its blunting. Beside the influence on the tool wear, the generated heat also affects the productivity of the machining process, the processed surface quality, the accuracy of machining and other output characteristics of the process. Therefore, the investigation, measurement and knowledge of the cutting temperature distribution within the tool and workpiece is of the utmost importance from aspects of practice. Based on this knowledge, optimum conditions, working regimes, quality, productivity and economy of the process and tool stability can be determined. Temperature measurement may differ according to the methods used for: measuring tool temperature, workpiece temperature and chips temperature. There are direct and indirect measurement methods. According to the type of temperature measurement sensor can use the following methods: natural thermocouple, semi-artificial thermocouple, artificial thermocouple, calorimetric, non-contact (photoelectric etc.). Increasing number of sensors are based on digital technology. The advantages of today's sensors are small size, reliability, no moving parts, long service life, efficiency and economy.

Temperature and flow measuring sensors can optimize the use of CF, thus reducing their negative impact. In industrial machining processes, thermal stability control is essential for achieving the required quality of the machined product and protecting the cutting tool used. This is particularly important in serial production, where the feed rate of the cutting machine is constantly optimized to achieve the maximum output rate in relation to efficiency.

Today, a large number of fluid flow sensors have more than affordable prices and are compatible with a large number of chemical agents. For many years, flow meters with floating bodies and magnetic field sensors have been used to control the minimum flow of provided CF. Out of these two, flow meters with floating bodies are susceptible to inaccurate measurements caused by dissolved solids in the CF, which tend to stick to the flow meter components.

To avoid the risk of damage to the workpiece, cutting tools and machines, it is necessary to constantly monitor the supply of CF. Flow detection based on the thermodynamic principle works with two measurement points in the sensor element. The first measurement point detects the temperature of the medium itself, while the second measurement point heated a several degrees over the temperature of the medium. Depending on the flow rate and heat capacity of this medium, it will cool down the heated measuring point. The temperature difference between the two measuring points is a flow rate indicator [20].

By using a flow sensor with a microcontroller, the flow rate can be calculated and the volume of liquid that has passed through a pipe can be checked and controlled as needed. The flow sensor can be connected to an LCD where it can display the amount of fluid passing through the valve. The flow sensor can work on different principles, e.g. the YF-S201 uses a Hall-effect to sense the fluid flow rate. The Hall-effect affects the creation of a potential difference in the electrical conductor when the magnetic field is applied in a direction perpendicular to the direction of current flow. The flow sensor is integrated with a magnetic Hall-effect sensor, which generates an electrical impulse during each revolution. Its design is such that the Hall-effect sensor is isolated from the fluid and allows the sensor to remain safe and dry. The sensor uses wires to power, connect to the GND and reads pulses. When the CF is not released the output of the flow sensor is zero (no pulse). When CF is used it rotates the wheel inside the sensor and the pulses generated by the sensor are still observed [21].

The flow meter measures the amount of CF used for internal and external cooling and lubrication of tools. The sensor can be installed at different positions in the piping system of the machine tool. Different models are available for the required flow rate and pressure stability. The measuring signal of the precise sensors is evaluated by the system for monitoring the active flow within the set limits and sets the defined alarms in case of deviation. Since the cooling effect is closely related to the flow rate, monitoring of this parameter is crucial for optimal use of CF. In addition to temperature sensors, flow sensors provide the information needed to control CF in order to prevent the overheating and damage of workpiece and tool during machining. Optimized use of CF is the key to efficient processing and good quality of the final product. The sensors quickly detect poor conditions of the cutting process and early intervention can prevent the associated costs caused by waste parts or increased tool wear, excessive use of CF and so on [22].

5. INFORMATION SYSTEM CONCEPT

The conceptual model of the smart information system for cleaner production by optimizing the use of CF is based on measuring the temperature of the cutting process and the flow of CF on CNC machines. Flow and temperature sensors work in conjunction to reduce the use of CF.

The process temperature must be within certain limits. If the temperature rises above the upper limit or falls below the lower limit, the system acts by respectively increasing or decreasing the cooling through adjusting the flow of CF.

The main phases of data flow from collection to model making are shown in the figure 5.

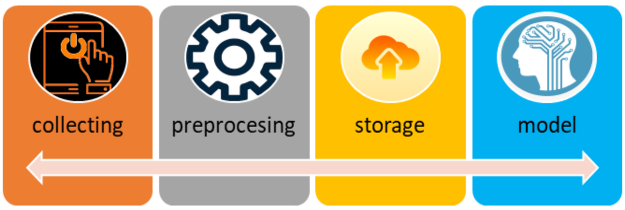

Figure 5. Data flow

In order to make a model that will help optimize the use of CF, it is necessary to collect data from two sources: the parameters of the cutting process (cutting speed, feed rate, depth of cut) taken from the control unit and information from the sensors.

Cutting speed and feed rate can be either measured or taken from already defined values according to the form or recommendations in the catalog. The sensor system consists of a flow meter and an industrial temperature sensor. The connection from the sensor can be wired or wireless via Bluetooth, GSM or Wi-Fi. The connection is made between a sensor and a mini computer (Raspberry Pi, Banana Pi or Arduino) attached to a CNC machine. In addition to the sensor data, process parameter data is also sent to the small computer. The data must pass through a filter (preprocessing), in order to remove unwanted by-product that is not relevant for analysis (noise, short circuit, and downtime).

Data can be stored locally on an SD memory card or some other type of external memory, and after a certain interval sent to the cloud or it can be directly save to the cloud. Sending data to the cloud is done through a gateway. The structure of the gateway is shown in the figure 6 [23].

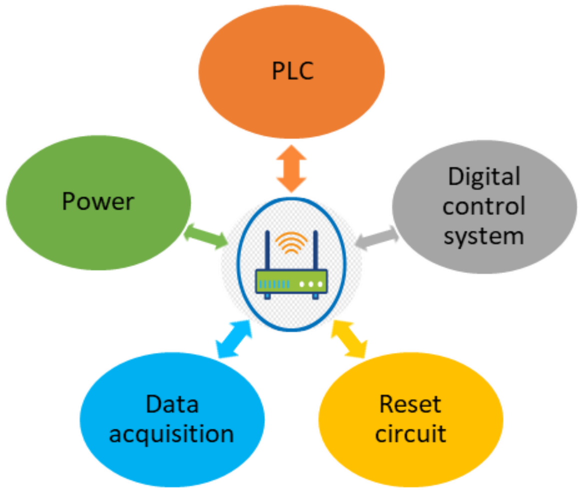

Figure 6. Structure of the gateway

By analyzing and processing (machine learning) of the collected data, a correlation is made between the process parameters data and the data obtained from the sensors, which enables creating a model of a sustainable turning process system. This structure of the information system can be applied in the case of milling.

The scheme of the overall structure of the intelligent information system for optimizing the use of cutting fluid in the cutting process is shown in the figure 7.

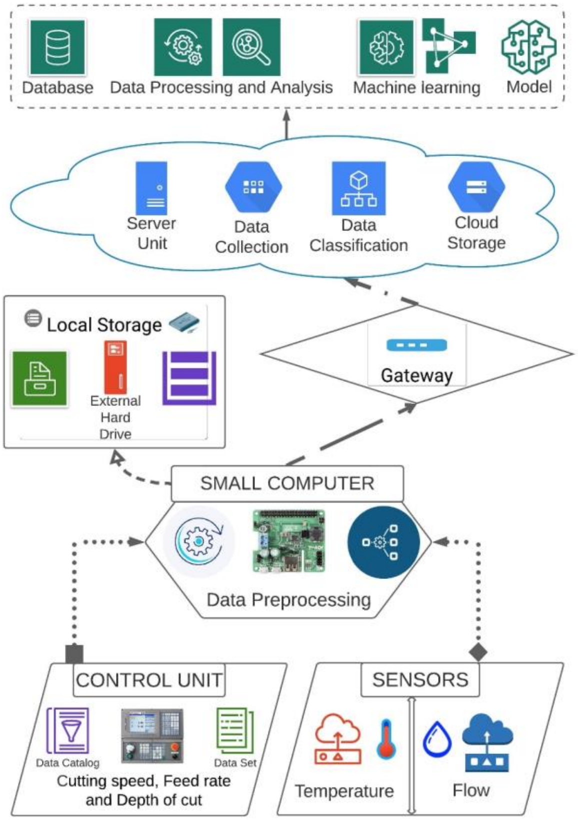

Figure 7. Scheme of the overall structure of the intelligent information system

When optimizing the use of CF, the goal is to maintain the required surface quality. What also has to be taken into account is that the main machine time (T_g) must be within certain limits. This way, the amount of CF would be reduced without reducing productivity and compromising production quality.

6. CONCLUSION

Given the positive impact and benefits it can have on manufacturing processes, IoT is expected to play an increasing role in CNC machining. The crucial element of any optimization model is data collection. In the above-described information system, IoT sensors provide the necessary data on the process temperature and the flow of CF. The relation between the data obtained from the sensors and the process parameters creates a model that will serve to optimize the use of CF. This system based on IoT is in line with the latest developments, industry 4.0 and the vision of achieving cleaner production.

ACKNOWLEDGEMENT

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EXPERIMENTAL IDENTIFICATION OF MILLING PROCESS DAMPING AND HIS IMPLEMENTATION IN STABILITY LOBE DIAGRAM

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Abstract: *Self-excited vibrations are one of the most unfavorable phenomena in the cutting process, which can result in accelerated wear or breakage of tools, rapid deterioration of the quality of the machined surface, increased noise, increased energy consumption, etc. To avoid these negative influences, when defining the cutting regimes, diagrams are used which, depending on the main spindle number of revolutions and the depth of cut, show the boundary between a stable and unstable machining area from the self-excitation vibrations point of view. However, at the low speed of the main spindle, the cutting process is damped, due to process damping, as a result of which the stability of the system increases, ie. the cutting depth limit increases. For efficient use of the stability diagram to predict the limit cutting depths at relatively low machining speeds, it is necessary to take into account the process damping.*
This paper presents an experimental method for process damping defining and its implementation in the mathematical method Zeroth Order Approximation (ZOA), as the most often used method for stability lobe diagram definition.

Keywords: *process damping; self-excited vibrations; frequency analysis; stability lobe diagram; milling process*

1. INTRODUCTION

Self-excited vibrations are the most unfavorable type of vibrations in the cutting process, which draw energy for their formation and amplitude growth from the machining process itself. These vibrations often lead to unstable operation of the machine tool, and as a result, they reduce the quality of the machined surface, the appearance of noise, accelerated wear of tools and elements of the machine tool [1], etc.

To avoid these negative influences, when defining the cutting regimes, diagrams are used which, depending on the main spindle number of revolutions and the depth of cut, show the boundary between a stable and unstable machining area from the self-excitation vibrations point of view. These diagrams, called - stability lobes diagram, are most often defined by some of the known mathematical models, such as Zeroth Order Approximation (ZOA) [2], Delay Differential Equations) (DDE) [3], advanced numerical simulation of the machining process [4].

However, at a relatively low number of main spindle revolutions, the so-called process dampingemerges, where the wavy machined surface, due to friction with the tool back surface (Figure 1b), dampens the oscillations in the radial cutting force direction. As a result, the dynamic stability of the system increases, ie. the cutting depth limit increases (Figure 1a).This phenomenon has a significant impact on the cutting process, which is why the mentioned mathematical methods for predicting the cutting depth limit must be corrected to adequately apply for machining at relatively low cutting speeds.[5-11].

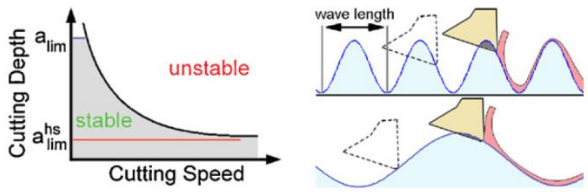


Figure 1. a) Influence of process damping on the stability lobe diagram; b) contact between the tool back surface and the machined surface[6]

Correction of the mentioned methods for the cutting process stability limit defining is possible only if, for a specific machining system, the damping coefficient of the process is known. This coefficient can be determined experimentally [10, 12].

Process damping is a very attractive area of scientific research, with emphasis is placed primarily on the experimental determination of the process damping coefficient.

Budak and *Tunc [6]* have proposed a method for identifying and modeling the damping process for turning and milling. Process damping coefficient was determined experimentally for turning the aluminum Al7075 and steel Ck50 workpieces, while the damping coefficient for milling operation is determined also for aluminum and steel, and titanium alloy Ti6Al4V. Experimentally defined damping coefficients were implemented in the model for defining the stability lobe diagram, based on which, the influence of the tool clearance angle and cutting edge radius on the process damping was analyzed.

Gurdal and associates [8] using equivalent viscous damping, modeled the damping of the milling process as a function of the period and amplitude of the wave on the machined surface, the wear of the tool, and the tool clearance angle.To define the stability lobe diagram, the mathematical model was implemented in the ZOA method, and to verify it, experimental investigations were conducted.

Li and associates [13], have developed a mathematical model for defining a stability lobe diagram for milling of the thin-walled workpieces, which also takes into account process damping. In addition to the mathematical model, the authors also proposed the application of the so-called anti-vibration clearance angle (α_1) (Figure 2). The anti-vibration clearance angle of the tool enables a longer contact between the machined surface and the tool back surface, which increases the process damping and thus the cutting depth.

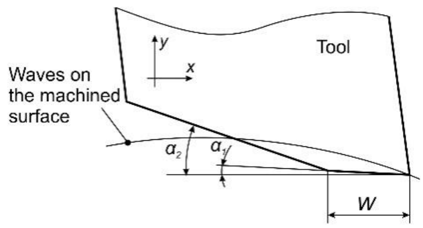


Figure 2. Anti-vibration back angle of the tool α_1[13]

Tyler and *Schmitz* [10], analyzed the stability of the turning and milling process taking into account the damping of the cutting process.The process damping is represented by an experimentally determined damping coefficient directly dependent on the cutting speed. By implementing the defined process damping coefficient into Tlusty's mathematical model [3], a stability lobe diagram is defined. In addition, the authors analyzed the influence of the back angle and the tool wear on the process damping, it is concluded that a decrease in the tool clearance angle and/or an increase in the wear on the tool back surface leads to an increase in process damping and thus to an increase in the stability limit at lower main spindle speeds.

As a continuation of this research, the same authors [11] formed a database on the example of heavy-duty materials C18 steel, Ti6Al4V titanium superalloy, and X5CrNi18 stainless steel, in which they, for two different clearance angles and two tool wear ranges, showed the damping coefficient, specific cutting force, and tool life.

Yusoff and associates [14] investigated the influence of the variable tooth pitch and the variable angle of the tool helix on the process damping, in the case of milling the Al7075 workpiece. The authors showed that the variable pitch and helix angle has a significant effect on increasing the process damping, that is, when machining with these tools, the process damping is increased up to two times compared to machining with conventional tools. A similar study was conducted by *Tang* and *Liu* [15] who considered the influence of helix angle and tool rake angle on the stability of the milling process. Based on experimental tests, they concluded that with the increase of these two angles, the stability of the milling process also increases.

The paper presents an experimental definition of milling process damping in the case of machining the 42CrMo4 steel workpiece at the EMCO ConceptMill 450 machining center. The process damping determined in this way was implemented in a mathematical model for defining the stability lobe diagram (ZOA method) to increase its accuracy in the range of relatively low cutting speeds.

2. MATHEMATICAL DEFINITION OF MACHINING SYSTEMS STABILITY LOBE DIAGRAM

The first part of the research presented in this paper refers to the mathematical definition of the stability lobe diagram of the EMCO ConceptMill 450 machining center (Figure 3), for the case of milling a 42CrMo4 steel workpiece with a ϕ10mm tool, Zeroth Order Approximation method.

It is known that the stability lobe diagram shows the boundary between the stable and unstable zone of the cutting process as a function of the axial depth of cutting b_{lim}, and the number of main spindle revolutions (Figure 4).To define the stability lobe diagram using a mathematical model, Altintas - Budak's model of Zeroth Order Approximation is presented below.[2].

Figure 3. EMCO Concept Mill 450 machining center

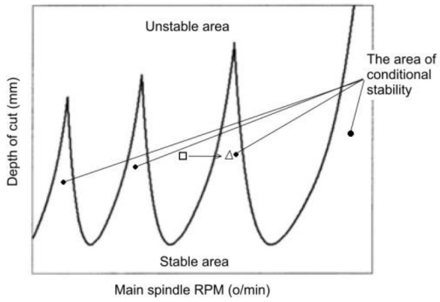


Figure 4. The layout of the stability lobe diagram

2.1. Defining a stability lobe diagram by the ZOA method

In the analytical definition of the stability lobe diagram by the ZOA method, Altintas and Budak considered the milling tool to be a dynamic system with two degrees of freedom (Figure 5), and in doing so they adopted the following assumptions [2]:

a. The oscillatory system is linear;
b. The direction of the variable component of the cutting force depends on the current position of the tool teeth in the cut;
c. The variable component of the cutting force depends on the oscillations in the direction of the X and Y axes of the machining system;
d. The size of the variable component of the cutting force varies proportionally and simultaneously with the change in the chip cross-section;
e. The system is modeled as a time variable and analyzes the stability for each tool position in the cut (from ϕ_{st} to ϕ_{ex})

The axial depth and the number of the main spindle revolutions are determined from the expression:

$$b_{\lim} = \frac{2\pi\Lambda_R}{NK_t}\left(1+\kappa^2\right) \quad (1)$$

$$n = \frac{60}{NT} \quad (2)$$

where is:

Λ_R and Λ_I -the real and imaginary part of a complex quadratic function defined based on the observed system FRF, where is: $\kappa = \frac{\Lambda_I}{\Lambda_R}$

$T = \frac{\varepsilon + 2k\pi}{\omega_c}$ -tooth passing period

k=0,1,2,3,... -the number of “waves” on the stability lobe diagram

ω_c -angular velocity of self-excited vibrations

$\varepsilon = \pi - 2\psi$ -phase shift between waves on the machined surface, which form two consecutive tool teeth, where is: $\psi = \tan^{-1}\kappa$

Ks -specific cutting force in the tangential direction

N -number of tool teeth

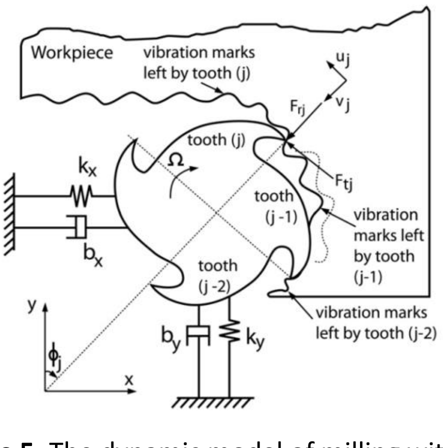


Figure 5. The dynamic model of milling with two degrees of freedom[2]

Self-excited vibrations in milling occur when the excitation frequency (forced vibrations, variation in the intensity of the cutting force due to the regenerative effect, or some other type of external excitation) coincides with the so-called natural frequency of the machining system critical element. When machining robust (rigid) workpieces, the critical element of the machining system is most often the tool - tool holder - main spindle assembly, while when machining thin-walled workpieces, the critical element is the workpiece. Taking into account the previous, in the analysis of self-excited vibrations, ie. when defining the stability lobe diagram of the machining system, it is necessary to know the modal parameters of the machine tool characteristic elements which are most often determined by experimental modal analysis.

2.2. Determination of modal parameters of machining systems

Experimental modal analysis by impulse excitation force is the simplest method for determining the frequency response function, and as such is most often used to define the modal parameters of machining systems.

In this test, by applying impulse excitation, the system is excited by a wide range of different frequencies in only one test, while the response of the system is usually monitored by the use of acceleration sensors. The experimentally obtained values are transformed into a frequency domain by applying a fast Fourier transform. The obtained frequency response function can be displayed as follows:

$$FRF_{ij}\left(\omega\right) = \frac{X_i(\omega)}{F_j(\omega)} \quad (3)$$

The frequency response function of the system is complex, ie. it consists of a real *G* and an imaginary *H* part:

$$FRF\left(\omega\right) = G + iH \quad (3)$$

Figure 6 shows the real (left) and imaginary (right) parts of the frequency response function.

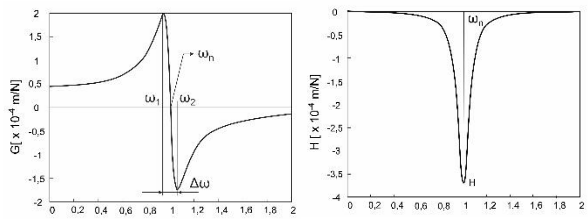


Figure 6. Real (a) and imaginary (b) part of the frequency response function

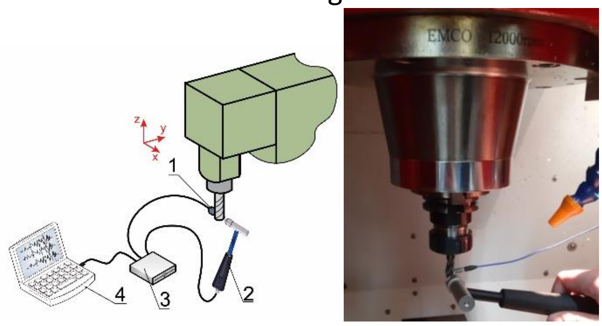
The modal parameters of the system that are calculated based on the real and imaginary part of the FRF are:

$$\zeta = \frac{\omega_2 - \omega_1}{2\omega_n}$$ - dimensionless damping coefficient ζ

$$k = \frac{-1}{2\zeta H}$$ -modal stiffness
Where H is the minimum of the imaginary part FRF

$$m = \frac{k}{\omega_n^2}$$ -modal mass

To determine the previously mentioned modal parameters for the observed machining system, it is necessary to experimentally define its frequency response function. The experimental model for determining the frequency response function of the EMCO ConceptMill 450 machining center (Figure 7a) consists of an acceleration sensor (PCB 352C33) (1), which measures the tooltip oscillation, and an excitation hammer, (Bruel & Kjaer 8206), (2), which excites the structure of the machine. The excitation hammer and acceleration sensor are connected to the A/D card (National Instruments USB-4432) (3), which sends the collected data directly to the computer (4). Figure 7b shows the experimental test procedure in the X-axis direction of the machining center.



a) b)

Figure 7. Experimental model (a) and test procedure (b) for determining the machining center FRF

The signal collected by the acceleration sensor and the hammer signal is sent via an A / D card to a PC, where they are stored in matrix form using the LabVIEW software system.By creating an algorithm in the Matlab environment, fast Fourier transform (FFT) of the obtained signals and determination of the frequency response function of the observed system is enabled. Figure 8 shows the real and imaginary part of the FRF for the ø10 tool clamped in the main spindle of the EMCO ConceptMill 450 machining center, measured in the X-axis direction, and Figure 9 in the Y-axis direction.

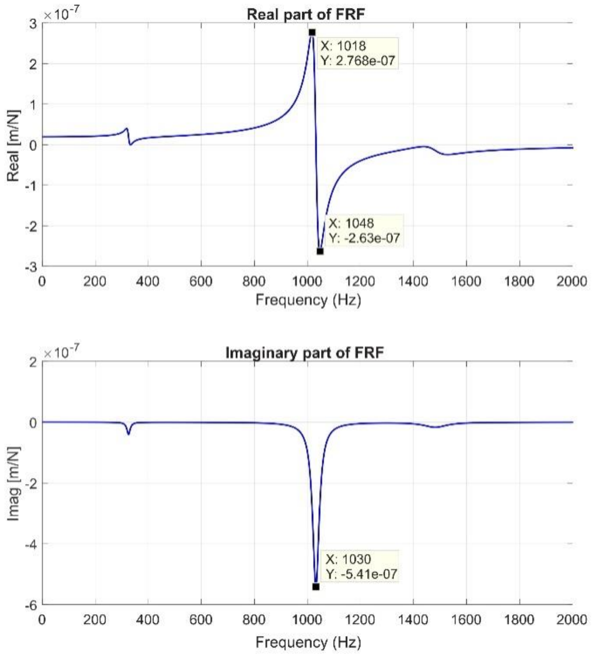


Figure 8. The real and imaginary part of the EMCO ConceptMill 450FRF measured in the direction of the X-axis

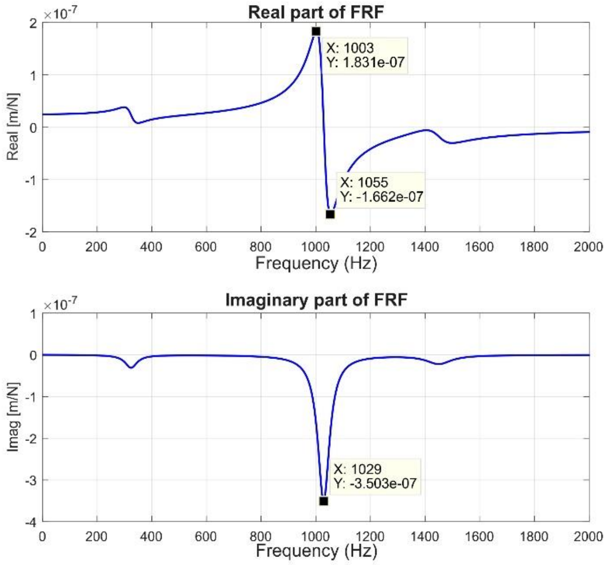


Figure 9. The real and imaginary part of the EMCO ConceptMill 450FRF measured in the direction of the Y-axis

In addition to modal parameters to define the stability lobe diagram, it is necessary to possess the data about workpiece material and the machining process. These data, together with the defined modal parameters, are shown in Table 1.

For the observed range of possible frequencies of self-excited vibrations, using equations (1) and (2) and based on the data shown in Table 1, the stability limit of the EMCO ConceptMill 450 machining center was defined and shown on the stability lobe diagram (Figure 10).

Table 1. Parameters required to define the stability lobe diagram

$\omega_{nx} = 1030[Hz]$	- natural frequency in the direction of the X-axis
$\zeta_x = 0{,}016$	- damping coefficient in the direction of the X-axis
$k_x = 1{,}04e8[N/m]$	- modal stiffness in the X-axis direction
$\omega_{ny} = 1014[Hz]$	- natural frequency in the direction of the Y-axis
$\zeta_y = 0{,}038$	- damping coefficient in the direction of the Y-axis
$k_y 6 = {,}63e7[N/m]$	- modal stiffness in the Y-axis direction
$\phi_{st} = 0^{\circ}$	- the entry angle of the tool into the cut
$\phi_{ex} = 180^{\circ}$	- the exit angle of the tool from the cut
$d = 10\ [mm]$; $N_t = 4$	- diameter and number of tool teeth

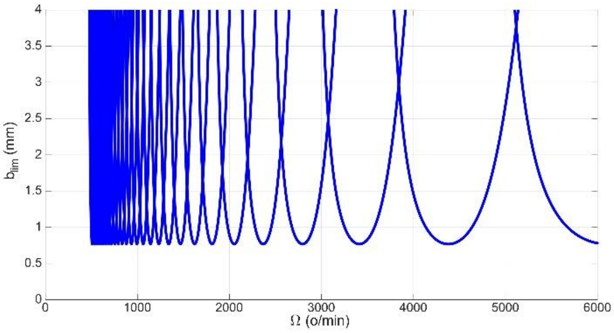


Figure 10. Stability lobe diagramof the EMCO ConceptMill 450 machining center defined by the ZOA method

3. EXPERIMENTAL DEFINITION OF PROCESS DAMPING

To define the damping coefficient of the cutting process, a series of experimental tests were performed on the EMCO ConceptMill 450 machining center, when cutting a 42CrMo4 workpiece (Figure 11). Namely, by a certain number of the main spindle revolutions, the cutting depth was increased by a certain increment, while the vibrations of the main spindle assembly were recorded with the previously mentioned acquisition equipment. The recorded signals were transformed from a time domain to a frequency domain by a fast Fourier transform to determine the relationship between vibration amplitude and cutting depth. When machining with a depth greater than the limit depth, the frequency of self-excited vibrations, which is close to the natural frequency of the tool-tool holder-main spindle assembly, becomes noticeable in the frequency characteristic of the vibration signal. The depth of cut at which the frequency of self-excited vibrations was extracted is considered to be the limit depth for the analyzed number of revolutions.

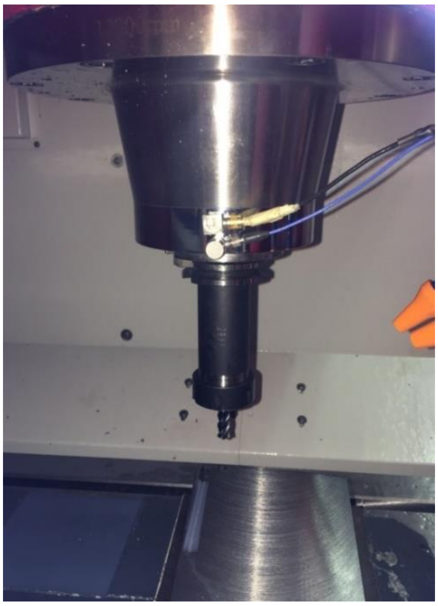


Figure 11. Machining of a 42CrMo4 workpiece at the EMCO ConceptMill 450 machining center

The cutting depth limits are defined for seven different main spindle speeds, which correspond to the recommended range of cutting speeds for machining 42CrMo4 steel (40 to 100 [m/min)[16]. The machining was performed with a 10 [mm]diameter tool, made of high-speed steel with a coating of titanium-aluminum nitride (TiAlN), while the tool feed per tooth was constant and was 0.02

[mm/tooth]. Table 2 shows the cutting regimes for all seven examined speeds.

Figure 12 shows the results of the frequency analysis of the vibration signal for the first experiment. The figure clearly shows that for cutting depths from 1 to 1.8 [mm] the amplitude of vibration is at a frequency of about 1038 [Hz], which represents a frequency close to the natural frequency of the main spindle assembly. In the latter case, when the depth of cut is 2 [mm], there is a sudden jump in the amplitude of the frequency of self-excited vibrations. Based on this, it can be concluded that the limit cutting depth for the main spindle speed of 1270 [rpm] is 2 [mm].

Table 2 Cutting regimes for experimental determination of limitcutting depth

No.	Cutting speed [m/min]	Spindle RPM	Feed [mm/min]	Cutting depth [mm]
1.	40	1270	101,6	1; 1.2; 1.4; 1.6; 1.8; 2
2.	50	1585	126,8	1.2; 1.4
3.	60	1910	152,8	1; 1.2
4.	70	2225	178	1; 1.2
5.	80	2550	204	1
6.	90	2865	229,2	0.7; 0.9
7.	100	3200	256	0.7

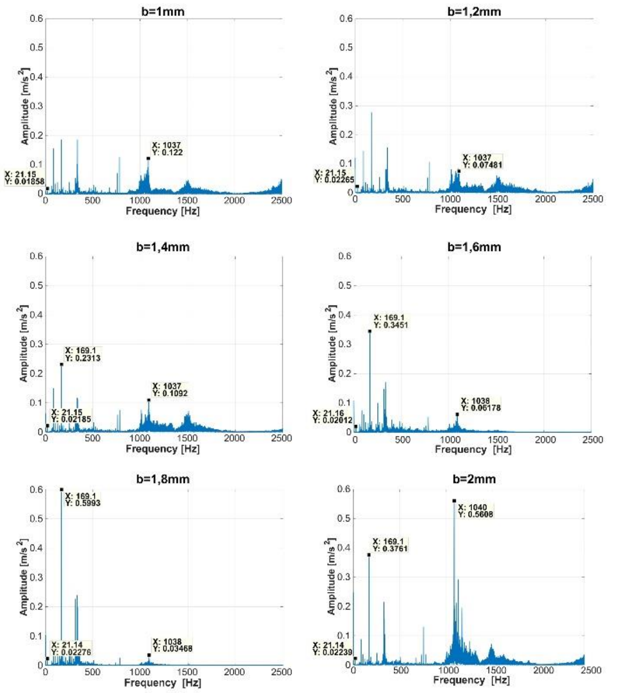


Figure 12. Results of Fourier transform of vibration signals for the first experiment

The limit cutting depths, defined experimentally by the previously described method and from the analytically defined stability lobe diagram, are shown in Table 3.

Table 3 Limit cutting depth defined by experimental tests and by ZOA

No.	Spindle RPM	Expe-riment	ZOA	
		b_{lim} [mm]	*b_{lim} [mm]*	Deviation [%]
1.	1270	2	1,1	45
2.	1585	1,4	0,89	36
3.	1900	1,2	1,38	-15
4.	2225	1	1,49	-24
5.	2550	1	1,36	-36
6.	2865	0,9	0,85	5,5
7.	3200	0,7	1,215	-73

By analyzing the results shown in Table 3, it can be concluded that the limit depths defined by the ZOA method significantly deviate from the limit depths obtained by experimental tests.The main reason for this deviation is the occurrence of process damping when cutting at lower speeds.Therefore, it is necessary to determine the damping coefficient of the system, basedon which it is necessary to correct the cutting depths provided by the ZOA method.

As the increase of the limit depth with the decrease of the main spindle number of revolutions is exponential, the process damping in this case is determined by the curveapproximation through experimentally defined limit depths (Figure 13).

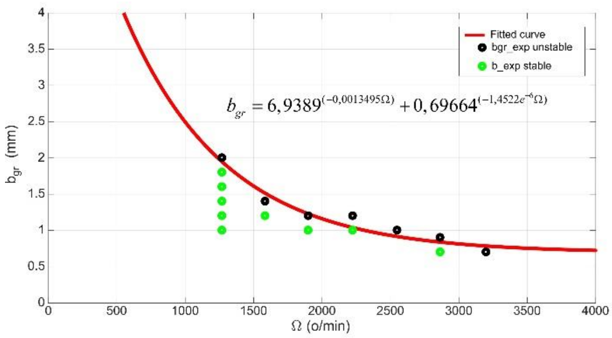


Figure 13. Exponential curve of the process damping

Based on the presented exponential function, the algorithm for defining the stability lobe diagram by the ZOA method was corrected. The corrected algorithm allows the limit cutting depth to be determined based on the equation shown in Figure 13 in the case of cutting 42CrMo4 steel on the EMCO ConceptMill 450 machining center with speeds less than 4000 (Slika 14).

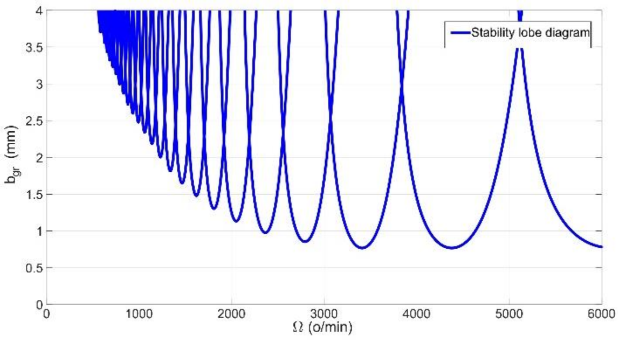


Figure 14. Stability lobe diagram defined by ZOA method for EMCO machining center and 42CrMo4 steel workpiece with process damping

4. VERIFICATION OF DEFINED STABILITY LOBE DIAGRAM WITH PROCESS DAMPING

For verification of the defined stability lobe diagram with process damping, new experiments were conducted to define the limit cutting depths. In order not to change the modal parameters of the machining system, and thus the stability lobe diagram, experimental tests were performed again at the EMCO machining center for milling 42CrMo4 steel workpiece, with a new 10 [mm] diameter tool and a feed of 0.02 [mm/tooth].

Table 4 shows the cutting regimes used in the experimental verification of the stability lobe diagram with process damping.

Figure 15 shows the results of the vibration signal frequency analysis for the first experiment.The figure clearly shows that for all three cutting depths, 1.4, 1.6, and 1.8 [mm], the vibration amplitude at a frequency of about 1039 [Hz], which is a frequency close to the natural frequency of the main spindle assembly, is relatively small. Based on that, it can be concluded that in none of the mentioned three cases did self-excited vibrations occur. The same procedure was applied to the vibration signals recorded in other experimental tests, and the results are shown in Figure 16.

Table 4 Cutting regimes for experimental verification of the defined stability lobe diagram

No.	Cutting speed [m/min]	RPM	Feed [mm/min]	Cutting depth [mm]
1.	30	955	76,4	1.4; 1.6; 1.8
2.	45	1433	114,6	1; 1.4; 1.6
3.	60	1910	152,8	1; 1.2
4.	75	2388	191	0.8; 1.2

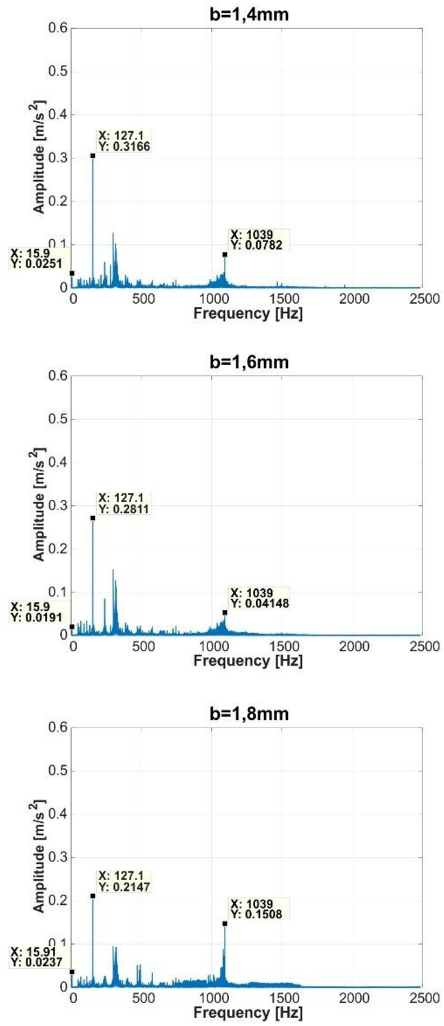


Figure15. Results of Fourier transform of vibration signals for the first experiment

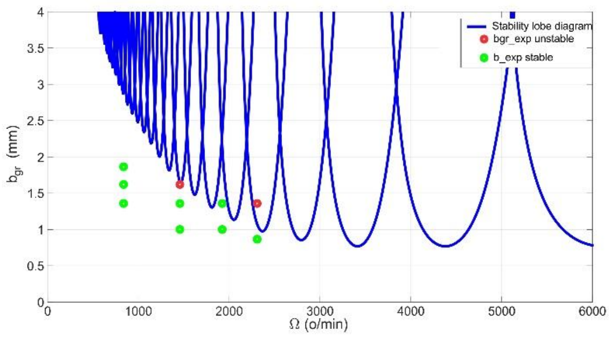


Figure16. Verification of the defined stability lobe diagram

5. CONCLUSION

Examination of self-excited vibrations during milling of structural steel 42CrMo4 at the EMCO ConceptMill 450machining center, it was found that when machining this material with the recommended regimes, there is a significant effect of process damping on the limit cutting depth. To solve this problem, the process damping for a specific machining system was experimentally defined and based on it, the algorithm for defining the stability lobe diagram by the ZOA method was corrected. Finally, experimental verification of the corrected stability lobe diagram was performed, which confirmed the occurrence of process damping, and its influence on the dynamic stability in milling of the observed material.

However, as process damping changes with the change of machining system elements (new tools, fixture, workpiece ...) the defined stability map, which takes into account process damping, is valid only for the current machining system configuration. The direction of future research is the analysis of the possibilities of mathematical modeling of the process damping phenomenon. If this is possible, defining a stability lobe diagram with process damping by mathematical methods would be significantly improved and facilitated.

ACKNOWLEDGMENTS

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SELECTION OF DIE AND PUNCH MATERIALS IN STEEL IRONING PROCESS

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Abstract: *Topic of this paper is experimental determination of suitability of different materials usage for tool making in the process of deep drawing with thinning of steel sheets. Workpiece material is DC04 steel (Č0148) and materials from which tools are made are hard metal WG 30 and tool steel X165CrMoV12 with Cr and TiN coatings. Suitability was evaluated on the basis of the friction characteristics in the process and on the basis of the quality of obtained samples surfaces. Various types of lubricants were used in the experiments and their influence on process success and compatibility with tool materials were determined. After the performed experiments, surface of obtained parts will be observed in SEM and EDS analysis of samples will be done.*

Keywords: *die, punch, ironing, galling, steel.*

1. INTRODUCTION

Deep drawing with thinning of steel sheets is a process that occupies a significant place in modern industry. The main advantages of such processes are obtaining precise parts with good mechanical properties and material savings. In order to have successful process, it is necessary to prevent the appearance of galling and reduce the frictional resistance between the workpiece and the tool. For mention reasons, many studies have been conducted to determine the compatibility of tool materials, lubricants and workpiece materials [1, 2]. In work [3, 4] used tools were made from tool steel, while samples were made of mild steel. In [3], two lubricants, low and high viscosity, were used to examine the effect of friction on the plastic deformation process. It was concluded that the contact pressure is determined by lubrication and that by increasing the reduction the friction stress does not change while the coefficient of friction first decreases and then increases. In [4], various lubricants based on paraffin and oil were used to evaluate their ability to prevent galling. It was concluded that mineral oils of higher viscosity give better results and that additives for extreme pressures and additives for improvement have similar characteristics in boundary lubrication, but additives for extreme pressures prevent the appearance of galling. Tool wear and the condition of the workpiece and tool surfaces in the drawing process with the thinning of mild steel were analyzed in detail in [6, 7]. In [8], the analysis of the temperature field on the tool and the workpiece during the drawing process with thinning is presented.

Different parameters have an influence on the drawing process with thinning. The most influential are the tool material, roughness of the die, drawing tool roughness, deformation degree, used lubricant, tool geometry, ie tool angle inclination and the speed of deformation. Successness of the process is evaluated on the basis of sheet roughness, drawing force, friction force, friction coefficient, tool wear and the appearance of galling on the workpiece. Friction force in deep drawing process with thinning plays a significant role. Success of the process depends on the workpiece stress state. Due to high contact pressures, workpiece material (softer material) may be welded or sticked to the tool (harder material). In order to avoid these phenomena, it is very important to choose the right tool material and the appropriate lubricant or coating for usage [9].

Galling is a type of wear that causes a metal to stick to another metal with which it is in contact. Galling occurs very quickly, rarely after a large number of cycles, therefore the sample surfaces will be analyzed in case of multiple drawing. It usually occurs on a microscopic level, but it can cause wear that is visible. Appearance of galling does not necessarily mean that the part is unusable, but in parts with narrow tolerances, appearance of galing at the microscopic level can jeopardize its functionality. Occurrence of galling can be prevented by choosing proper materials and lubricants, which is the subject of this paper.

According to [1], there are four types of galling:

- Planar type,
- Linear type,
- Spotty type and
- Edged type.

Multiphase drawing is used when in the process of deep drawing with thinning it is necessary to achieve a higher degree of deformation [9]. In the multiphase drawing process, the process is performed sequentially through multiple dies. During the process, contact conditions change occurs due to the squeezing of lubricants, changes in surface roughness, etc. which causes a change in contact conditions. After each phase there is a change on the contact surfaces therefore a change of the drawing force occurs.

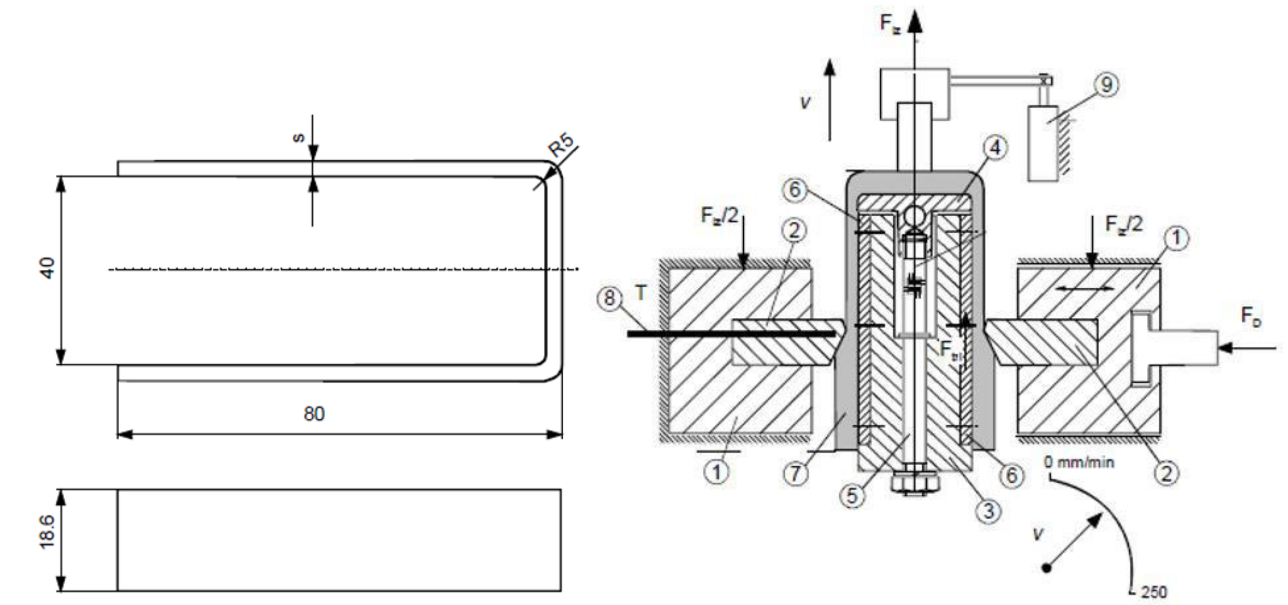
2. EXPERIMENTAL INVESTIGATION

The experiment was performed on an experimental Ericson 142/12 hydraulic press. A specially constructed device is placed on the press, the scheme of which is shown in Figure 1. The basic data on the process are given in Table 1.

Sheet steel samples 2mm thick were made by cutting from a strip of sheet metal and U-bending. To adequately choose lubricant, it is important to properly consider workpiece material, tool material as well as the properties of the lubricant such as viscosity and origin. Used steel sheet belongs to the group of quality sheets and is intended for processing by deformation in the cold state. Chemical composition of workpiece material is given in Table 2.

Table 1. Basic process conditions

Tool material	Hard metal WG 30
	Tool steel X165CrMoV12
Tool angle	$10°$
Drawing speed	$20 mm/min$
Lubricant	M1 - molybdenum disulfide (in combination with phosphated samples)
	M2 - oil for high pressure operation
	M3 - oil for deep drawing
Workpiece dimensions	Thickness 2mm, Figure 1 1
Other conditions	Room temperature



a) b)

Figure 1. a) The sample prepared by bending b) process scheme [10]

Table 2. Chemical composition of steel DC04 (ferrite structure)

	Content of elements in%				
	C	Si	Mn	P	S
Prescribed	Up to 0,1	Up to 0,2	0,2 to 0,45	max. 0,03	max. 0,035
Determined	0,06	In traces	0,28	0,014	0,021

Tools are made of hard metal and alloy tool steel. Chemical composition of alloy tool steel is given in Table 3. TiN coating was used, which was performed by PVD technique. Hard metal is tungsten carbide and the binder material is cobalt. Chemical composition of hard metal is 15% Co and the rest is WC.

Lubricants listed in Table 1 belong to different types of lubricants. Phosphating of the workpiece is often used in forming processes because the combination of phosphated surface and molybdenum disulfide has good lubricating properties. Phosphating makes the process more expensive but gives very good results. When the samples were phosphated, molybdenum disulfide (M1) was used. Since large deformations occur in the drawing process with thinning, high values of contact pressure are present. Therefore, lubricants that are specially designed for operation at high pressures (M2) are used. Third lubricant (M3) used is classic lubricant for deep drawing. Characteristics of lubricant are shown in Table 4. Plan of the experiments is shown in Table 5.

Table 3. Chemical composition of alloy tool steel (%) X165CrMoV12 (Č4750)

C	Si	Mn	P max	S max	Cr	Ni max	Mo	V	W
1,65	0,3	0,3	0,035	0,035	12	0,25	0,6	0,1	0,5

Table 4. Lubricants properties

Lubricant	M1	M2	M3	D
Consistency	Grease	Oil	Oil	Without lubrication (dry)
Lubricant type	Li+MoS_2	Paste	Non-emulsifying mineral oil with mild EP properties	

Table 5. Process parameters

Sample label	FD holding force (kN)	Die angle α (°)	Die material
1	17,4	10	X165CrMoV12
2	8,7	10	X165CrMoV12
3	17,4	10	WG 30
Die lubricant	**Punch material**	**Punch roughness (mean height of unevenness Ra, (µm)**	**Lubricant on the punch**
M2	X165CrMoV12	0,01	dry
M3	X165CrMoV12	0,01	M3
PH.+M1	X165CrMoV12	0,01	dry

3. EXPERIMENTAL RESULTS

3.1 Condition of surfaces and appearance of galling

After drawing with thinning, surfaces were observed on SEM. Deformation ratio is same for all samples, so it is possible to make an adequate comparison. Galling occurred in sample 1. Appearance of 3D surface of sample 1 before and after ironing is shown in Figure 2. Figure 2.b clearly shows the damaged surface, ie. appearance of rises. When testing sample 1, die angle was α= 10°, die and the punch were made of alloy tool steel, lubricant M2 is applied on the die and the punch was not lubricated.

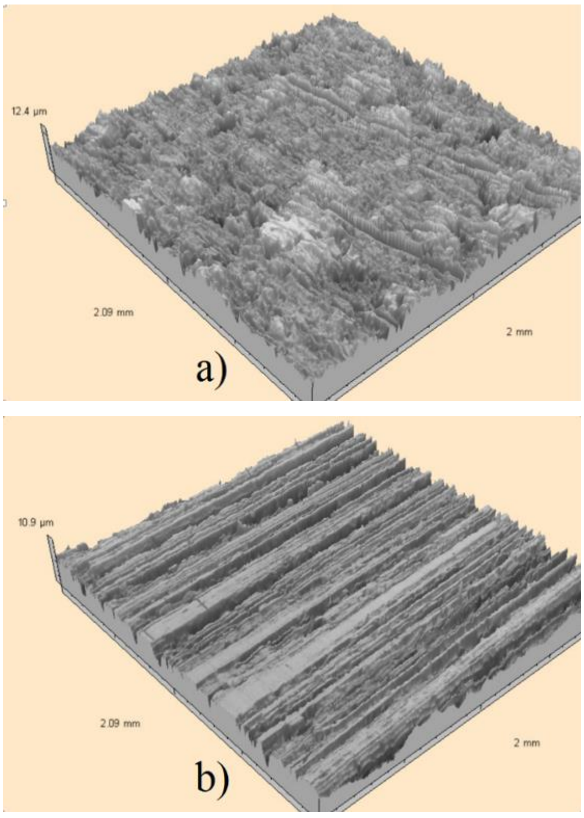


Figure 2. 3D appearance of the surface of sample 1 a) before and b) after drawing

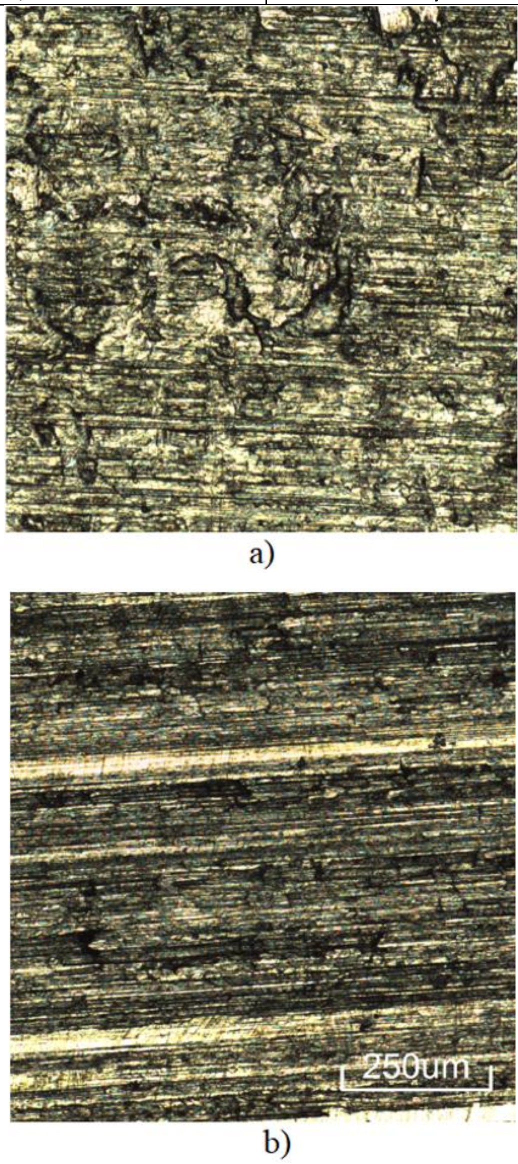


Figure 3. Micro photograph of sample 1 a) before and b) after drawing

Microphotographs shown in Figure 3 clearly show the rises. By recording the 3D profile of the surfaces and on the basis of microphotographs, it was concluded that galling occurred, EDS analysis was performed. Aim of the EDS is to determine if there are residues of tool material on the tested sample.

Table 6. Process parameters

	First draw	Second draw	Third draw
S_a (μm)	0,132	0,16	0,387
S_t(μm)	8,61	5,78	6,18
S_z(μm)	5,4	4,74	5,47

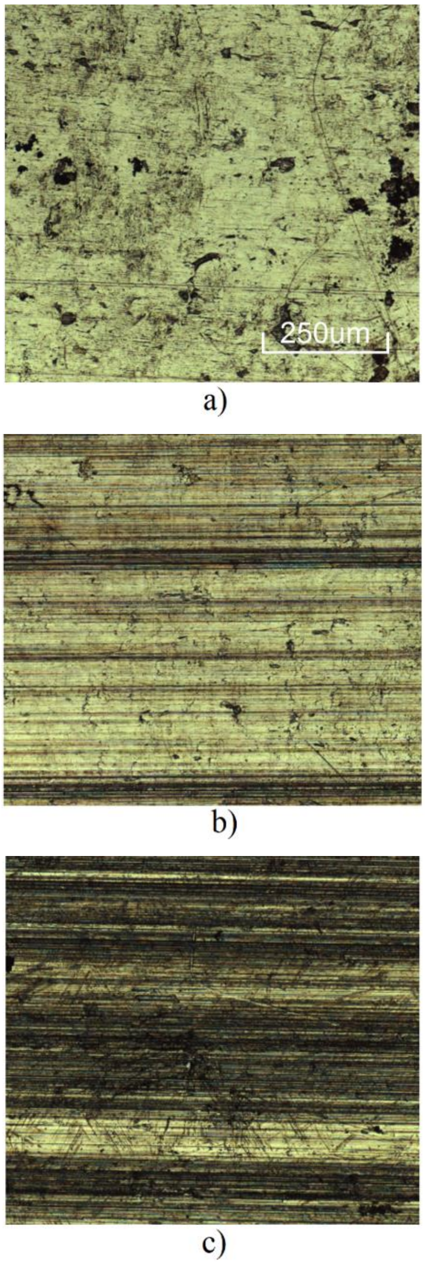


Figure 4. Microphotographs of sample 2 after a) first b) second and c) third drawing

By observing the surfaces of the tools, it was concluded that no stickers appeared. Galling did not occur on samples 2 and 3. Figure 4 shows microphotographs of sample 2 after each drawing. After second and third draws, rises occurred. Table 6 shows surface parameters of the sample. Values for the arithmetic mean deviation of the surface (Sa), the total surface height (St) and the height of ten surface points (Sz) are given. Mean deviation of the surface increases in each drawing, which confirms that occurrence of surface damage occurred.

Figure 5 shows microphotographs of the surface of sample 3 after each drawing operation.

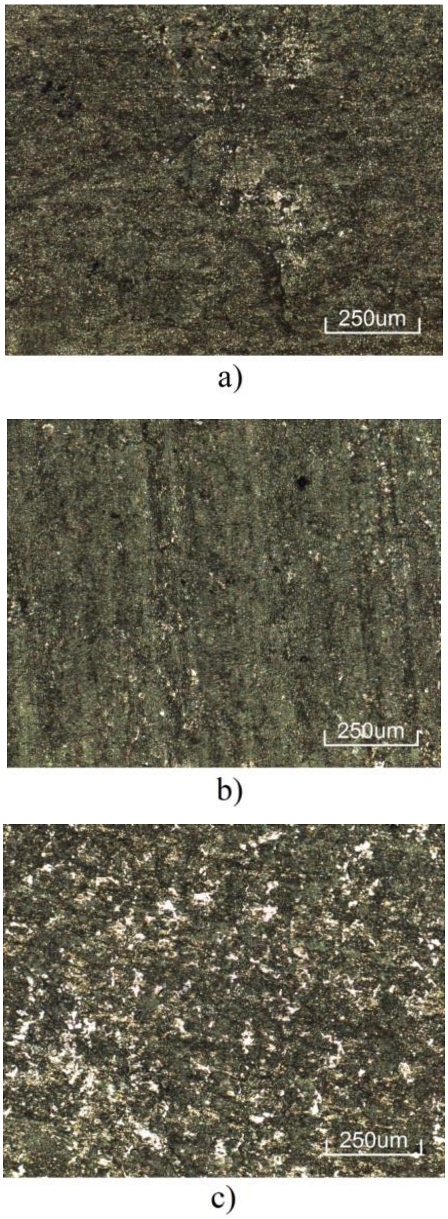


Figure 5. Microphotographs of sample 3 after a) first b) second and c) third drawing

Values of the surface parameters are given in Table 6. It can be concluded from the table that the arithmetic mean deviation of the surface decreases in each subsequent draw. For the other two parameters, there is a decrease in the value in the second drawing and then an increase in the third of total surface height and height of ten points.

Table 7. Surface parameters of the phosphated sample

	First drawing	Second drawing	Third drawing
S_a (μm)	0,245	0,206	0,192
S_t(μm)	3,84	2,08	4
S_z(μm)	3,5	1,86	3,28

Results obtained in the experiment showed matching with the results of other researchers. Surface of the sample is without scratches in the case when the sample is phosphated and when molybdenum disulfide is used. During the drawing of workpieces 1 and 2, rises and galling appeared.

3.2 EDS analysis of samples

The analysis showed that the surface of sample 1 has a higher content of C and Fe (figure 6) and that there are oxides. The appearance of sodium, silicon and phosphorus in traces that represent lubricant residues was also noticed.

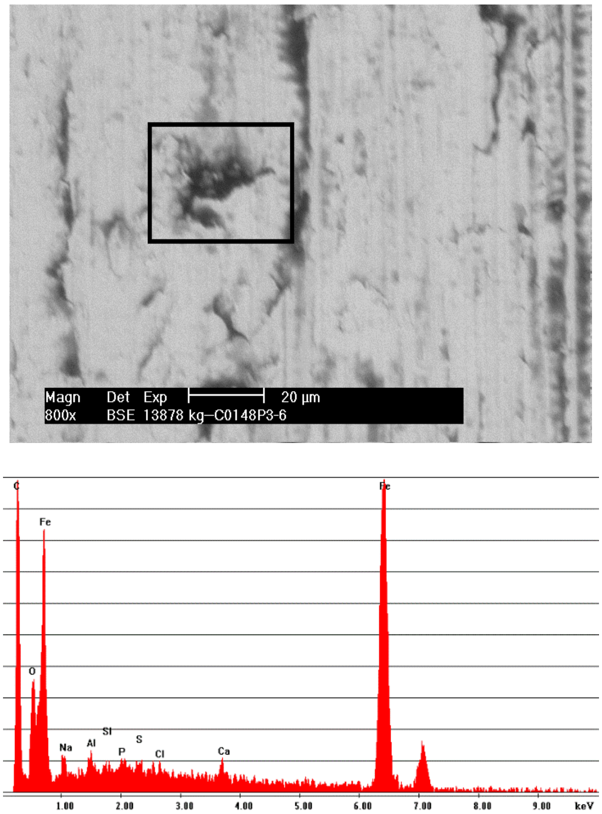


Figure 6. Results of chemical analysis of sample 1

Figure 7 shows the results of the EDS analysis of the surface of sample 2. As in the case of sample 1, the EDS analysis confirmed that there are labels on the sample.

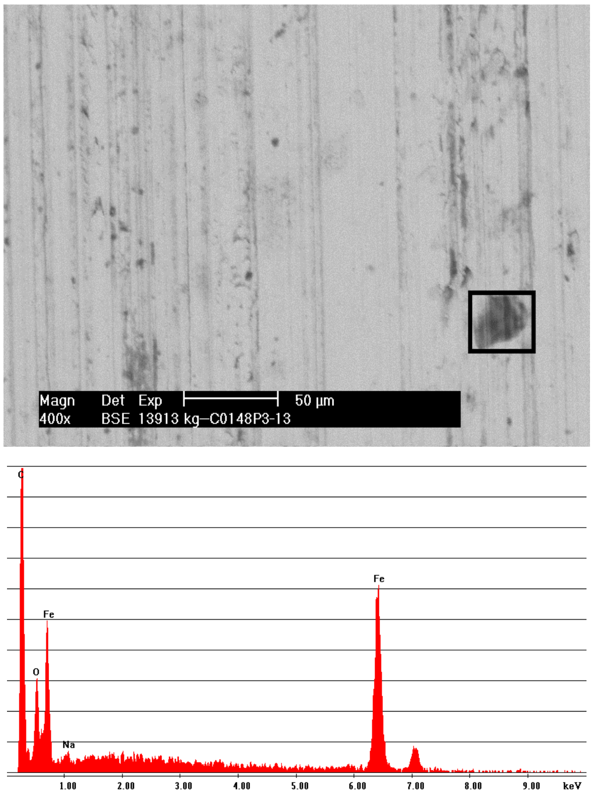


Figure 7. Results of chemical analysis of sample 2

Figure 8 shows results of EDS sample 3. Analysis shows that zinc-phosphate coating is stable even after third drawing.

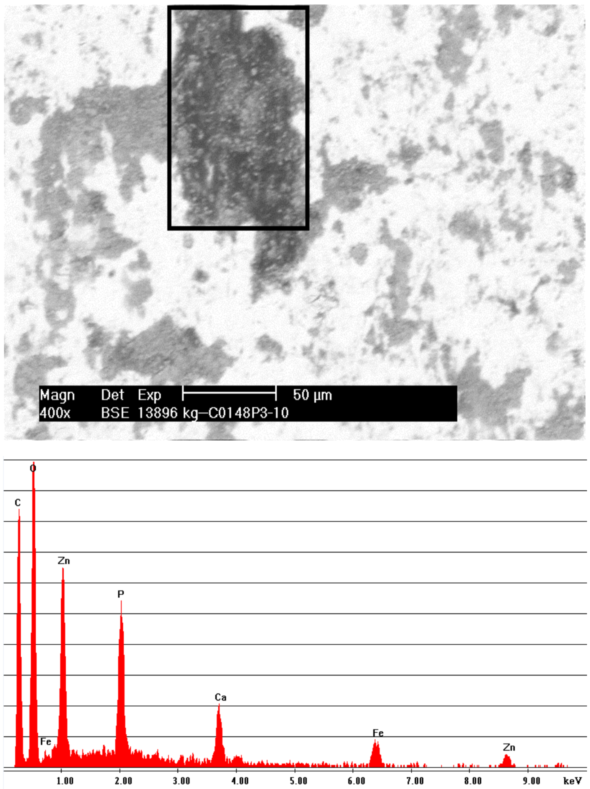


Figure 8. Results of chemical analysis of sample 3

4. CONCLUSION

Results of the experiments clearly showed which materials are suitable for making tools in the process of drawing with thinning. Three considered combinations of tool and lubricant materials represent three solutions that differ in price and complexity of production. First combination is the cheapest variant, tools are made of tool steel and M2 lubricant is used. Although economically and technically is least demanding, this combination does not meet technical requirements because there was sort of jam ie galling appeared. Linear galling was noticed on the surface of the workpiece, and chemical analysis showed remains of tool material. In the second case M2 lubricant was used, better results were achieved, but there are clearly visible scratches on the surface. In the third case, when the surface of the workpiece was phosphated, the best results were achieved. In this case, there was no galling or the formation of rises as it happened in previous two cases. Disadvantage of this combination of materials and lubricants is its cost and preparation time, since it is necessary to introduce an additional phosphating operation. Conclusion based on experiment results is that phosphating of samples despite its price leads to significantly better results than when the surface is not chemically prepared, which coincides with results of the cited research. Recommended combination of material for making the die/punch is hard metal/tool steel.

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THE FORWARD EXTRUSION PROCESS ANALYSIS BASED ON PLASTIC DEFORMATION OF METAL GRAIN STRUCTURE

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Abstract: *The determination of optimal values of parameters for achieving the desired metal forming process performances is of prime importance in real industrial conditions. In the defined production conditions, tool design and its geometry (die angle, lengths of certain zones in the die, deformation force transfer mode, die rigidity etc.), which are developed by tool designers using CAD software and FEM analysis, have considerable effects on process performance. On the other hand, complex extrusion temperature, die temperature, deformation rate, deformation degree, lubrication conditions and contact friction are the main controllable parameters of the extrusion process*

Keywords: *Cold extrusion, grain structure, statistic analysis.*

1. INTRODUCTION

The basis for a detailed analysis of strain and stress in the deformation zone and process modeling and optimization can be derived from the microstructure of the metal continuum. The predictions of the evolution of microstructure and establishment of correlations with the process parameters, in the variety of materials, are an active field of research and subject matter of many technological and scientific investigations based on different approaches to the mechanical continuum. Choi et al. [1] investigated the influence of the hard martensite particles on the orientation gradients of the soft ferrite phase within dual phase steel under plane-strain flange deformation during a cup deep-drawing process. The presented study analyzed the effects of ferrite orientation on the orientation gradients in the vicinity of a martensite particle, and relatively stable, metastable and unstable orientations were considered in crystal plasticity finite element method as the initial orientations of the ferrite matrix. In the approach proposed by Berbenni et al. [2], grain size effects on the macroscopic plastic flow stress of heterogeneous materials were studied using a systematic statistical method, assuming a given grain size distribution with higher moments than the mean grain size. The viscoplastic strain rate was described by an isotropic power law including the grain diameter through the reference stress. Numerical results firstly displayed that the plastic flow stress of the material depends on both the mean grain size and the grain size dispersion of distribution. Sarma and Dawson [3] proposed the polycrystalline model constructed using a different spatial arrangement of the same set of crystals, so as to alter the neighbourhood of each crystal. Deformation rates data for all crystals obtained from these simulations were analyzed using the method of empirical eigenfunctions and using statistical methods. Each finite element was treated as a single crystal, whose deformation is influenced by its interaction with neighbouring crystals. Brahme et al. [4] used texture data, in the form of fibre texture intensities, as well as carbon content, carbide size and amount of rolling reduction as input parameters to the ANN model. The subject of this study is the methodological approach for the analysis of grain structure and texture deformations in the forward extrusion process of low carbon steel, AISI C15 (C 0.13-0.18; Mn 0.3-0.6; P 0.04; S 0.04), at the ambient temperature. The method assumes that on the level of grain structure there are always deformed grains whose deformation degree can be approximated by the ideal grain. On the basis of these deformations, one can develop an appropriate mathematical model in the form of a trained neural network. In such a way, one can predict the deformation degree for any die angle, i.e. one can determine possible deformation states within the extrusion technology as well as within other metal forming processes.

2. THE BASE OF EXPERIMENTAL INVESTIGATION

The basic idea of this research is based upon a well-known method, called visio plasticity, but with a new approach. It is known that this method, in its experimental part, requires physical separation of the billet and placing the coordinate networks by chemical etching, for the purpose of monitoring the degrees of deformation [5,6].
The starting assumption is that the microstructure of the metals being deformed can itself be used for analysis (low carbon steel, AISI C15, R_m = 325 N/mm^2; φ_m = 0.22). The mere forward extrusion process, with the degree of deformation φ = 0.22, and with the coefficient of contact friction μ=0.15, was performed in experimental tools with variable central die angles 60°, 90° and 120° on a mechanical cam press with the extrusion force from 500 to 700 kN. Namely, as the metal grain microstructure, though of a very irregular shape, gets deformed under the impact of the extrusion force and of the tool walls, it obtains an oriented structure - deformation texture [7]. This points to the fact that the grains of the given metal sample being deformed also undergo a deformation in the proportion to the external load conditions [8]. Moreover, on the basis of the parameters of the grain material structure at the cross-section before and after deformation, the data about magnitude and degree of the deformation can be obtained at the cross-section points of the deformed volume. The determination of these displacements, at the level of the grain microstructure and due to the plasticity deforming, is done on the basis of the microstructure picture at the already defined measurement places at the meridian section of the extruded billet with a diverse angle of the cone die (Fig.1).

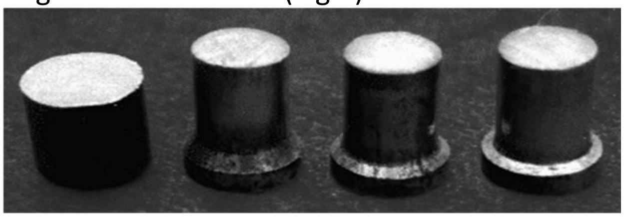
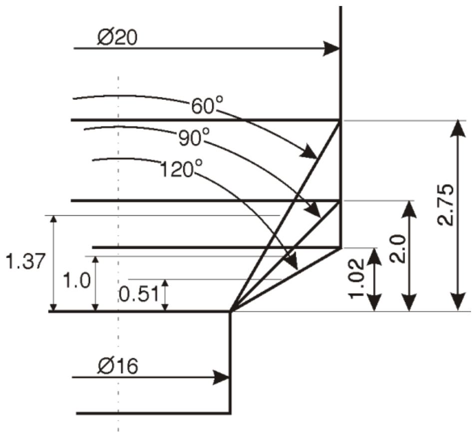


Figure 1. The billet and finished parts with different extrusion angles

The die angle is located within the range of 60° (Fig. 2). The choice and definition of the measurement places at the cross-section of the extruded and deformed billet must satisfy several criteria.



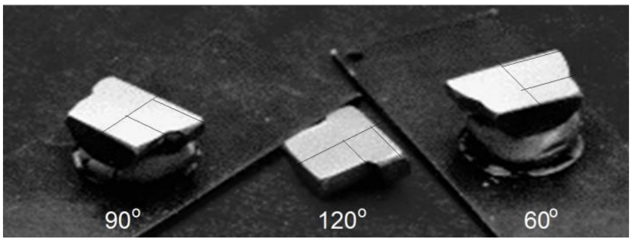


Figure 2. Geometry of the deformation zone in the meridian cross section and workpieces after polishing

Since it is an axisymmetrical stress and strain state, it is sufficient, for observing and following deformations, to remain in the midst of the meridian section in the characteristic points on the flow lines (Fig. 3).

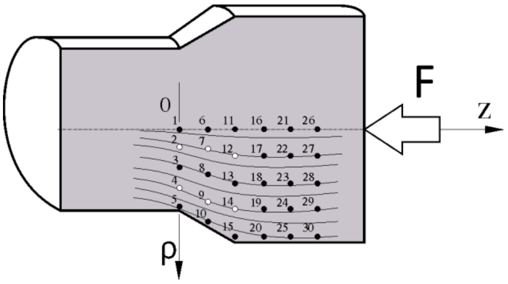


Figure 3. Recording places at the meridian cross section

4. MICRODEFORMATIONS AT THE GRAIN LEVEL

The complexity of the problem itself springs from the fact that the objects dealt with are of irregular and diverse shapes both in the space and in the section plane [7]. The method requires a great number of objects, that is, measurement of a great amount of grains at the cross-section of the deformed sample [8]. Likewise, since the grain microstructure represents tiny objects to be measured the order of their size being a hundredth part of a millimeter - such measurement places at the cross-section of the deformed sample have to be much more numerous, in this case 30, in order to have an insight into the degree of deformation throughout the material volume.

In order to solve the presented problem in the best possible way, that is, to obtain as accurate results as possible, a software solution was used. Consequently, the data about the picture that can be completely statistically processed are obtained and they can serve as the basis for deriving the required conclusions [9].

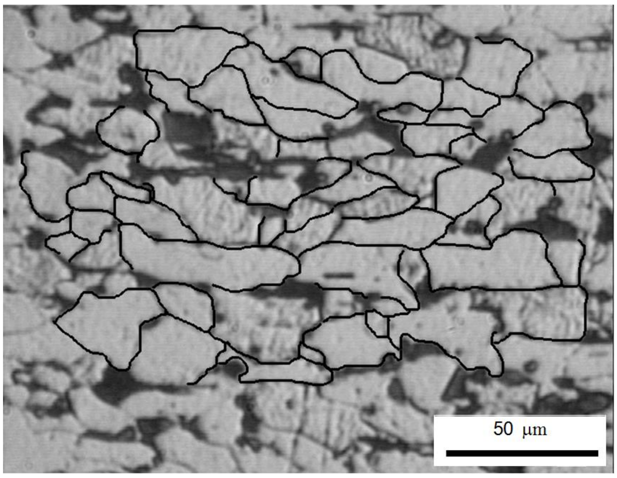


Figure 4. Micrograin structure at the die angle of 120°, recording place 11

For an analysis of the metal grain microstructure, the input information is a picture of that structure at the selected place, taken by recording the sample (Fig. 3) with a high resolution CCD camera. In the picture thus obtained, it is easy to distinguish lighter fields of soft ferrite structure (88%) as well as darker fields of cementite (12%) (Fig. 4). The transition between these fields in the picture represents a borderline of the grain microstructure.

The software recognition of the borderline between the grains represents an important step in the definition of the picture that will later be analyzed. In the obtained pictures of the grain structure there are great irregularities in shape, size and grain area so that the process of the grain separation is primarily conducted with respect to parts of the grain borderlines that are already clearly distinguished in the picture and in the previously made structure pictures. Thus, the picture of the sample structure at the chosen recording place is obtained and can be analyzed according to the given pre-determined criteria.

Since the pictures of the grain structure can be considerably complex with great irregularities, the criteria must be defined against which the object recognition will be carried out. The monitoring of the metal grain structure as well as analysis and comparison belong to the geometric analysis. This means that, at the grain level as the basic and initial form of observation, it is necessary to analyze changes in of the geometric parameters through which the sizes of the grain deformations can be given later. The number of parameters that can be chosen in the software is great and it can serve for very detailed analyses (Table 1).

Table 1 Geometric characteristics of an ideal grain at place No. 4, 60°

Stats	Area		Aspect	Ar/Bo	Box	Angle	Maj. Ax	Min. Ax	Av. Dia.	Perim.	Roun.	Per Ar
	μm²				μm²	°	μm	μm	μm	μm²		
1	2		3	4	5	6	7	8	9	10	11	12
Min	515		1.417	0.283	1.167	71.70	54.54	11.56	28.605	121.184	1.34	0.001
(Obj.#)	38		29	8	29	29	18	38	40	40	24	38
Max	7252		5.783	0.768	4.307	38.71	176.4	75.45	92.05	427.19	5.50	0.023
(Obj.#)	35		12	47	38	41	13	29	35	27	8	35
Range	6737		4.366	0.484	3.14	57.1	121.8	63.88	63.44	306.01	4.15	0.021
Mean	3087.0		2.923	0.553	2.062	104.67	102.97	37.64	57.99	266.09	2.05	0.009
Std.Dev	1742.4		0.9161	0.107	0.649	13.25	32.04	13.17	15.37	80.215	0.63	0.005
Sum	15435		146.15	27.64	103.1	5233.7	5148.8	1882.4	2899.9	13304.9	102.8	0.498
Samples	50		50	50	50	50	50	50	50	50	50	50

5. CONCLUSION

The methodological approach proposed in this study enables a stress strain analysis within the material, regardless of the forming process. Any deforming procedure will cause changes in the material microstructure. This fact itself points to the conclusion that the material with its microstructure will always "contain" the information about the load magnitude and size at the grain microstructure level. Furthermore, the advantage of the proposed approach is that it enables an analysis of the microdeformations of metal parts, measurement and analysis of the deformation texture parameters on the basis of which one can train a neural network.

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INFLUENCE OF CUTTING PARAMETERS ON THE TOOL LIFE IN END MILLING OF BIOCOMPATIBLE TITANIUM ALLOY TI6AL4V

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Abstract: *In present paper, the goal is to identify optimal cutting parameters in order to achieve maximum tool life in end milling biocompatible titanium alloys Ti6Al4V. The observed cutting parameters are cutting speed, feed rate and depth of cut. Experiments were carried out in dry condition as per Taguchi's L_9 orthogonal array. Tool life is defined in the effective cutting length by the milling cutter in the milling process.The cutting parameters were optimized using Taguchi's techniques (signal-to-noise ratio), while analysis of variance was employed to determine the significance of the process parameters influencing the tool life. The analysis of the results were showed that cutting speed and feed rate significant on the tool life. The feed rate is the most significant parameter on the tool life. The optimization process was achieved an improvement for the tool life of 12.16%.*

Keywords: *end milling, tool life, Ti6Al4V, optimization*

1. INTRODUCTION

In the field of science, biomaterials are defined as any biocompatible materials, natural or artificial, used to replace or repair a part of an organ or tissue [1, 2, 3]. The term biocompatibility is a statement on how well the tissue of the human body reacted with the material and how this interaction meet planned expectations for a particular purpose implantation [3]. Materials, in order to meet the requirement of biocompatibility, must have biological properties, corrosion resistance and resistance to ion release, or a suitable biological effect of the released ions [1, 2]. In order to possess these properties, specific metal biomaterials make of stainless steel, cobalt alloys or titanium alloys. These materials have in common is that they belong to difficult-to-machining materials. For this reason, a many research has been done on the machinability of these materials in order to make progress in this field. In addition to the fact that these materials are biocompatible, they found great application in the aviation industry due to their good characteristics, which is an additional reason why there is a lot of research in field of machinability this materials.

One of the most commonly used materials as a biocompatible material is titanium alloy Ti6Al4V, which is the main reason for many studies of the machinability of this material. Rotella et al [4] investigated the influence of different cooling conditions on the quality of the machined surface during the processing of Ti6Al4V alloy, where they were machined under dry conditions, cryogenic cooling and MQL conditions. The influence of the cutting parameters on the surface roughness during milling of titanium alloy Ti6Al4V was also investigated in research [5]. Halil and Meric [6] analyzed the cutting forces, chip morphology and surface finish when using tools with different coatings for face milling of Ti6Al4V alloy. Li et al. [7] investigated tool wear in high-speed dry milling of Ti6Al4V alloys for different cutting speeds and different feed rates. Khanna and Davim [8] measured and investigated the cutting forces, feed forces and cutting tool temperature for milling three different titanium alloys, where they used Taguchi's techniques to conduce the experiment and process the data. Ravi and Kumar [9] researched the influence of tool tip radius, cutting speed, feed rate and cutting depth on machined surface quality and tool wear during Ti6Al4V alloy machining and optimized these machining parameters using Taguchi's optimization method to reduce tool wear and better quality of the machined surface. In their work, Nural et al. [10] presented a comparative analysis tool life of an uncoated WC – Co tool and a tool with polycrystalline diamond inserts at different cutting speeds of Ti6Al4V alloy. Tool wear in helical dry milling was investigated in their study by Vidal et al [11] for different cutting speeds and feed rate when milling Ti6Al4V alloy. Harsha et al. [12] emphasized tool wear and surface roughness as two indicators of the machinability of Ti6Al4V alloy. In their work, they investigated the influence of cutting speed, feed rate and cutting time on tool wear and surface roughness. They used artificial intelligence techniques to predict the value of tool wear and surface roughness. Zhao et al [13] determined tool wear, productivity, surface roughness and dimensional deviation during roughing and final milling of thin-walled Ti6Al4V alloy workpieces.

From the review of previous research, it can be easily concluded that when researching in the field of machinability of Ti6Al4V alloy, most attention is paid to defining the optimal machining technology and optimal cutting parameters. Accordingly, the aim of this research is to determine the influence of machining parameters (cutting speed, feed rate and cutting depth) on the tool life and optimization of the same when end milling Ti6Al4V alloy. Tool life was defined based on the length of the effective tool path in the cutting process. The realization of these goals were accomplished using Taguchi's L_9 orthogonal plan of the experiment.

2. THE TAGUCHI METHOD AND DESIGN OF EXPERIMENTS

Taguchi method, developed by Taguchi [10], is a simple and robust statistic technique for optimizing the process parameters. To solve the problem of experiment complexity with increasing number of factors, Taguchi developed a specially designed method called orthogonal array (OA) or orthogonal experiment design where it is possible to study the entire parametric process with a smaller number of experiments. Within this method, Taguchi suggests using a quality loss function that links the deviation of characteristics from the target value. The value of this function is further transformed into a signal-to-noise (S/N) ratio. S/N ratio is employed for the determination of the optimal process parameter settings. Typically, there are three categories of the performance characteristic in the analysis of the S/N ratio: smaller-the-better (Eq. 1), larger-the-better (Eq. 2) and nominal-the-best (Eq. 3).

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (3)$$

where $\bar{y}$ is the average of observed data, s_y^2 is the variance of y, n is the number of observations and y is the observed data.

Furthermore, in order to analyze the impact of the process parameters on the on the performance characteristic a statistical analysis of variance (ANOVA) is usually performed.

In this paper, the design of the experiment was performed according to the previously described method. Taguchi's L_9 orthogonal array was selected, from which it follows that the three control factors were varied at three levels. The milling process was analyzed, and the varied control factors were cutting speed, feed rate and milling depth, Table 1.

The experiments were performed on a CNC vertical machining center EMCO Concept Mill 450 with SIEMENS Sinumerik 840D control unit. The main spindle of the milling machine has a power of 11kW, speed ranging from 50 to 12000 rpm and standard tool holder ISO 40. The milling operation was performed with end mill SANDVIK R390-016B16-11L, 16 mm in diameter, with two inserts R390-11 T3 08M-PM 1130. The workpiece was made of biocompatible Ti6Al4V alloy, dimensions 47 × 47 × 40 mm, Fig. The chemical composition of Ti6Al4V alloy is given in Table 2.

The tool life was observed as the output value of the experiment. Tool life was defined based on the length of the effective tool path in the cutting process. The flank wear is the most commonly used parameter for determining the value of the tool wear. The reason for this is that flank wear value directly affects the roughness of the machined surface, and also has an impact on the value of the cutting force. For these reasons, in this paper, VB is taken as a tool wear parameter. The value VB = 0.3 mm was adopted for the upper wear limit of the tool. The VB value was measured using a Mitutoyo TM-505 instrument microscope equipped with a high-resolution MOTICAM 5 camera and connected to a PC using Motic Images Plus 2.0 software.

Table 1. Machining parameters and their levels

Parameter	Parameter designation	Levels		
		1	2	3
Cutting speed (m/min)	A	40	80	160
Feed (mm/z)	B	0.05	0.1	0.2
Depth of cut (mm)	C	0.5	1	2

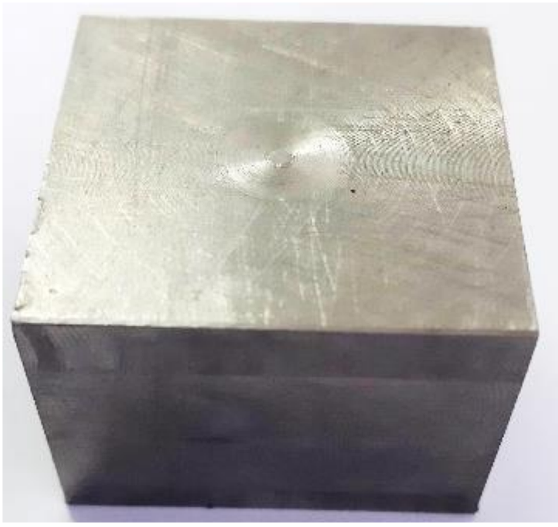

Figure 1. Workpiece

3. ANALYSIS OF EXPERIMENTAL RESULTS

Table 3 shows the experimental results. The analysis of the results was performed using the software Minitab 2018. This analysis of the results included the analysis of the influence of input parameters on the tool wear.

The procedure for determining the tool life is based on setting a flank wear limit, which is 0.3 mm. After achieve this wear limit of the insert, the tool is no longer used. During the exploitation of the tool, the measurement of tool wear is performed several times, based on which we obtain wear curves for each of the experiments. Tool wear curves are shown in the graph in Figure 2.

Tabela 2. The chemical composition of Ti6Al4V alloy

C	Fe	N_2	O_2	Al	V	H_2	Ti
≤0.08	<0.25	<0.05	<0.2	5.5-6.76	3.5-4.5	<0.0375	Balans

Tabela 3. Experimental design using L9 orthogonal array and experimental results

No.	Experimental design			Cutting parameters			Tool life L [mm]	S/N ratio [dB]
	A	B	C	Cutting speed (m/min	Feed (mm/z)	Depth of cut (mm)		
1	1	1	1	40	0.05	0.5	82	38.2763
2	1	2	2	40	0.1	1.0	109	40.7485
3	1	3	3	40	0.2	2.0	189	45.5292
4	2	1	2	80	0.05	1.0	88	38.8897
5	2	2	3	80	0.1	2.0	168	44.5062
6	2	3	1	80	0.2	0.5	266	48.4976
7	3	1	3	160	0.05	2.0	148	43.4052
8	3	2	1	160	0.1	0.5	257	48.1987
9	3	3	2	160	0.2	1.0	226	47.0822

When analyzing the tool life, it is necessary to analyze the influence of cutting speed, feed rate and milling depth on the tool life. Given that the price of tools is high, in order to ensure economical production, the task is to find the greatest possible tool life. From this it is obviously concluded that in this study the objective function must be set as: larger-the-better. The S / N values for each experiment are shown in Table 3. The S / N response for each input parameter is shown in Table 4, and the tool life response for each input parameter is shown in Table 5.

Table 4. S/N response table for tool life

Level	A	B	C
1	41.52	40.19	44.99
2	43.96	44.48	42.24
3	46.23	47.04	44.48
Delta	4.71	6.85	2.75
Rank	2	1	3

Table 5. Mean response table for tool life

Level	A	B	C
1	126.7	106.0	201.7
2	174.0	178.0	141.0
3	210.3	227.0	168.3
Delta	83.7	121.0	60.7
Rank	2	1	3

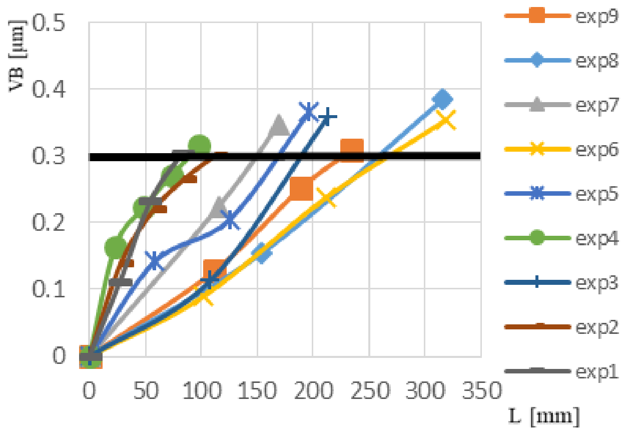

Figure 2. Tool wear curves

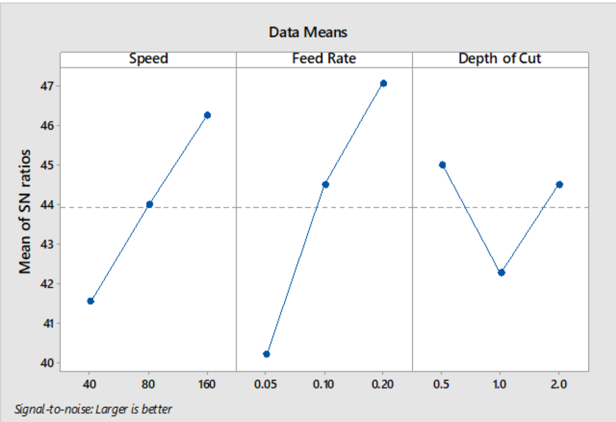

Figure 3. S/N response for tool life

From the analysis of S / N ratio, it is easy to determine which of the three compared parameters have the greatest influence on the tool life during the end milling of Ti6Al4V alloy. From Table 4, based on the rank of impact, and Figure 3, it was obtained that the greatest impact on the tool life has a feed rate. On the other hand, the depth of cut has the least impact. Thus, the largest factor dependence for tool stability is for S / N with the largest graph slope. From Table 4 and the graph from Figure 3, the optimal cutting parameters within the offered levels can also be seen, considering the criterion for the goal function "larger-the-better". The optimal combination of selected parameters is the cutting speed at level 3, the feed rate at level 3 and the depth of cut at level 1.

Analysis of variance was performed to determine the statistical significance of cutting speed, feed rate and depth of cut on the tool life. The results of the analysis of variance are shown in Table 6. The analysis was performed with a confidence level of 95%.

Table 3 revealed that two parameters i.e. cutting speed and feed rate have significant effect on tool life. The P-values of each of these factors indicate the confidence level is more than 95.00%, which shows their very strong influence. The influence of cutting speed, feed rate and depth of cut had been again calculated by percentage contribution. It has been observed that percentage contribution of feed rate (factor B) to the tool life was the largest (57.05%), followed by cutting speed (factor A) and depth of cut (factor C) with contributions of 27.11% and 14.22%, respectively. The remaining 1.62% is due to the error of the experiment, ie the influence of other factors. As the error of the experiment is very small, it follows from this that the experiment is very well set up and that, in the observed case, there are no significant influences of other factors on the tool life.

Table 6. Results of the analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% učešće
Speed	2	10560.7	5280.3	16.69	0.057	27.11
Feed Rate	2	22226.0	11113.0	35.13	0.028	57.05
Depth of Cut	2	5538.7	2769.3	8.75	0.103	14.22
Error	2	632.7	316.3			1.62
Total	8	38958.0				100

Based on the previously analyzed data, the optimal tool life can be predicted. Using the data from Table 5, we obtain the predicted optimal tool life in the following way:

$$L_{opt.pred} = A3 + B3 + C1 - 2x(Y)$$

$$L_{opt.pred.} = 210.3 + 227.0 + 201.7 - 2 * 170.33 = 298.34 \text{ mm} \quad (4)$$

With this prediction, it can be concluded that the maximum tool life within the offered machining parameters is 298.34 mm. Table 7 shows how much improvement was achieved in relation to the best value of tool life obtained by the experiment. From this comparison, it can be seen that with the optimization procedure, an improvement of 12.16% was achieved.

Table 7. Initial and optimal levels

	Initial	Optimal	Improve-ment
Level	A2B3C1	A3B3C1	12.16 %
Tool life [mm]	266	298.34	

4. CONCLUSIONS

In this paper, the influence of cutting speed, feed rate and cutting depth on the tool life during the final milling of titanium Ti6Al4V alloy was analyzed. The experiment was performed according to Taguchi's L_9 orthogonal array. Taguchi techniques were used in the optimization process, and ANOVA analysis was used to determine the level of influence of cutting parameters on tool life.

From the present investigation, the following conclusions may be drawn:

- From S / N analysis, the optimal combination levels of machining parameters for maximizing tool life were cutting speed of 160 m / min, a feed rate 0.2 mm/z and cutting depth of 0.5 mm (A3B3C1).
- The ANOVA also reveals that the most significant factor in affecting the tool life was the feed rate having a percentage contribution of 57.05%, followed by cutting speed and depth of cut and with percentage contribution of 27.11% and 14.22%, respectively.
- According to ANOVA results, the error contribution was 1.16%, which undoubtedly reveals the absence of the interaction effects of machining parameters on optimization of performance characteristics.
- Finally, it is noted that the optimization process was completed successfully. With this optimization, an improvement of 12.16% is obtained in relation to the best result achieved during the performed experiments.

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APPLICATION OF STEP-NC PROTOCOL FOR MILLING ON MACHINE TOOLS THAT USE FANUC-SIEMENS-LINUXCNC CONTROL SYSTEM

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Abstract: *This paper presents a method for the application of STEP-NC protocol for milling on machine tools that have Fanuc, Siemens, or LinuxCNC control systems. The programming method used ISO 10303-238 (AP-238) standard for programming CNC machine tools. Application and validation of an indirect programming method according to STEP-NC protocol are performed using available CNC machine tools with different control systems.*

Keywords: *STEP-NC, programming, virtual machine, control system*

1. INTRODUCTION

This paper discusses the possibility of application STEP-NC protocol for milling machine tools that have different control units. In this regard, the application of an indirect programming method based on the new standard ISO 10303-238 (AP-238) known as STEP-NC (Standard for Product Model Data Exchange for Numerical Control) is considered [1-4].

The article presents research results on the application of a new programming method in actual production conditions, whereby machining process based on complete technology-based according to the STEP-NC standard is achieved. The aim is to show the possibilities of application and realization in cases when it is necessary to take over and realize the technology of machining a part, which was prepared based on of STEP-NC standard (ISO 10303-238) [3-5].

In today's real production conditions, machine tools which can read only G-code files are dominant. In this regard, the most common application of the STEP-NC protocol is indirect, so that STEP-NC programs are translated into G-code using a developed translator. This level is indirect programming based on STEP-NC [1-7].

2. OUTLINE OF THE CONCEPT OF STEP-NC PROTOCOL APPLICATION

The STEP-NC standard has been developed to challenge the standardization of the exchange of product data along the manufacturing digital chain (CAD-CAPP-CAM-CNC), which includes simulation, optimization, and convert or export code capabilities [1], Fig. 1. The digital thread for manufacturing in this paper considered various CNC machine tools with the different control units.

The STEP-NC provides a comprehensive model of the manufacturing technology. It is object and feature-oriented and describes the machining operations executed on the workpiece, and not machine-dependent axis motions. It will be running on different machine tools or controllers [8].

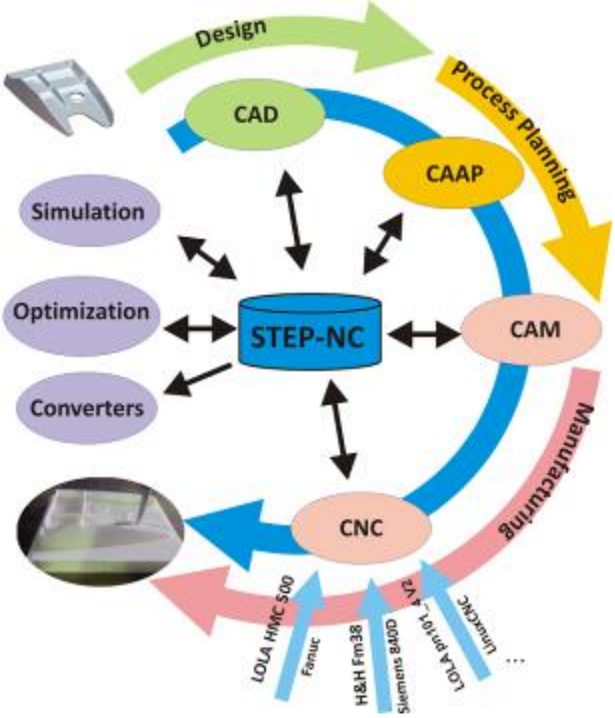

Figure 1. Digital chains based on STEP-NC

If the part machining technology is based on the STEP-NC protocol, and the available machines can only execute G-code, there must be that there are appropriate translators or converters that will be able to convert the STEP-NC program into corresponding G-code.

For now, for most users, this new method of programming based on STEP-NC cannot be completely used with all the benefits provided by STEP-NC [1]. This paper presents the possibilities of applying for the native STEP-NC program, post-processing or converting STEP-NC program into G-code and executing on the different machine tool which is only able to interpret-only G-code files, Fig. 2. This application scenario is realistic, for most users, and can be realized in three ways. The first way is using CLF, exported from STEP-NC file, which is specifically imported into the available CAD/CAM system and post-processed for the selected machine tool. This approach is used when users have already developed a postprocessor in CAD/CAM system. CAD system takes reference model and workpiece in STEP format and CL File. Verification of material removal is done in a CAD/CAM system in the module (NC Check). CAD/CAM system uses configured postprocessor to generate G-code for the available CNC machine tools [1,5], Fig. 2.

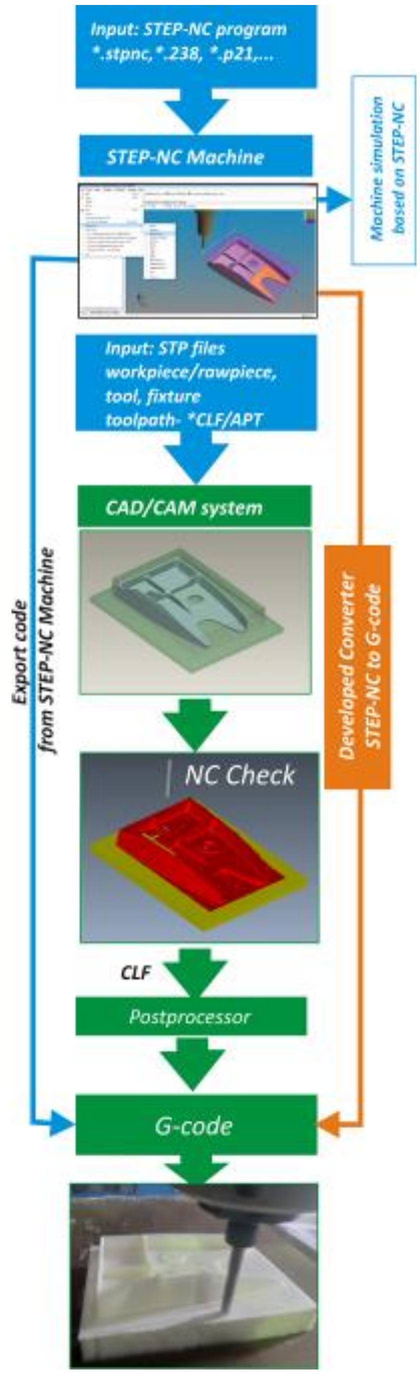

Figure 2. Outline of the concept for the application of STEP-NC protocol on CNC machine tools that are only able to read G-code

The second way uses an export code option of STEP-NC Machine which can directly export STEP-NC program into G-code from the available control units, offered by software (Fanuc, Siemens, Okuma, Haas, etc.), Fig. 3.

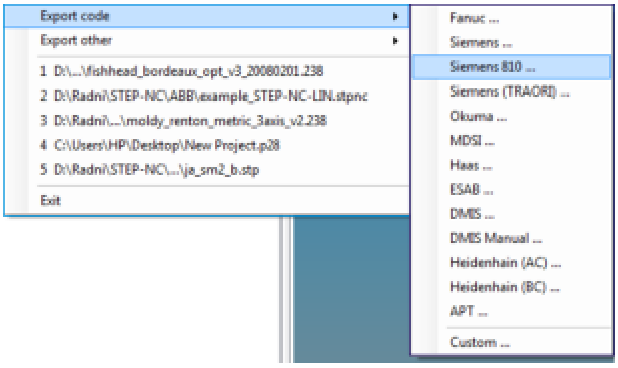

Figure 3. Exporting of code from STEP-NC Machine

The third way is parsing the STEP-NC file and converted into G-code using developed converters [1].

3. MACHINE SIMULATION BASED ON STEP-NC

STEP-NC Machine can display and simulate the machining process within a STEP-NC file, including the simulation of virtual machine tools, and it can be extended as needed to simulate the kinematic of new machines. Thus, the STEP-NC Machine environment allows configuring its own virtual CNC machine tools. In this way, it is possible to perform a simulation of STEP-NC based technology [1].

This is important to gain insight into the proposed technology and prepare adequate technological documentation for machining on machines that perform only G-code. Also, the possibility of configuring your own machines enables verification of toolpath by the virtual machine, before converting STEP-NC file into G-code.

For the machine tools considered in this paper (LOLA HMC 500, H&H FM38, and LOLA pn101_4 V2), the appropriate virtual machines were configured and integrated into the licensed STEP-NC Machine software. A detailed procedure for configuring new machine tools in STEP-NC machines is given in [9].

For the considered configured virtual machines, a machining simulation was performed based on the original STEP-NC file, Fishhead [10], which is shown in Fig. 4.

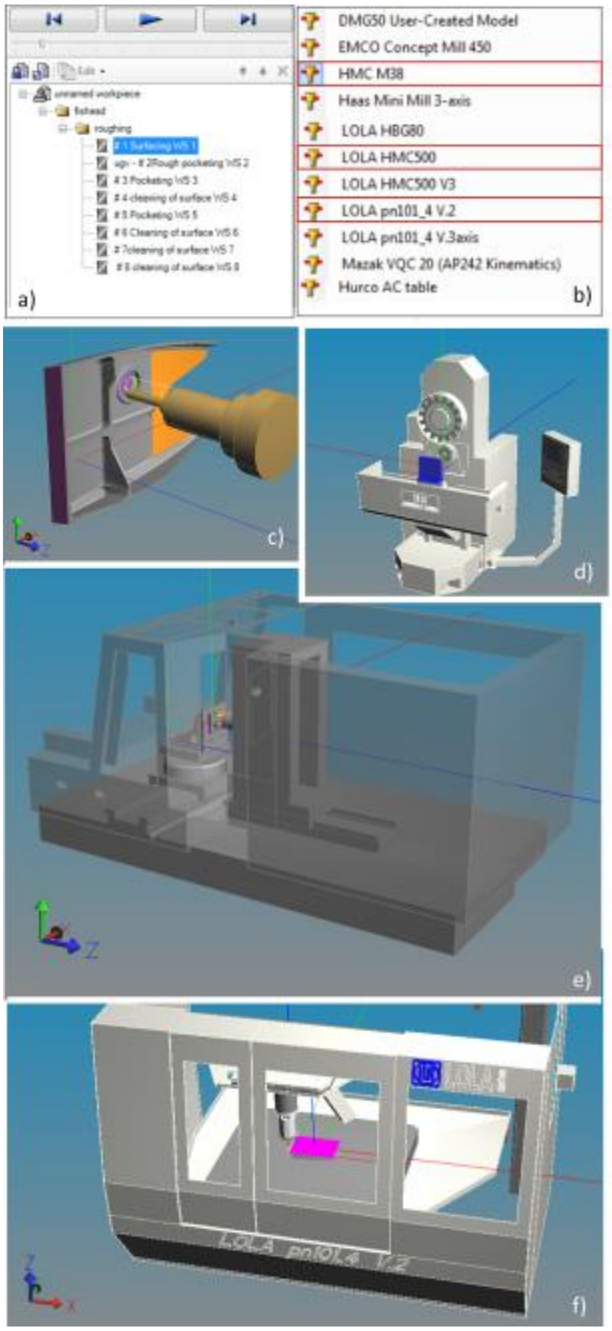

Figure 4. Machine simulation based on STEP-NC

Based on the insights of the performed simulations on three different machines, it is evident that an identical STEP-NC program is executed. Since machines that execute the G-code are used in this case, it is necessary to prepare for the conversion of the STEP-NC program into the G-code, according to one of the ways proposed in Fig. 2.

4. CONVERTER FROM STEP-NC TO G-CODE

In our research presented in papers [11,12] is described an Indirect programming method, based on standard ISO 10303–238, which is used the own developed converters. These converters are employed for translating the exported STEP-NC *.p21 file into (i) G-code, or (ii) robot programming language.

These converters can be used for both industrial robots and machine tools with appropriate customization of the program output format, where for this paper only the part that converts the STEP-NC program to G-code for CNC machine tools is used, Fig. 5.

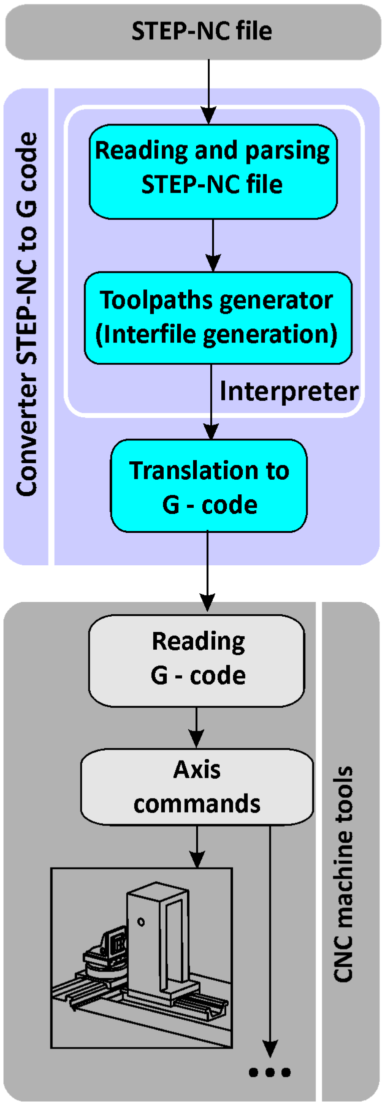

Figure 5. Developed converter for machine tools

The complete procedure of STEP-NC program conversion to G -code or robot language can be seen in [11,12]. This procedure should involve a STEP-NC program interpreter and its translation into an appropriate language. Main activities during translation STEP-NC program are: (i) reading and parsing P21 file, (ii) toolpath generator (Interfile generation), (iii) translation to G-code, (iv) toolpath simulation of generated G-code, and (v) execution of the program on the real CNC machine tool.

5. APPLICATION OF STEP-NC PROTOCOL IN REAL PRODUCTION CONDITIONS

Machining experiments related to the machining of original STEP-NC file, from STEP Tools [10], machining of part Fishhead was performed.

The considered example of the original STEP-NC file is Fishhead, and for this example, the STEP-NC file (ISO10303-238) is translated into the G-code and then it was machined on three different machines, with three different control systems: (i) LOLA HMC 500, Fanuc (FME-BG), (ii) 3 axis vertical milling machine with parallel kinematics LOLA pn101_4 V2, LinuxCNC (FME-BG), and (iii) CNC Horizontal machining center, H&H FM38 Siemens 840D (FTN-NS), Fig. 6.

For machining Fishhead on LOLA HMC 500 with Fanuc, the control unit is used the possibility of applying the available CAD / CAM system in which there is a configured postprocessor for this machine was used. From STEP-NC is used exported CLF, and STEP files of the workpiece, which is imported in CAD/CAM system were used available postprocessor for generating G-code.

For machining Fishhead on 3-axes vertical milling machine with parallel kinematics LOLA pn101_4 V2 with LinuxCNC control system used developed converter [11] from STEP-NC to G-code.

For machining Fishead on CNC Horizontal machining center, H&H FM38 with Siemens 840D control unit is used export code option of software STEP-NC Machine. In this way, it is possible to export the program directly from the STEP-NC program to the G-code for different control units, with Siemens being selected here in this case.

The obtained G-codes were in all three cases machined in laboratory real production conditions on selected machines. A soft material, Styrofoam and wood, was used for machining.

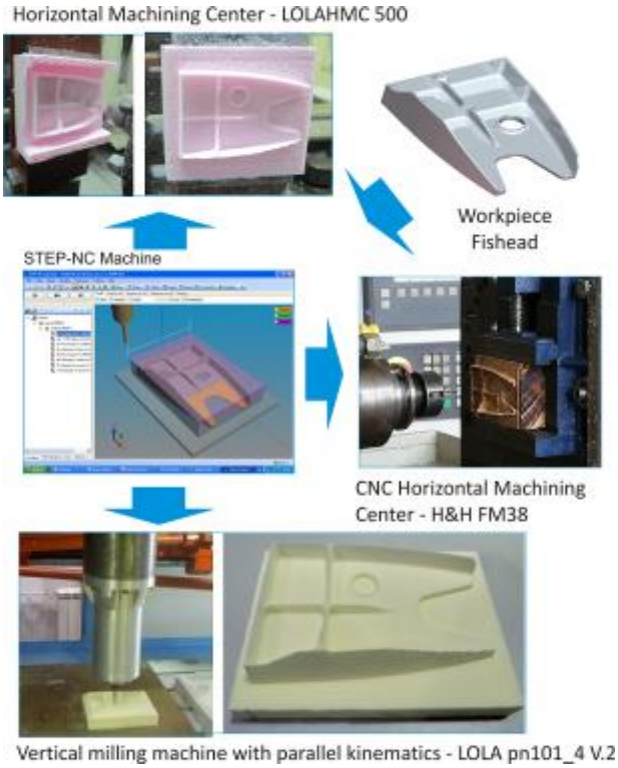

Figure 6. Machining experiments on three different machines

The performed machining experiments confirmed the accuracy of translating the STEP-NC program into G-code by achieving correct machining of the original Fishhead part.

6. CONCLUSION

The paper shows the possibility of applying the exchange of machining technology based on the STEP-NC file for machine tools that have different control units. Verification was performed by processing the original STEP-NC file according to ISO10303-238 on available machines, whereby the STEP-NC file was converted to G-code.

For now, the application of STEP-NC-based programming methods is limited and is applied mainly at the first indirect level that applies to machines that can only execute G-code.

The future works includes the further development of converters for specific G-code, as well as the transition to the level of direct interpreted STEP-NC programming where axis command is directly executed from STEP-NC file. In order to fully realize this concept, the development of a STEP-NC compliant control unit is crucial.

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INFLUENCE OF TEMPERATURE ON THE BEHAVIOR OF WELDED ALLOYED STEEL UNDER VARIABLE LOAD CONDITIONS

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***Apstract**: Investigation of the influence of temperature on the behavior of butt-welded joint of steel sheets SA-387 Gr. 91 in the conditions of action of variable load was done with the aim to determine the points in S-N diagram (construction of the Weller curve) and to determine the dynamic strength, Sf. From the S-N diagram, it is possible to determine the stress at which a crack does not appear on a smooth test tube even after 2x10^6 cycles a defined number of cycles at which the dynamic strength of the welded joint is determined. The standard for these tests provides for a large number of tubes (minimum 3 for determined amplitude at a constant load ratio R). Therefore, this test is extremely expensive and justified when design data are required, primarily from the aspect of fatigue and fracture mechanics, when designing parts exposed to long-term variable load in the total design life of the structure.*

***Keywords:** alloyed steel, welded joint, variable load, Weller curve, dynamic strength*

1. INTRODUCTION

Alloyed Cr-Mo steel marked SA 387-Gr. 91 is intended for the manufacture of pressure vessels, steam pipelines and gas installations in the chemical and petrochemical industries, as well as thermal power plants, which operate in conditions of elevated temperature and corrosive environment. Due to its extremely good mechanical properties, as well as excellent resistance to the presence and propagation of cracks in operating conditions, its application will achieve significant savings in material compared to conventional steels. The strength of the welded joint at variable loads, such as those occurring in non-stationary operating modes, is an important characteristic in the assessment of integrity and remaining life, [1, 2]. It should be borne in mind that damage in the form of cracks occurs after a large number of load changes at voltages lower than the yield stress (high-cycle fatigue). At the load level lower than the yield stress, characteristic of high-cyclic fatigue, the test is most often performed in the rigid regime, at a given voltage amplitude S_a, MPa. It is clear that the strength at high cyclic fatigue depends on the properties of the constituents of the welded joint. It should be borne in mind that the characteristics of high-cyclic fatigue change significantly only at temperatures above 400°C for steel for pressure vessels and for their welded joints, and these tests make it justified only for operating temperatures, which for this group of materials are max. 575°C. The tests included the determination of high - cyclic fatigue parameters of butt weld and OM (base metal) at room and elevated temperatures of 575°C.

2. TEST MATERIAL

Alloyed steel SA-387 Gr. 91, which belongs to the group of Cr-Mo steels, has a yield stress of at least 450MPa and a guaranteed impact energy at room temperature of at least 41J. It was produced in "Železarna ACRONI" Jesenice. The chemical composition of the tested steel is given in Table 1.

Table 1. Chemical composition of the tested batch of steel SA-387 Gr. 91

Element	%	Element	%	Element	%
C	0,129	**Ni**	0,01	**Al**	0,007
Si	0,277	**Cu**	0,068	**Sn**	0,005
Mn	0,443	**Mo**	0,874	**W**	0,016
P	<0,001	**V**	0,198	**Co**	0,009
S	<0,001	**Ti**	<0,001	**B**	0,0005
Cr	8,25	**Nb**	0,056	**N**	0,031

Considering the type of material and technical-technological regulations that need to be complied with, and having in mind that it is micro-alloy steel, welding of test specimens was done with two procedures and additional materials, as follows:

- Roots weld-TIG welding (according to SRPS EN ISO 6947, [3]), 4 (four) passes. The additional material used for the TIG is a wire marked BOEHLER C 9 MV-IG, diameter 2.4 mm (international mark W CrMo 91 according to SRPS EN ISO 21952, [4]).

- Filling-REL welding (according to SRPS EN ISO 9692-1, [5]), other passes. The additional material used for REL is an electrode marked BOEHLER FOX C9 MV, diameter 2.5 and 3.2 mm (international mark E CrMo 91 B 4 2 H5 according to SRPS EN ISO 3580, [6]).

The chemical composition of the additional material is given in Table 2, and the mechanical properties in Table 3.

Table 2. Chemical composition of additional material

Additional material	Welding process	Chemical composition, %											
		C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Nb	N
C 9 MV-IG	TIG	0,11	0,23	0,5	0,006	0,003	9,0	0,93	0,5	0,19	0,03	0,07	0,04
FOX C9 MV	REL, 2,5mm	0,09	0,19	0,55	0,01	0,006	8,5	1,00	0,5	0,19	0,1	0,04	0,05
FOX C9 MV	REL, 3,2mm	0,11	0,26	0,66	0,008	0,005	8,5	0,94	0,5	0,20	0,1	0,06	0,04

Table 3. Mechanical properties of additional material

Additional material	Welding process	Flow voltage, $R_{eL}/R_{p0,2}$, Mpa	Tensile strength, R_m, MPa	Elongation, A, %	Impact energy, KV, J
C 9 MV-IG	TIG	≥ 530	≥ 620	≥ 17	≥ 50
FOX C9 MV	REL, 2,5mm	≥ 550	≥ 680	≥ 17	≥ 47
FOX C9 MV	REL, 3,2mm	≥ 550	≥ 680	≥ 17	≥ 47

In order to avoid the problem of defining the position of the notch in the HAZ (heat affected zone), a butt welded joint with a regular symmetrical K-groove was chosen, Fig. 1. In relation to the thickness of the plates, the order and number of welding passes are defined. The welding order is given in fig. 2. Argon (Ar), flow rate 12 liters / min was used as shielding gas.

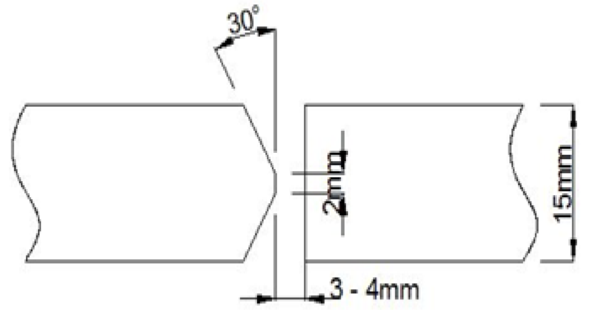

Figure 1. Seam shape for material SA-387 Gr. 91

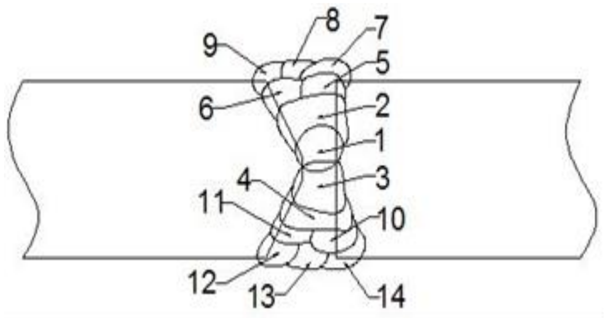

Figure 2. Welding passes SA-387 Gr. 91

The order of passage shown in fig. 2 is as follows:

- 1 ÷ 4 - TIG, 2.4mm diameter wire
- 5 ÷ 9 - REL, electrode diameter 2.5mm
- 10 ÷ 14 - REL, electrode diameter 3.2mm

3. VARIABLE LOAD TESTS

The test procedure, as well as the test tube are defined by the standard BS EN 6072-10 Aerospace series - Metallic materials - Test methods - Constant amplitude fatigue testing, [7], as well as the recommendations of professional international organizations authorized to define quality control conditions for welded joints. A sketch of the test tube is given in fig. 3, and the appearance of the finished tubes for testing with variable load is given in Fig. 4.

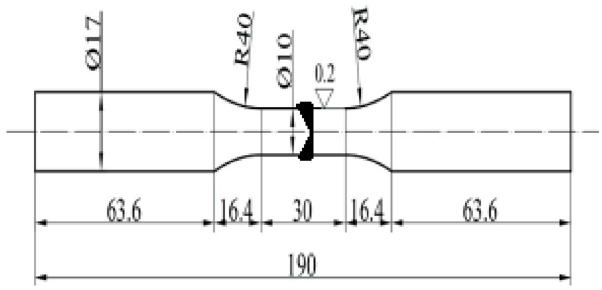

Figure 3. Test tube for dynamic tests according to standard EN 6072: 2010

Figure 4. Appearance of finished test tubes for dynamic tests

The test was performed on a SHIMADZU servo-hydraulic machine, Fig. 5 at room temperature and at a humidity of 65%, as well as at 575 ° C

Figure 5. Servo-hydraulic machine SHIMADZU

The SHIMADZU servo-hydraulic machine can achieve a sinusoidal alternating variable load in the range from -100kN to + 100kN. The mean load and load amplitude were recorded with an accuracy of ± 20N. The achieved frequency was defined at 45Hz for the test at room temperature and 30Hz for the test at 575 ° C. In order to more fully assess the behavior of the material under the action of variable load, and having in mind the dimensions of the test tube, the most critical case of variable load action was done, namely alternating variable load tension-pressure (R = -1), [8, 9].

In this test, as a rule, only the number of changes in load to fracture under the action of a constant span load is determined, and only information on the magnitude of the stress at which fracture does not occur after $2x10^6$ cycles is required.

The influence of temperature on the values of dynamic strength, S_f, the maximum dynamic stress at which no crack type error is initiated in smooth specimens, is shown graphically in the form of Weller curves (S-N diagrams) in Fig. 6 for test tubes of butt welded joint, and in fig. 7 for OM test tubes.

Analyzing the obtained test results of high-cyclic fatigue of smooth specimens with the aim of constructing the Weller curve and determining the dynamic strength, we see that the test temperature significantly affects the obtained values of dynamic strength at $2x10^6$ cycles, which is shown in Fig. 8.

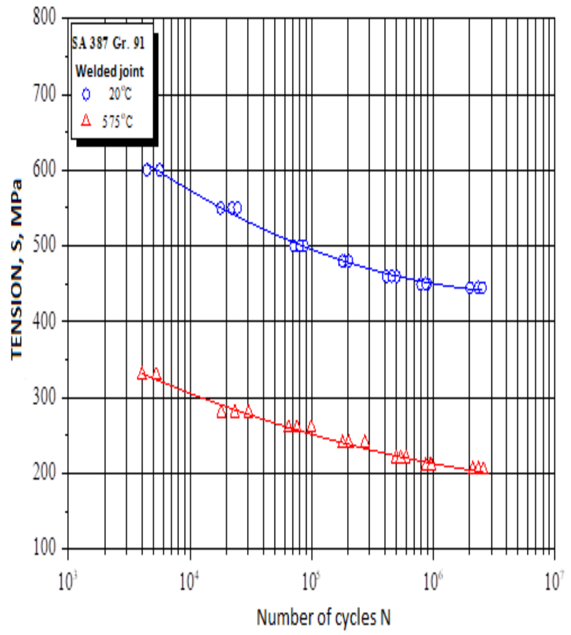

Figure 6. S-N diagram of tubes taken out of butt welded joint and tested at room temperature and at 575 ° C

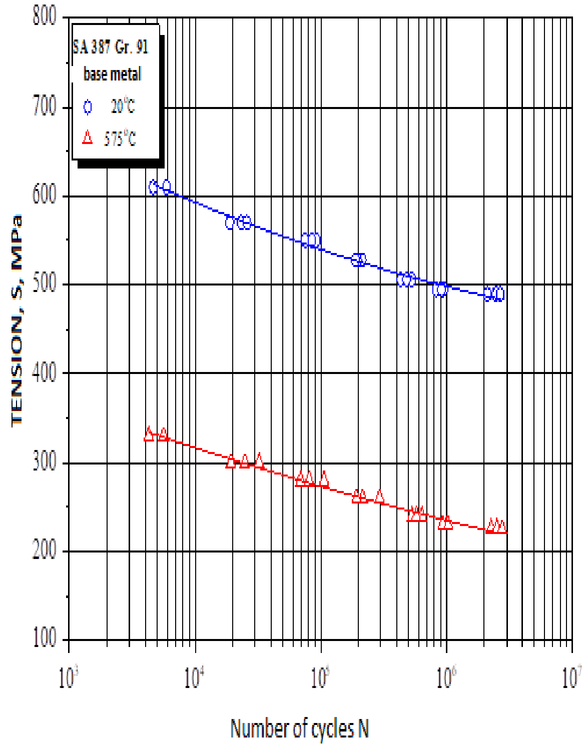

Figure 7. S-N diagram of tubes extracted from the base metal and tested at room temperature and at 575 ° C

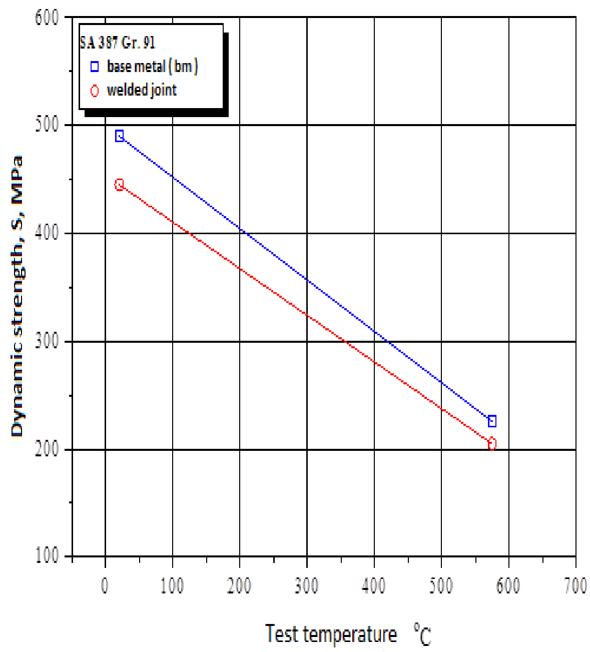

Figure 8. Change in the value of dynamic strength Sf at $2x10^6$ cycles depending on the test temperature

4. DISCUSSION AND CONCLUSION

Resistance to crack initiation decreases with increasing temperature, ie the tendency to fracture increases. This is more pronounced with a welded joint than with a base metal.

As the test temperature increases, the value of dynamic strength decreases at $2x10^6$ cycles for both the base metal and the welded joint. The dynamic strength, S_f, of the parent metal at room temperature is 490MPa, and at 575 ° C it is 226MPa. The situation with the welded joint is similar, at room temperature it is 445MPa, and at 575 ° C it is 205MPa.

When it comes to the welded joint, the dynamic strength value of 445 mpa is quite high, taking into account the potential heterogeneity of structural and mechanical properties of the welded joint. In support of these results is the place of fracture of the test tube. Namely, all broken tubes, tested at loads higher than the load of dynamic strength of the welded joint, burst either in haz or in wm (weld metal), and test tubes tested at loads close to the load of dynamic strength of welded joint burst in haz. Increasing the test temperature reduces the dynamic strength value at $2x10^6$ cycles. In this case, too, the welded test tubes were tested on loads bigger than the load of the dynamic strength of the welded joint were shot either in the haz or in the wm.

5. ACKNOWLEDGEMENTS

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QUALITY OF MACHINED SURFACE TOPOGRAPHY BASED ON CLAMPING ERROR AND DEVIATION OF MILLING TEETH

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Abstract: *As a metal machining process, end milling is the most widely used processes in industry.. In process of milling the quality of the machined surface depends of many factors, for example, tool geometry, cutter parallel axis offset and cutter axis tilt, tool deflection due to cutting forces, tool and work piece vibrations etc. This paper presents the development of mathematical model for determination of the quality of the machined surface topography. This experiment examined and analyzed the influence of the milling clamping error, as well as the error due to the radial deviation of the milling tooth teeth (which occurs due to fabrication, wear) on the generated part surface. The surface topography can be predicted on the basis of the mentioned model and dimensional and geometrical deviations can be determined, so immediately before processing, by measuring the parameters of clamping error and radial deviation of teeth.*

Key words: *mathematical model, surface topography, clamping error, milling teeth, radial deviation*

1 INTRODUCTION

Milling is the process of removing material from a workpiece in shape of small individual ships. As a metal machining process, end milling is the most widely used processes in industry. In process of milling the quality of the machined surface depends of many factors, for example, tool geometry, cutter parallel axis offset and cutter axis tilt, tool deflection due to cutting forces, tool and work piece vibrations etc.

Pioneer work on analytical determining of the cutting edge tool path in milling operations was given by Martellotti [1]. He brought up the parametric equations with trochoidal toolpath cutting tool edges and evaluated the elements such as the curvature radius of the tooth path, clearance and rake angles, tooth path lengths, radial thickness of the chip and their effect on the milled surface quality, power consumed, and the cutter life.

Up milling (UM) and down milling (DM) don’t use the same part of trochoidal tooth path while cutting because of different rotational moving tool directions, as presented on figure 1. At DM, the tooth mark height (height of roughness) marked with h_{down} is larger then the one at UM, h_{up} obtained with the same feed. Thus is the roughness bigger at DM then at UM [1]. The roughness height (h) is connected to the feed per tooth (f_Z), cutting tool radius (R), and the number of tooth (z) and can be determined from the next expression [2]:

$$h = \frac{f_Z^2}{8\left(R \pm \frac{f_Z \cdot z}{\pi}\right)} \quad (1)$$

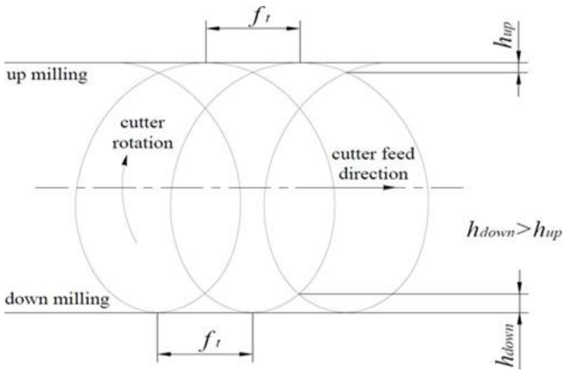


Figure 1. Trochoidal tool path in up and down-milling [2]

Kline et al. [3,4] study the error influence due to the cutter parallel axis offset on the tool teeth marks that due to the machining stay on the work piece surface. They allegate the generation of the heterogenity band and the concept of effective radius and develop the model for cutting geometry calculation and prediction of cutting forces with the cutter parallel axis offset effect of the work piece made out of aluminum 7075. Schmitz et al. [5], investigates the effect of cutter parallel axis offset on milling surface topography, surface location error, and stability in end milling. Li and Li [6] found that the change of cutter radius for a tooth relative to its preceding one is the most important factor in evaluating the effects of cutter runout. Babin et al. [7,8] developed the cutting model with cutter parallel axis which they added tool deflection due to cutting forces as well as the influence of cutter parallel axis offset on the surface roughness value change for different milling surface heigts at different spindle speeds to. Ismail et al. [9] performed the model taking into consideration cutter parallel axis offsets and included the effects of mill vibration and flank facewear and analyzed the irregularities in feed marks. Raganath and Sutherland [10] present a three-step methodology for runout estimation, including cutter grind, parallel axis offset, and cutter tilt in peripheral milling. Gao et al. [11] developed meshindependent direct computing method. The simulation of machined surface topography is carried out for both end and ball-end milling processes. Stori et al. [12] besides cutter parallel axis offsets take into consideration cutter axis tilt and perform machining parameter optimization for peripheral finish milling operations. Ryu et al. [13] cutting forces and tool deflections are calculated considering tool geometry, tool setting error (parallel axis offset and cutter tilt) and machine tool stiffness in side wall machining under various cutting conditions generally used in die and mold manufacturing. Also the characteristics and the difference of generated surface shape in up milling and down milling are discussed.

Omar et al. [14] developed the model that includes the effects of tool runout (parallel axis offset and cutter tilt), tool deflection, system dynamics, flank face wear, and the tool tilting on the surface roughness. Arizmendi et al. [15] placed the general model for tool path end mill determination over transformational matrixes, taking in consideration parallel axis offset and cutter tilt. They comprehensively analyze the occurence of roughness heterogeneity bands on milled surfaces. In the next work Arizmendi et al. [16] in the model equations of the cutting edge paths added tool vibrates during the cutting process. The model allows prediction of the topography, the roughness values and the form errors of the milled surfaces. Arizmendi et al. [17,18] performed model effects of two factors that produce tool runout: tool setting errors and cutter grinding errors. They continue to analyze heterogeneity bands in the new-occuring conditions as well. Ehmann and Hong [19] develop the model (called surface-shaping system) for prediction of the topography of the milled surface over the influence of tool runout, machine deformation and vibration, as well as higher order motions over transformation matrixes.

2 MATHEMATICAL MODEL OF THE MILED SURFACE

Definitive equations of point movement that takes in consideration the error of tool setting through the parallel position change and axis tilt in the function of angle rotation α shown in matrix shape is obtained by replacing matrixes (2). Surface topography obtaining requires simulation of teeth paths for getting the roughness profile in every plane π_i. This simulation includes calculating position (*x*,*y*) every cutting edge point on discrete feed of rotation angle α. To generate a roughness profile on height *z*i, intersection points between cutting edge paths have to be specified, and to know which tooth leaves its trail on a workpiece, a comparison must be carried through stages. Once when the roughness profile on every plane π along axial depth is established, all profiles are combined to form a surface topography. From figure 2-a all teeth marks can be noticed, and that from those 4 teeth only 2 perform cutting, or that to a certain height (*z* border I) only 1 tooth cuts (tooth *4*), and from the next border (*z* border II), and further cutting is done by only 1 tooth, and that is tooth 4. In the area between these borders they are changing. This crossing is called transition mark, and the appearance is called heterogeneity band (Figure 2-b).

$$\begin{bmatrix} x_{P(a,k)}^{(\alpha)} \\ y_{P(i,k)}^{(\alpha)} \\ z_{P(i,k)}^{(\alpha)} \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 & \dfrac{f}{2\pi}\alpha \\ -\sin(\alpha) & \cos(\alpha) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & \rho \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\phi) & -\sin(\phi) & 0 & 0 \\ \sin(\phi) & \cos(\phi) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \cos(\tau) & 0 & -\sin(\tau) & L\cdot\sin(\tau) \\ 0 & 1 & 0 & 0 \\ \sin(\tau) & 0 & \cos(\tau) & L\cdot[1-\cos(\tau)] \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\lambda) & -\sin(\lambda) & 0 & 0 \\ \sin(\lambda) & \cos(\lambda) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} R\cdot\cos\left[\left(L-\dfrac{(L-z_i)}{\cos(t)}\right)\dfrac{\tan(\omega)}{R}+(k-1)\dfrac{2\pi}{N_t}\right] \\ R\cdot\sin\left[\left(L-\dfrac{(L-z_i)}{\cos(r)}\right)\dfrac{\tan(\omega)}{R}+(k-1)\dfrac{2\pi}{N_t}\right] \\ L-\dfrac{(L-z_f)}{\cos(\tau)} \\ 1 \end{bmatrix}$$

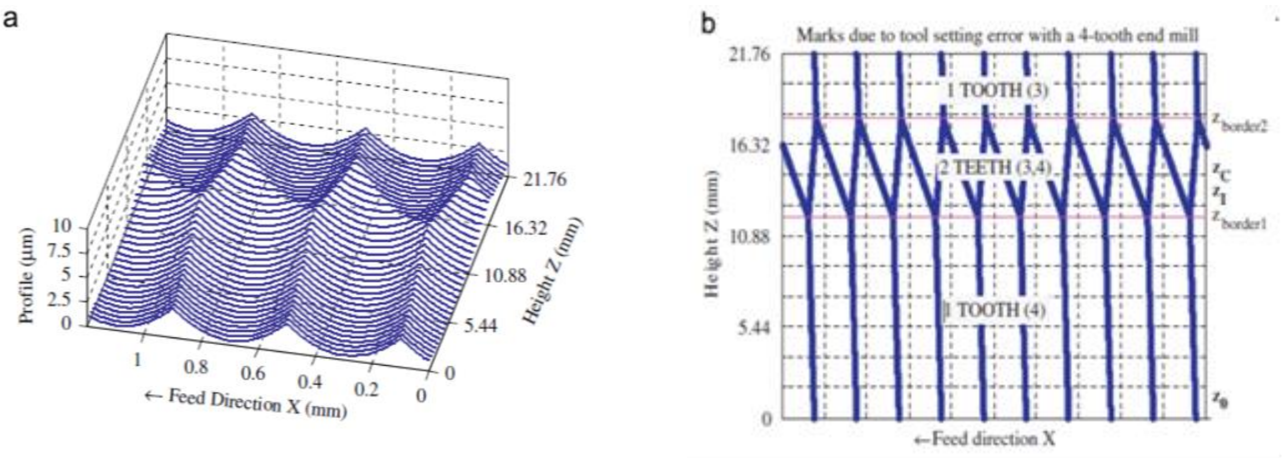


Figure 2. Topography of the milled surface [16]

The main cause of measurement deviations is its production. As well as every other machine element, the tooth mirror measures are given at construction in certain tolerances and regardless on the fact that those tolerances can be very narrow, it can happen that in milling with small feed some of mill teeth do not pursue cutting. The same applies to over sharpened mills [20]. Regardless if the mistake happened due to bad setting of the mill or due to development (or sharpening), if e.g. two teeth don't cut at all, the tooth that comes after them will process three times larger amounts of materials then it had to, so the resistances on that tooth will be much larger then expected, process of wearing more intensive, and the quality of the processed surface will be worse and more rough. Measuring deviations of milling edge can be brought down on three basic[7]: radial ($\Delta_{r,i}$), tangential ($\Delta_{t,i}$) and axial ($\Delta_{a,i}$), ($i \epsilon 1,..,Nk$) (Figure 3), that format adequate angle deviation: ($\Delta\alpha_{k,k-1}$ = (k-1)$2\pi/N_t - \alpha_{k-1,k}$

On figure 3 a view from top of a mill with 4 teeth is shown. Hypothetically measuring deviations of a mill were selected so that the tooth 1 has no deviations. Tooth 2 contains only radial deviations, while teeth 3 and 4 contain radial and tangential deviations. Specified deviations cause reduction or increase of angle α that in a ideal mill, with a mill that has 4 teeth is 90°. Axial deviations of tooth measures (deviations along mill axis) is not shown on the figure but can be assumed. If the teeth don't have same elevation, height in comparison on some referent horizontal plane, or rather, some of mentioned teeth are not lying in the horizontal plane and unevenly are apart from it, among them is present axial measure deviations.

Although it's clear that their influence exists, here the influence of tangential and axial deviations is neglected, because it's assumed that, in difference of radial, they don't have considerable influence on topography of the milled surface at an extensive milling.

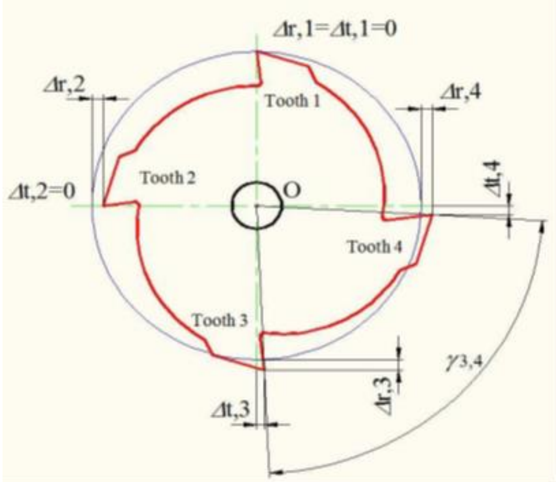


Figure 3. Example of measurement deviations of a 4 tooth mill [20]

To bring in the influence of radial deviations a pre-made model that takes in consideration the errors of setting the mill, primarily we will derive an expression for an effective cutting edge radius that takes the pre-specified error parameters of tool setting, and then introduce in the same the error due to mill measurement deviations.

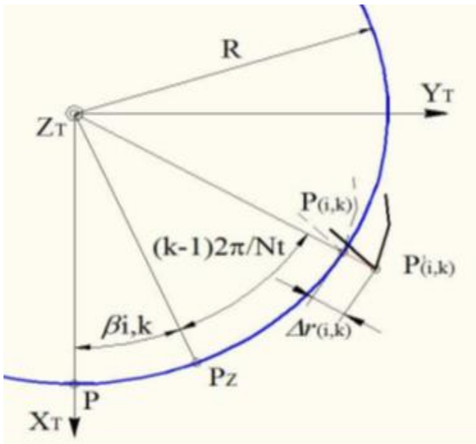


Figure 4. Radial deviation of the point $P(i,k)$ on the cutting edge[21]

The influence of tooth radial deviations on generating a milled surface is obtained by a simple addition of their values into the equation (2). By adding radial deviation $\pm\Delta r(i,k)$, point $P(i,k)$ moves to position $P'(i,k)$ (Figure 4).

It is important to say that with the specified process some assumptions were made because of the clearly insignificant errors and easier calculations, so: $\pm\Delta r(i,k) = \pm\Delta' r(i,k)$. Also neglected was the change in mill diameter due to radial deviations by height *z*i. So we get the matrix of coordinates of the point deviations on the cutting edge of the mill tooth *P*α*Δ*(*i,k*) that takes in consideration the deviations due to mill error settings and radial tooth deviations (3).

$$\begin{bmatrix} x^{(\alpha)}_{P\Delta(i,k)} \\ y^{(\alpha)}_{P\Delta(,k)} \\ z^{(\alpha)}_{P\Delta(i,k)} \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 & \frac{f}{2\pi}\alpha \\ -\sin(\alpha) & \cos(\alpha) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & \rho \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\phi) & -\sin(\phi) & 0 & 0 \\ \sin(\phi) & \cos(\phi) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\tau) & 0 & -\sin(\tau) & L\cdot\sin(\tau) \\ 0 & 1 & 0 & 0 \\ \sin(\tau) & 0 & \cos(\tau) & L\cdot[1-\cos(\tau)] \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\lambda) & -\sin(\lambda) & 0 & 0 \\ \sin(\lambda) & \cos(\lambda) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \left(R \pm \Delta r_{(i,k)}\right)\cdot\cos\left[\left(L - \frac{(L-z_i)}{\cos(\tau)}\right)\frac{\tan(\omega)}{R} + (k-1)\frac{2\pi}{N_t}\right] \\ \left(R \pm \Delta r_{(i,k)}\right)\cdot\sin\left[\left(L - \frac{(L-z_i)}{\cos(\tau)}\right)\frac{\tan(\omega)}{R} + (k-1)\frac{2\pi}{N_t}\right] \\ L - \frac{(L-z_i)}{\cos(\tau)} \\ 1 \end{bmatrix} \quad (3)$$

Experiment in this paper examined and analyzed the influence of the milling clamping error, as well as the error due to the radial deviation of the milling tooth teeth (which occurs due to fabrication, wear) on the generated part surface. The clamping error takes into account the parallel displacement of the milling axis as well as the inclination of the milling axis in relation to the axis of the working spindle of the machine. The error of making or wearing the teeth of the milling cutter means changing the radius of each tooth of the milling cutter individually. The surface topography was obtained using the model given in Chapter 2 (Equation 3) using MatLAB software and compared with the measured and recorded (camera) surface roughness profile.

3 MATERIALS AND EQUIPMENT

Experimental tests were performed on a 3-axis vertical milling machine HAAS TM-1 with three CNC controlled axes (Figure 5), which is located at the Faculty of Engineering, University of Kragujevac within the laboratory for production machinery. The characteristics of the Haas TM-1 vertical milling machine are: X-Y-Z axis range: 762-305-406 mm, maximum speed 4000 rpm, auxiliary axis speed 5.1 m / min, total power 5.6 kW.

Figure 5. HAAS TM-1 milling machine

The tool used is a spindle cutter made of hard metal (VHM): diameter 15 mm, cutting length 28 mm, overhang length 50 mm, total length 84 mm, angle coils 30 ° and the number of teeth 4. The selected milling cutter has a larger diameter for the reason that the effect of tool deflection minimized, as well as to make tooth marks more visible. The machined part is a prismatic plate made of aluminum alloy 6005A-T6 dimensions 135x100x25 mm on which prismatic protrusions (Figure 6) with dimensions of base 20x20 mm and height 16 mm are made on one side. The shoots (preparations) were made with a spindle cutter with a diameter of 20 mm (high stiffness) with a larger number of passes. In this way, shoots of the correct dimensions were obtained without deviations due to possible bending of the tool. It is assumed that the errors due to other machining factors are equal to zero, that the machine-tool-clamping system is absolutely rigid.

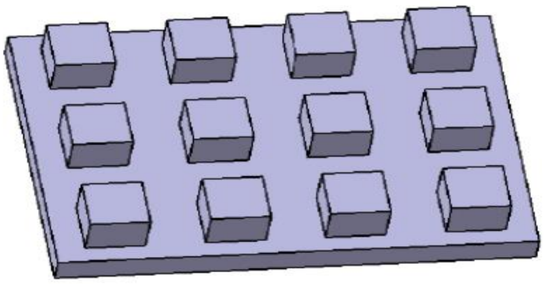


Figure 6. CAD model of part

The surface topography (images and equations of the milling tooth path) was obtained by application model listed in Chapter 2 (Equation 3) using MatLAB R2015a software.

Figure 7 shows the parameters that define the error of placing the cutter in clamping sleeve, as follows: parallel displacement of the vertex axis from the axis of the working spindle (ρ, mm), angle of inclination of the cutter axis from the axis of the working spindle (τ, o), tooth placement angle 1 s with respect to the x-axis (ϕ, o) and the placement angle (λ, o) of tooth 1 with respect to the plane Rt. On the picture is marked with XSYSZS coordinate system of the working spindle, while XTYTZT – coordinate a milling system that takes into account these deviations.

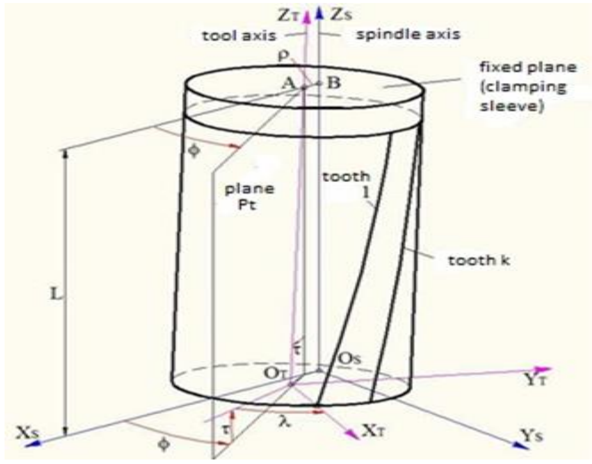


Figure 7. Tool placement error parameters and radial tooth deviation

Ejection of the cutter from the axis and its beveling was done by inserting supports of appropriate thickness. The method of placing the supports is shown in Figure 8.

The radial deviation of the teeth Δr (i, k) (Figure 9-b) of the cutter represents the radial displacement of the point of the cutting edge tip (from P (i, k) to P` (i, k)) in the radial direction. These deviations were measured with a comparator at a height of Z = 3 mm and Z = 13 mm (Figure 9-a and Figure 9-b).

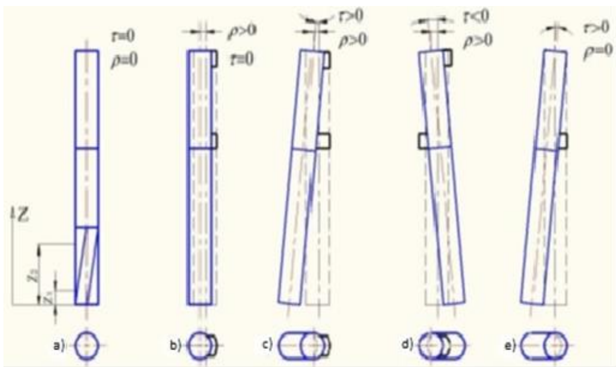
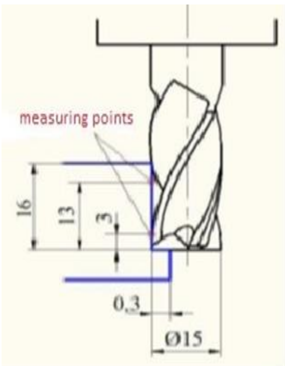


Figure 8. Variants of the clamping error experiment

[a]



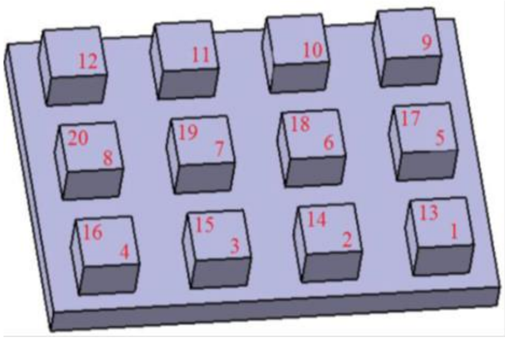
[b]

Figure 9. Plan for measuring radial tooth deviation

Surface roughness was measured with a TALYSURF-6 measuring system connected to a computer, and the results are shown in the diagrams using Microsoft Excel software. Roughness was measured at the height of Z = 3 mm and Z = 13 mm of the shoot. The roughness of the characteristic surfaces was photographed with a magnifying digital camera EHEV1-200USB DIGITAL PEN (Figure 10). The features of this camera are: high-quality CMOS sensor with 2 MP, resolution 1600x1200, USB2.0 port, number of frames per second 30, magnification of 1-400h and focus 10mm - ∞.

Figure 10. EHEV1-200USB DIGITAL PEN camera

The machined parts, the surfaces of the machined parts are flat protrusions of prismatic shape, of the same dimensions, previously machined to the dimension 20x20x16 mm. Figure 11 shows the CAD model of the part with the processing plan. The lateral (front according to the picture) surfaces of the shoots (1, 2, ..., 12) and the lateral (last according to the picture) surfaces of the shoots (13, 14,..., 20) were processed.



[a]

[b]

Figure 11. Shoot processing plan and processed part

All shoots were processed by counter-milling. Processing was performed with a speed of 200 rpm, while the step per tooth is variable.. The cutting width (axial depth) is 16 mm for all machined shoot surfaces. The cutting depth (radial depth) for all machined surfaces is 0.3 mm.

The experiment was performed in 5 clamping variants. The first variant (Figure 12-a) takes into account only the error of the radial deviation of the tooth. In the second case (Figure 12-b), the axis of the cutter is shifted by the value $\rho > 0$, the placement of the teeth is $\lambda > 0$, while the other parameters of the clamping error are equal to zero. The third variant (Figure 12-c), in addition to the positive parameter ρ, introduces the bevel of the axis $\tau > 0$. In the fourth case (Figure 12-d), the axis of the cutter was shifted by the value ρ> 0, while the bevel was performed on the opposite side τ<0, and the angle setting ϕ is positive. In the fifth clamping (Figure 12-e), the cutter is not moved from the axis (ρ = 0), while the bevel is present (τ> 0).

The measured values of the radial deviation of the teeth at a height of 3 mm and a height of 13 mm, measured from the tip of the milling cutter, are given in Table 1.

Table 1. Values of radial deviation of milling teeth

Height	Tooth	Deviation Δr,mm
Z=3mm	1	0,002
	2	-0,009
	3	-0,014
	4	-0,014
Z=13mm	1	0,002
	2	-0,009
	3	-0,012
	4	-0,017

The values of the variable machining parameters (steps) and clamping error parameters are given in Table 2.

Table 2. Values of the variable machining parameters

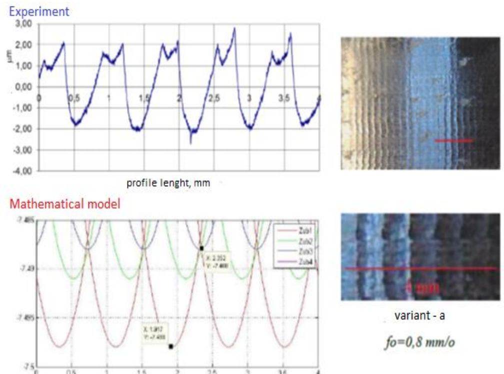
variant	a	b	c	d	e
Fo,mm/o	0,8	0,8	0,8	0,8	0,8
P, mm	0	0,005	0,005	0,005	0
τ°	0	0	0,005	-0,005	0,005
ϕ°	0	0	0	90	0
λ°	0	45	0	0	0

4 RESULTS AND ANALYSIS OF RESULTS

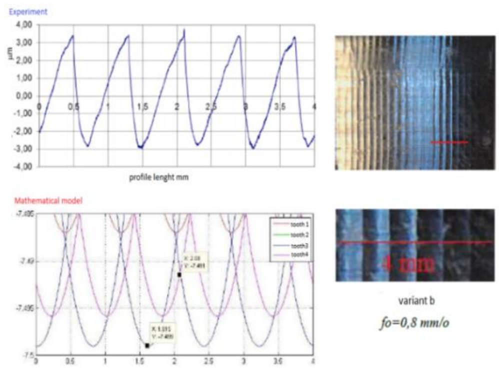
The lines of tooth movement were obtained using the mentioned model. The surface roughness was measured with a roughness measuring device. The camera photographed the treated surfaces.

The following figures (Figures 12-a, b, ..., e) show the test results for research variants. The measured surface roughness profile during the experiment is shown at the top left. At the bottom left are the lines of tooth movement obtained using a mathematical model. The photo of the treated surface is shown at the top right, and below it is an enlarged segment of the measured length of the profile (marked with a red line). The figures refer to step values of 0.8 mm. This step values are shown for better visibility and to match the measured roughness values with the curve obtained from the model. The height of the shoot at which the roughness was measured is 13 mm. The curves obtained using the model also refer to a height of 13 mm. The length of the profile measurement is 4 mm.

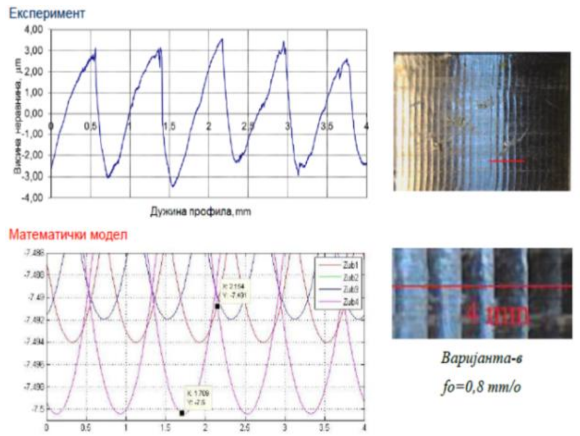
Variant A (Figure 12-a) shows how the radial deviation of the tooth affects the generation of surface topography. By observing the curves obtained with the help of models, which simulate the paths of teeth with a step of 0.8 mm / o (Figure 12-a), it can be concluded that two teeth participate in the cutting (and the third, whose influence is insignificant). Tooth 1, which carries the least deviation, is the most influential tooth. Tooth 2 covers part of the surface of the part, while tooth 3 slightly affects the topography. The impact of tooth 2 and tooth 3 becomes greater by increasing the steps from 0.8 mm. A decrease in surface roughness can also be noticed (read) due to the engagement of more teeth.



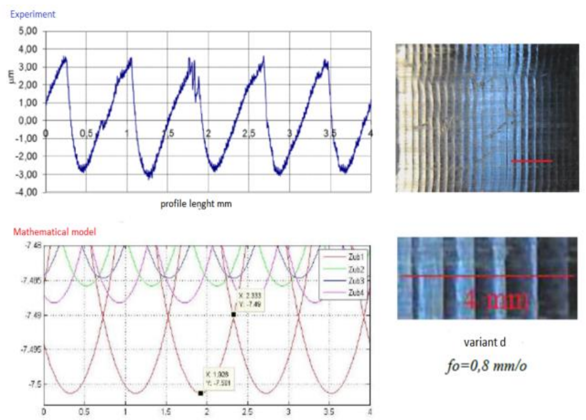
12-a



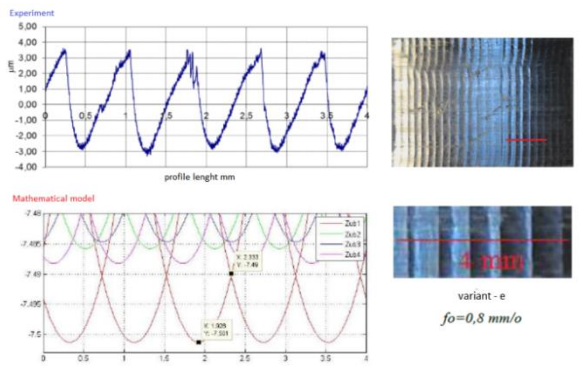
12 -b



12 – c



12-d



12– e

Figure 12. The radial deviation of the tooth affect on the generation of surface topography

5 CONCLUSION

Based on the results of experimental tests, the correctness of the mathematical model for determining the surface topography was confirmed.

Since the model monitors the position of tooth movement in space, it is possible to measure the calculated heights of irregularities (roughness) left by the teeth. In addition, by measuring the lateral movement of the tooth, the deviation from the desired depth of cut, it is possible to measure the dimensional deviation. It is possible to monitor the movement of the tooth path along the height, and thus to measure the calculated geometric deviations.

As the surface topography can be predicted on the basis of the mentioned model and dimensional and geometrical deviations can be determined, so immediately before processing, by measuring the parameters of clamping error and radial deviation of teeth, the quality of machining can be improved.

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STRENGTH ANALYSIS OF THE WINDOW PROFILES MADE OF POLYVINYL CHLORIDE (PVC)

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Abstract: *This paper presents research results related to the study of the resistance of polyvinyl chloride (PVC) profiles to the side wind gusts and longitudinal loads during the handling and installation of windows, as well as to study how the use of the recycled material within the window profiles affects the strength of the profile. ALTERRA PVC profiles were used for the research. Profiles were made by the extrusion at GMT system line, followed by the post processing, and joining by welding at Murat Makina system. Flat and angular profiles were investigated. One group of samples was made from non-recycled PVC, while recycled material was applied as the inner layers to make the second group of samples. A universal testing machine was used for testing. The obtained results showed that the tested samples have good resistance to compression.*

Keywords: *Polyvinyl chloride (PVC), Window profiles, Extrusion, Welding, Wind load, Compression test.*

1. INTRODUCTION

Polyvinyl chloride (PVC) is one of the most suitable materials resistant to weathering, chemical degradation, corrosion, shock, and abrasion and it is used in many industries [1]. Parts made of PVC have low weight, are resistant to wear, have good mechanical strength and toughness [2,3]. PVC is used to make pipes, profiles for windows, doors, and shutters, floor coverings, roof membranes, cable insulation, PVC sheets, medical products such as blood bags, and infusion tubes [4-7].

Polymer materials, including PVC, are made in the form of powder, flakes, granules, grains, or resins, and their processing into finished products is performed by processing routes such as: pressing, extrusion, extrusion injection, extrusion blowing of hollow bodies, calendering, soaking (lamination). PVC window profiles are connected to each other by welding, directly or indirectly (by using the welding wire) [4,8]. When the plastic mass is in a thermoplastic state and by the action of pressure, a joint occurs.

In the papers [5, 8-9], the angles of PVC windows obtained by welding from extruded profiles were considered. Welding was performed using different temperature values and with different clamping forces [5]. The test specimens prepared in this way were cut in accordance with the standard, and then their mechanical properties were determined and analysed [5].

The material from which the frames are made determines the appearance, endurance, durability, thermal and acoustic insulation characteristics of the window. The profiles are exposed to different types of loads during installation and operation, such as tension and static torsion; forces during opening and closing as well as the wind gusts. When the window is moved or closed, the air and wind is stopped by its surface, hence the dynamic energy of the wind is transformed to a pressure. The pressure acting on the surface transforms into a force. Wind, as a manifestation of the movement of air masses, is characterized by the intensity of its speed and direction [10-12]. Wind load calculators can be used to measure the load acting on both the window and the window profile [13].

2. MATERIALS AND METHODS

For the production of PVC window profiles, a mixture of materials of the following composition was used: 85% of PVC powder and 15% of the micro-ingredients including heat stabilizers, pigments, TiO2, lubricants, impact modifiers, processing aids, UV stabilizers, and fillers.

2.1 Production of the PVC window profiles

To obtain the profile, a PVC Ceiling Panel Extrusion Machine SJZ65 + YF600 from Kunshan Bonzer was used (Figure 1a). The technical characteristics are given in Table 1. Extrusion is the process of converting thermoplastic powder into a continuous product by softening the material through a mould.

In order to obtain the correct dimensions, the profile was transported through the calibration moulds and processed. After that, the profiles are cooled in special moulds. The profiles obtained by this procedure are shown in Figure 1b.

Table 1. Technical characteristics of SJZ65+YF600 production line

Power Supply	380 V, 50 Hz, 3-phase or customized
Extruder	SJZ65/132
Screw Diameter	Φ 65/132 mm
Heating Power	4 zones, total 19 kw
Main Motor Power	37 kw
Extruder Dimension	4250 mm x 1500 mm x 2150 mm
Extruder Weight	3500 kg
Output	200-250 kg/h
Max Product Width	600 mm

Figure 1. Extrusion Machine - a and PVC profiles - b

After extrusion, the next stage is cutting the profile. When cutting the profile, the quality of the cutting edges was taken into account, so that no additional processing is required before welding. The profile was cut at Murat TT 405 machine (Figure 2a).

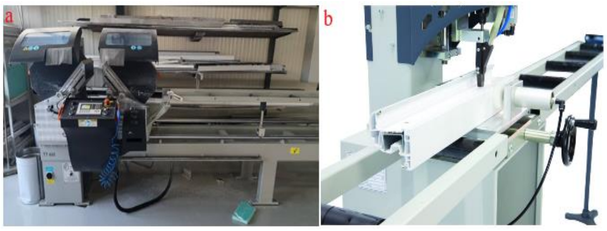


Figure 2. Murat TT 405 machine – a and Murat DV 404 machine - b

Specially profiled steel reinforcement is cut to the appropriate length, and then placed in the cavities of the PVC profile and screwed using Murat DV 404 machine (Figure 2b). Drilling of the openings for handles, locks, as well as the drainage and ventilation openings, was performed at Murat FT 386 machine (Figure 3a).

The interconnection of the machined formed profiles was performed at Murat KC 258 welding machine (Figure 3b). The welding parameters are given in Table 2. The thickening that occurs during the welding process was not removed from the samples used for testing.

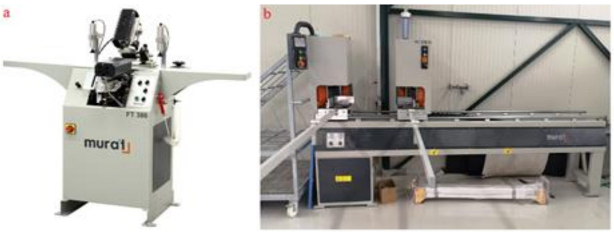


Figure 3. Murat FT 386 machine – a and Murat KC 258 machine - b

Table 2. Welding parameters

Welding temperature	250 °C
Clamping pressure	0.5 Mpa
Welding pressure	0.4 Mpa
Joint pressure	0.5 Mpa
Welding time	25 s
Joint time	30 s

2.2 Production of PVC window profiles

Profile testing was performed at the universal mechanical testing machine (Figure 4). The machine consists of four basic functional parts (a device for creating, transmitting, and registering force, and a device for measuring deformation). The loads that can be realized on this machine are in the range 0 - 20 000; 0 - 50 000 and 0 - 100 000 N. The machine has a device for automatic diagram drawing. The force exerted in the test is read on an appropriate scale and transmitted in proportion to the chart paper. The test parameters are given in Table 3.

Table 3. Test parameters

Load range [N]	Sample label	Test temperature	Test speed [mm/min]
0-20000	WN, GN	room	10
0-50000	WL, GL	room	10
0-100000	WCN, GCN, GC	room	10

According to the type of material from which the test samples are made, we divide them into two groups (Figure 5). Figure 5a shows a sample made without recycled material, and Figure 5b shows a sample made with a proportion of recycled material.

Figure 4. Universal mechanical testing machine

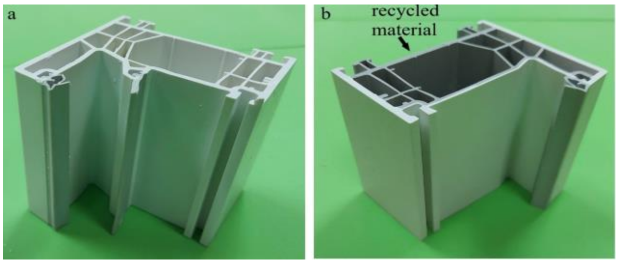


Figure 5. The appearance of test samples made: a) without recycled materials and b) with the share of recycled materials

The samples were cut from the side parts of the profile (flat samples) Figure 6a, as well as by welding the two side parts of the profile (corner samples) of Figure 6b.

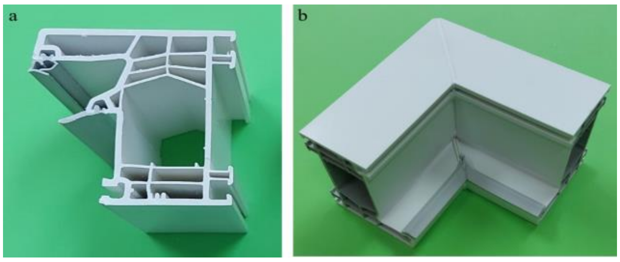
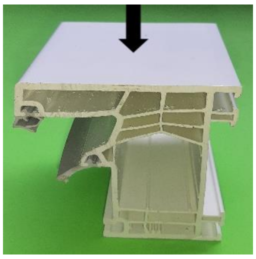
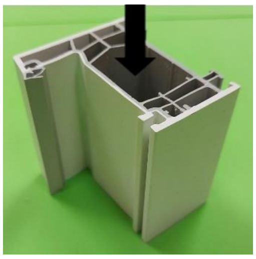


Figure 6. The appearance of flat and angular patterns: a) flat patterns, b) angular patterns

The plan of the experiment is given in Table 4, showing the materials used in samples, and load directions applied on the samples.

Table 4. Experimental plan

Test No.	Sample label	Material	Load direction	
1	WN	without recycled material		normal
2	GN	with recycled material		normal
3	WL	without recycled material		longitudinal
4	GL	with recycled material		longitudinal
5	WCN	without recycled material		normal
6	GCN	with recycled material		normal
7	GC	with recycled material		

The test is designed to investigate the loading of the window frame exerted by the wind gusts, with a loading direction perpendicular to the direction of extrusion (Table 4. tests 1,3,5). The action of force along the extrusion direction is examined by how much maximum loads during assembly and handling can withstand both the individual profile and the assembled window (Table 4. tests 2,4,6). The load direction in test 7, shown in Table 4, is a standard test (EN 12211) for testing of the welded joints of window profiles. An overview of the above sample tests is given in Figure 7, showing the samples within the testing device – compressive tests, with different directions of the loading on the different samples. The position of the samples was designed to provide load action within the central zone of the sample upper surface.

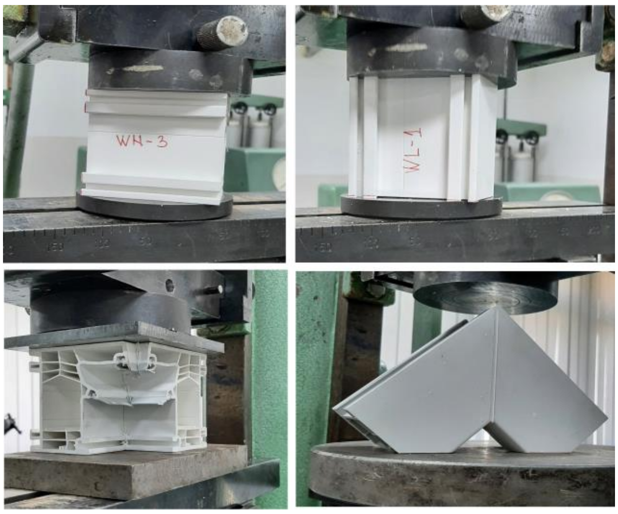


Figure 7. Demonstration of the sample testing

3. RESULTS AND DISCUSSION

3.1 Flat test samples (WN and GN) loaded under normal force

Figures of the samples after the pressure test are shown in Figure 8. It can be noticed that both groups of samples suffered the greatest deformation in the central part. Samples without recycled material (Figures 8a and 8b) deform towards the inside when pressed (Figure 8b). Samples with recycled material (Figures 8c and 8d) deform towards the outside when pressed (Figure 8d). Based on the values of the maximum load (Table 5), for these two groups of samples, it can be concluded that higher resistance to compression is shown by samples made by using the recycled material. Also it can be noticed that the values of the maximum load at WN test samples are grouped in a smaller range (4100 N - 4250 N) while the load range of the GN test samples is much larger (5000 N - 5750 N).

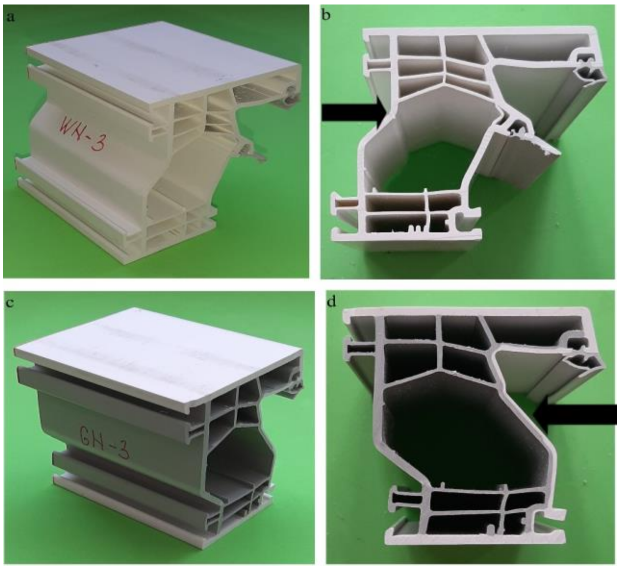


Figure 8. Test samples WN-3 (a, b) and GN-3 (c, d) after the testing

Table 5. Maximum load values

Sample label	Maximum load values [N]
WN-1	4100
WN-2	4250
WN-3	4150
GN-1	5050
GN-2	5000
GN-3	5750

The resulting compression diagram for these two groups of samples is given in Figure 9.

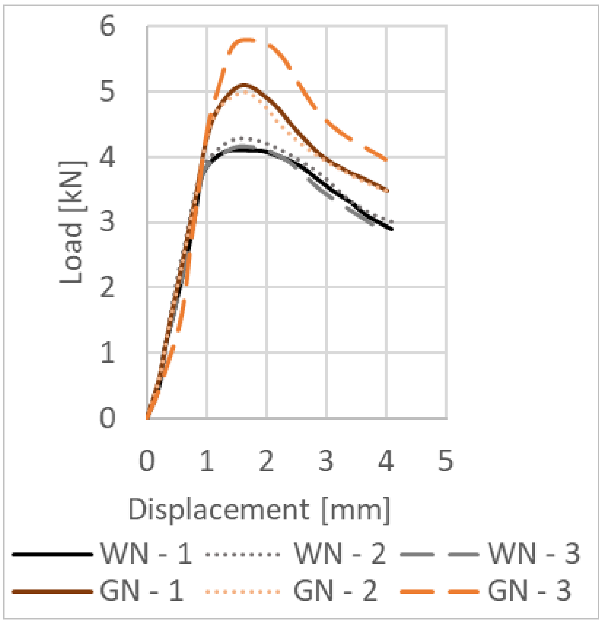


Figure 9. Load-displacement diagram for samples WN and GN

3.2 Angular test samples (WCN and GCN) loaded with normal force

Figures of the samples after the compressive test are shown in Figure 10. It is noticed that in both groups, the samples cracked in the welded joint (Figure 10). From Figure 10, it can be seen that after removing the sample from the machine, the elastic deformation disappears (Figure 10b, d).

Figure 10. Test samples WCN-2 (a, b) and GCN-1 (c, d)

In this group of test samples, based on the value of maximum load, it can be concluded that samples made using recycled material showed higher resistance to compression. The values of the maximum load for WCN samples ranged from 10400 N to 10600 N, while for GCN test samples these values ranged from 18 550 N to 18 900 N.

To calculate the wind load, a WIND LOAD CALCULATOR was used that takes into account wind speed, air density, window area, and the angle at which the wind blows. The wind speed was determined on the basis of the Beaufort scale. It should also be noted that the average maximum wind strength in Serbia on the Beaufort scale is 7 and 17.1 m/s, respectively, while in the world there are hurricane winds of 12 or ≥ 32 m/s. The air density is 1.225 kg/m3. Regarding the surface of the window, three standard dimensions were taken into account. The highest value of the load due to the wind action, is when the wind blows at a right angle, and for this reason, 90% is taken as the value of the angle. The values of the wind loading are given in Table 6.

Table 6. Maximum load values

Window dimensions	Wind strength		Wind load [N]
0.52 m x 0.6 m	17.1 m/s	32 m/s	3.88 - 195.5
1.2 m x 1.2 m			257.9 – 903
2 m x 1.4 m			501.5 – 1756

3.3 Flat test specimens (WL and GL) loaded with longitudinal force action

Images of the samples after the compressive tests are shown in Figure 11. In contrast to the previous groups of test samples, where higher resistance to the compression was shown by samples where recycled material was used, in this group of samples, higher resistance to compression was shown at samples without recycled material. The value of the maximum load for WL test samples ranged from 51,500 N to 54,800 N, while for GL samples these values were slightly lower, 46,600 N - 48,200 N. The deformed samples can be seen in Figure 11.

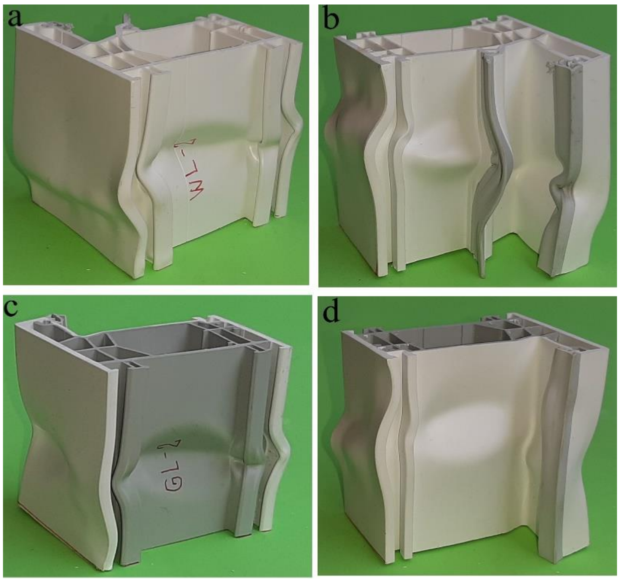


Figure 11. Test samples WL and GL, after the testing

The resulting compression diagram for these two groups of samples is given in Figure 12.

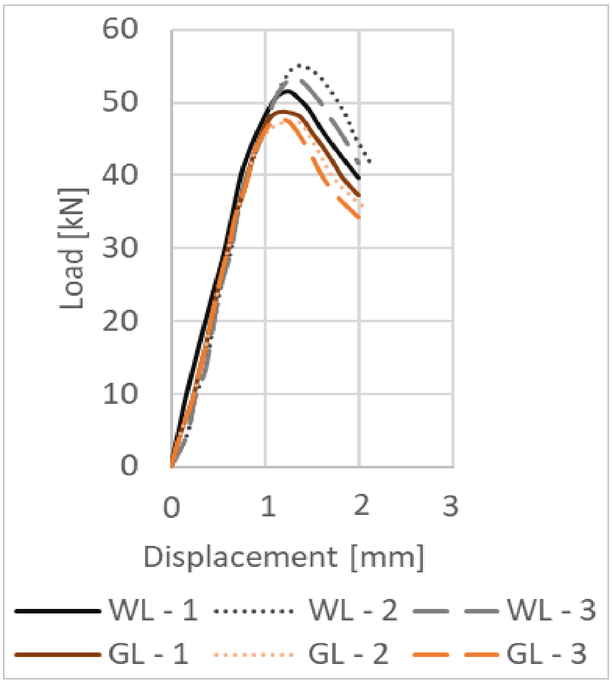


Figure 12. Load-displacement diagram for WL and GL samples

3.4 Angle test of the sample GC

Figures of the samples after the pressure test are shown in Figure 13. From the Figure, it can be seen that during the loading there was a complete separation of the profile along the welded joint. The separation of the samples occurs when the compressive load overcomes the friction force achieved by the test sample with the pressure plates of the machine. In another research [5], the profile was broken, not completely separated, because during that testing there was no friction between the samples and the pressure plate, only rolling friction occurred. The maximum load values ranged from 14650 N to 14700 N.

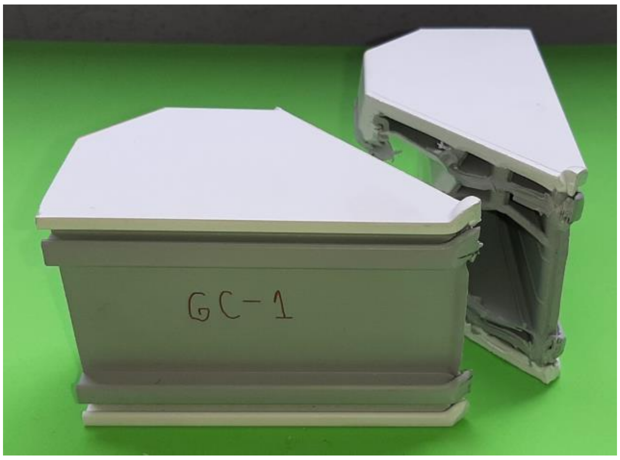


Figure 13. GC test samples after testing

4. CONCLUSION

In this work, the samples containing recycled material were used, and samples made without the use of recycled material. Flat and angular profiles were examined.

The results of this study showed that the following conclusions can be made:

- When the load is perpendicular on the extrusion direction, better characteristics were shown by the samples made of recycled material;
- When the load direction is parallel to the direction of extrusion of the profile, better characteristics were shown by samples without recycled material.
- It can be concluded that windows tested in this work, whether made with or without the recycled material, can withstand even gusts of hurricane-force winds.

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DIRECT INVERSE CONTROL OF TWO-TANK SYSTEM USING NEURAL NETWORKS

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Abstract: *In this paper, the implementation of the controller based on neural networks for controlling two-tank system is presented. A ready-made mathematical model of the Amira DTS200 system, which is a typical example of a slow nonlinear process, is used. Among the most important applications of artificial neural networks is their application in the control of nonlinear processes. The applied controlling structure represents Direct Inverse Control. Experimental results of the obtained process response for a given reference input using implemented inverse controller are given.*

Keywords: *Neural Network, Direct Inverse Control, Two-Tank System.*

1. INTRODUCTION

Linear algebra offers a multitude of various tools for linear process analysis and control. Consequently, the assumption of system linearity is often conveniently used in order to apply a certain control theory that achieves the desired behaviour of linear processes. However, most real-word systems are nonlinear in nature, and the use of linear models often cannot "capture" the complex dynamic behaviors of nonlinear systems. Conventional methods of modeling and control of dynamic processes try to form a physically based mathematical model that is close to the input-output relation of the observed real system. In practice, this usually involves engineering assumptions to obtain simpler system models, which require extensive experience and often result in poorer controller performance. On the other hand, modeling and control of nonlinear systems involve specific problems, with no simple and unified theory available.

Neural networks provide an alternative approach to the identification and control of nonlinear processes in process engineering [1]. Process modeling using neural networks does not require a priori knowledge of physical process phenomena. Instead, neural networks learn by using data to extract existing templates, i.e., patterns that describe the relationship between inputs and outputs regardless of the physical nature of the process. The neural network has been trained when the appropriate inputs are applied, through which it acquires knowledge of the process environment. As a result, the neural network adapts itself according to information that can be called up later. Neural networks are able to perform fast processing of complex nonlinear problems and reduce the engineering effort required to develop an appropriate controller. The possibility to approximate an arbitrary continuous nonlinear function up to the desired accuracy is their most important feature from the point of view of modeling, identification, and control of nonlinear processes.This paper is divided into five sections. In Section 2, the two-tank system and the theoretical setup of the neural network model are described. The design of the controller using a neural network is presented in Section 3. Experimental results are presented in Section 4. Final conclusions are given in Section 5.

2. THEORETICAL BACKGROUNDS

Figure 1 shows a simplified representation of the controlled system, which consists of two tanks of equal height and cross-sections *A* [2]. The water is pumped into the first tank, from where it flows into the second tank via a pipe, with the cross-section of the pipe regulated via a valve a_1. The second tank has a drainpipe, the cross-section of which is regulated by the second valve a_2. Pump pressure u, which regulates the inflow of water into the first tank, is a manipulated variable, while the water level h_2 in the second tank is the controlled variable. Valve openings are herein considered as system disturbances.

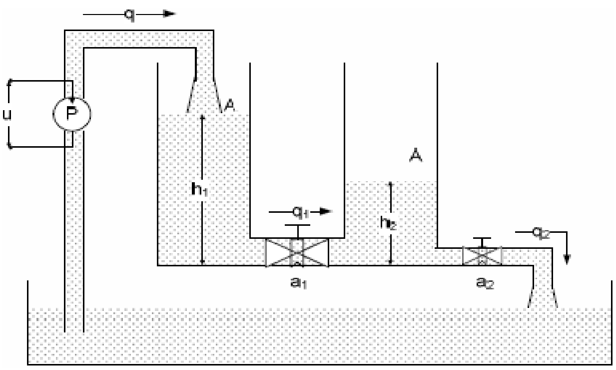

Figure 1. Schematic representation of a two-tank system

A ready-made nonlinear model of the Amira DTS200 system was used as a process model in this paper. Due to the fact that there is a nonlinear model, which very faithfully describes the actual process, all simulations were performed on this nonlinear model, which was realized in Simulink [3], Figure 2.

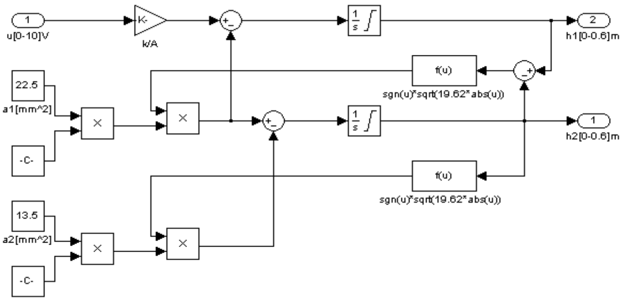

Figure 2. Simulink model of the two-tank system

2.1 Neural Network

For the purpose of this paper, the neural network is considered as a function approximator herein. By adjusting neural network weighting coefficients, an unknown function can be approximated by it so that it produces the same output when the same input data is applied to that particular arbitrary mathematical function (Figure 3). Herein, the unknown function is, in fact, a real process (a two-tank system) that is controlled, and the neural network is used to implement an already identified process model. Additionally, an unknown function can also represent an inversion of the system we want to control, and in that case, the neural network is used to implement the controller.

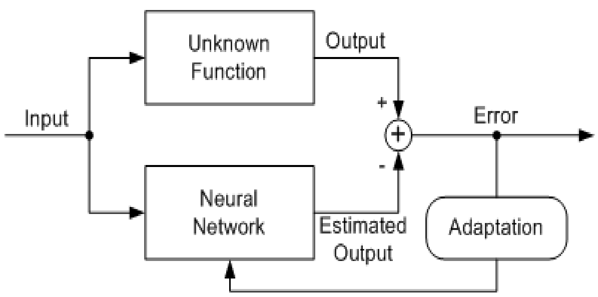

Figure 3. A neural network as a function approximator

For the purpose of nonlinear process modeling, the multilayer perceptron can be interpreted as Nonlinear AutoRegressive with eXogenous input model (NARX).

2.2 Neural Network AutoRegressive with eXogenous input model (NNARX)

The general NARX model is obtained by applying nonlinear regression to previous samples of process output and input signals. The NARX model of a nonlinear process with one input and one output can be presented as [4,5]:

$$y_p(k) = f\begin{pmatrix} y_p(k-1),\ldots,y_p(k-n), \\ u(k-1),\ldots,u(k-m) \end{pmatrix} + w(k) \quad (1)$$

where $y_p(k)$ and $u(k)$ samples of process outputs and inputs at the *k*-th time instance respectively, *n* is the number of previous output values, *m* is the number of previous input values, $f(\cdot)$ is a nonlinear function that describes the behavior of the process, $w(k)$ is additive Gaussian white noise. The first term in equation (1) depends on the previously measured input and output process signals, while the second term does not, and thus cannot be identified. Given that real process output $y_p(k)$ is available, the associated predictor is a feedforward network (there is no feedback):

$$\hat{y}(k+1) = \hat{f}\begin{pmatrix} y_p(k),\ldots,y_p(k-n+1), \\ u(k),\ldots,u(k-m+1) \end{pmatrix} \quad (2)$$

where $\hat{y}(k+1)$ is the output signal of the process model at the moment $k+1$, and $\hat{f}$ is the approximation function of f. The output signal of the process model $\hat{y}(k+1)$ is calculated in the *k*-th step, based on the currently available measured values of input and output process signals $\left[y_p(k),\ldots,y_p(k-n+1),u(k),\ldots,u(k-m+1)\right]$. Therefore, $\hat{y}(k+1)$ represents the estimated value of the process output signal $y(k+1)$ in $k+1$-th step, calculated one step ahead, in *k*-th step. Therefore, model (2) is called the predictor model of the process, and the error between the output signals of the process and the model is called the prediction error:

$$e(k+1) = y_p(k+1) - \hat{y}(k+1). \quad (3)$$

If the assumed model is correct, the prediction error $e(k+1)$ is equal to noise $w(k+1)$, and its variance is minimal. Therefore, a neural predictor can be created using a multilayer perceptron (Figure 4):

$$\hat{y}(k+1) = g\begin{pmatrix} y_p(k),\ldots,y_p(k-n+1), \\ u(k),\ldots,u(k-m+1);\theta \end{pmatrix} \quad (4)$$

where $g(\cdot)$ is a function realized by a neural network and θ is a vector containing the weighting coefficients of the network. In abbreviated notation, NNARX can be described as:

$$\hat{y}(k+1) = g\left(\varphi(k);\theta\right) \quad (5)$$

where

$$\varphi(k) = \left[y_p(k)\ldots y_p(k-n+1)\ u(k)\ldots u(k-m+1)\right]^T$$

is a regression vector that defines the regression structure of the neural network input. The NNARX model does not contain feedback, i.e., its regressors do not depend on the model parameters. This feature makes the NNARX model numerically stable while making the numerical procedures for estimating model parameters simpler compared to feedback models. Consequently, the NNARX model structure allows the simple application of static neural networks for the approximation of nonlinear functions.

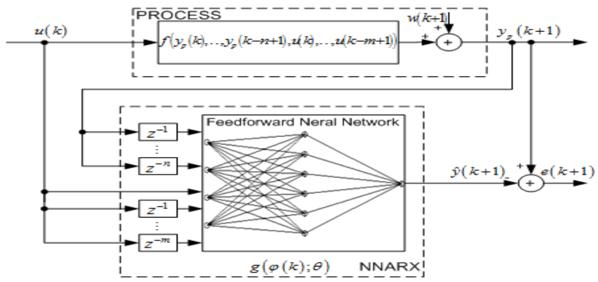

Figure 4. Process modeling using a neural NARX model

3. DESIGN OF THE CONTROLLER USING A NEURAL NETWORK

There is a significant number of controller designs based on the application of neural networks that can be found in the literature [6]. Herein, the structure and application of the Direct Inverse Control strategy, in which the controller represents an inverse process model, is presented. Inverse control is based on the application of an inverse process model, which is applied in series with the process, thus creating a system with an instantaneous unit gain response between the input to the inverse model $r(t)$ and the process output $y(t)$. Therefore, the inverse process model, represented by a neural network, acts as a controller. This is the most basic control strategy using a neural controller. Figure 5 shows an off-line diagram of neural network training, i.e., inverse process modeling.

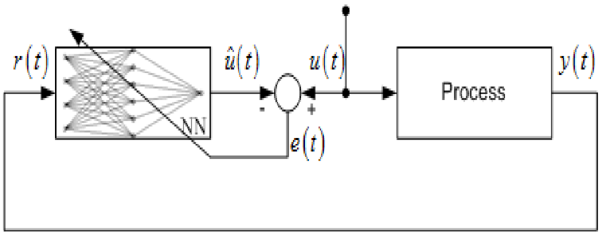

Figure 5. Inverse process modeling by a neural network

The NARX process model (1) can be written in the following form:

$$y(k+1) = f\begin{pmatrix} y(k),\ldots,y(k-n+1), \\ u(k),\ldots,u(k-m+1) \end{pmatrix} \quad (6)$$

where $y(k)$ and $u(k)$ are process output and input samples. The inverse model of the process described by expression (6), which output is in fact the manipulated signal, is given by the following equation:

$$u(k) = f^{-1}\begin{pmatrix} y(k+1),\ldots,y(k-n+1), \\ u(k-1),\ldots,u(k-m+1) \end{pmatrix} \quad (7)$$

The inverse process model (7) also belongs to a NARX structure. By applying a neural network that approximates function $f^{-1}(\cdot)$, an inverse neural network controller is obtained. According to expression (7), the output of the inverse process model in *k*-th step depends on the value of the process output in $k+1$-th step, i.e., $y(k+1)$, which is not available in *k*-th step. However, the reference (desired value) of the process output signal $r(k+1)$ is available at the *k*-th step, and this value is used to implement the inverse neural controller. Thus, the inverse neural controller can be described by the following expression:

$$\hat{u}(k) = \hat{f}^{-1}\begin{pmatrix} r(k+1),\ldots,y(k-n+1), \\ u(k-1),\ldots,u(k-m+1);\theta \end{pmatrix} \quad (8)$$

where $\hat{f}^{-1}(\cdot;\theta)$ is approximation function, i.e., neural network function of $f^{-1}(\cdot)$ with parameter vector θ. Figure 6 shows the strategy of direct inverse control using NNARX controllers.

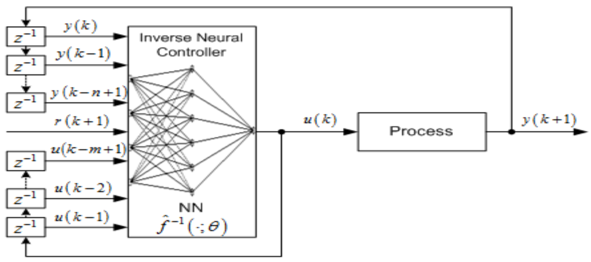

Figure 6. Inverse control system using NNARX controller

4. EXPERIMENTAL RESULTS

Figure 7 shows the implementation of a direct inverse controller used to control the two-tank system previously described. The NNARX inverse model presented in the previous section was used as a controller. The controller generates a control signal in the range [0-10] V.

Figure 8a) shows the process output for a given reference signal with implemented inverse controller, while the generated control output is given in Figure 8b).

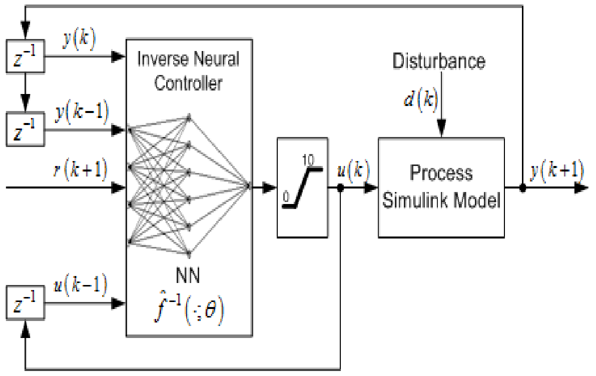

Figure 7. Direct inverse control of the two-tank system

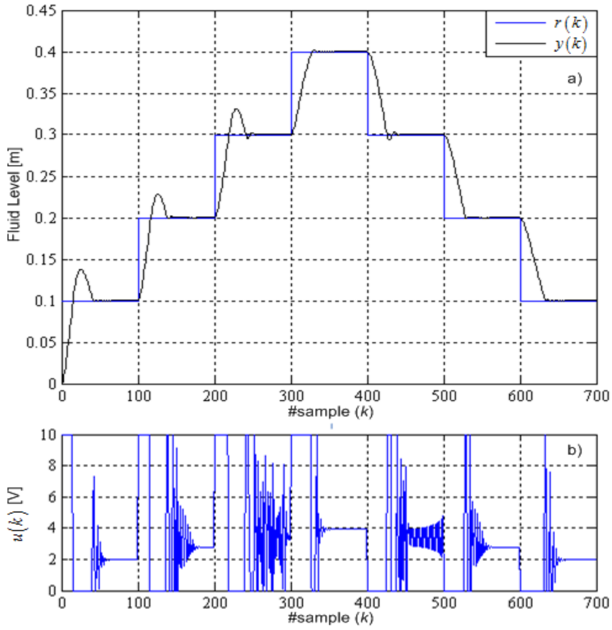

Figure 8. Direct inverse control of the two-tank system a) r(k) - reference input and y(k) - process output b) controller output

From the process response from Figure 8, it can be concluded that for the instances of the step changes in the set-point value, in order to quickly reduce the error between the set-point value and the current value of the output signal (the level of the second tank h_2), a large positive or negative value of manipulated signal (depending on whether the change of the set-point signal is positive or negative) is generated. Due to physical limitations, the values of the controller output are limited to the range [0-10] V, which is most commonly used in practice. Also, in order to reduce the abrupt jump-like large changes and to mitigate large oscillations of the controller output, a reference prefilter can be introduced in order to smooth out the jumps (large step changes) of the reference value. In this way, the controller is adjusted to the system dynamics, and overshoot is reduced.

5. CONCLUSION

In this paper, the application of static neural networks for the purpose of the identification and control of nonlinear dynamic processes is presented. From the point of view of process identification, their most important feature is the ability to approximate arbitrary continuous functions. The NARX structure of the neural network, which relies the process outputs as feedback, is used for the development of the inverse and the direct process models. Consequently, obtained neural network-based models are numerically stable, and numerical training procedures to obtain appropriate network parameters are simpler compared to recurrent neural networks.

Direct inverse control applied to a real nonlinear mathematical model is also presented. Presented controller structure based on direct inverse control gave satisfactory results for the set reference value tracking, even in the presence of disturbances. The presented control system is not able to completely suppress the disturbance, and consequently, the steady-state error appears, which is, however, negligible for the case of the presented two-tank system. Controller output oscillations can be reduced by introducing a reference prefilter into the control system.

ACKNOWLEDGEMENT

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OBJECT DETECTION AND TRACKING IN COOPERATIVE MULTI-ROBOT TRANSPORTATION

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Abstract: *Contemporary manufacturing systems imply the utilization of autonomous robotic systems, mainly for the execution of manipulation and transportation tasks. With a goal to reduce transportation and manipulation time, improve efficiency, and achieve flexibility of intelligent manufacturing systems, two or more intelligent mobile robots can be exploited. Such multi-robot systems require coordination and some level of communication between heterogeneous or homogeneous robotic systems. In this paper, we propose the utilization of two heterogeneous robotic systems, original intelligent mobile robots RAICO (Robot with Artificial Intelligence based COgnition) and DOMINO (Deep learning-based Omnidirectional Mobile robot with Intelligent cOntrol), for transportation tasks within a laboratory model of a manufacturing environment. In order to reach an adequate cooperation level and avoid collision while moving along predefined paths, our own developed intelligent mobile robots RAICO and DOMINO will communicate their current poses, and object detection and tracking system is developed. A stereo vision system equipped with two parallelly placed industrial-grade cameras is used for image acquisition, while convolutional neural networks are utilized for object detection, classification, and tracking. The proposed object detection and tracking system enables real-time tracking of another mobile robot within the same manufacturing environment. Furthermore, continuous information about mobile robot poses and the size of the bounding box generated by the convolutional neural network in the process of detection of another mobile robot is used for estimation of object movement and collision avoidance. Mobile robot localization through time is performed based on kinematic models of two intelligent mobile robots, and conducted experiments within a laboratory model of manufacturing environment confirm the applicability of the proposed framework for object detection and collision avoidance.*

Keywords: *Intelligent mobile robots, Object detection and tracking, Stereo vision system, Convolutional neural networks, Collision avoidance*

1. INTRODUCTION

Intelligent multi-robot system cooperation includes integration of multidisciplinary research in fields such as robotics, computer vision, deep learning, process planning and scheduling, etc. Recent advancements in the aforementioned research fields allowed for consideration of multi-robot teams utilization for a wide range of complex tasks execution. A comprehensive survey of implementation of cooperative heterogeneous multi-robot systems for various tasks can be found in [1], where task decomposition, coalition formation, task allocation, perception, and multi-agent planning and control are analyzed in detail. Deep learning has also greatly influenced the field of multi-robot systems, where Convolutional Neural Networks (CNN) can be used for carrying out computer vision tasks that require extraction of useful information from visual data (i.e., scene understanding, semantic segmentation, image classification, object detection and tracking, etc.). The promising potential of deep learning in robotics, with a focus on computer vision and machine learning, is presented in [2]. The deep learning approach showed excellent results for visual control of mobile robotic systems. In [3], the authors implemented a stereo image-based visual servoing algorithm based on CNN and object detection. The utilization of this approach for visual servoing reported improved accuracy of the point feature detection algorithm. Furthermore, Mobile Robots (MRs) with perception systems based on a deep learning framework can better understand and navigate in a dynamic environment. An example of successful implementation of a deep learning-based perception system utilized for semantic segmentation in real-time is presented in [4].

In this work, we propose heterogeneous multi-robot collision avoidance during the performance of transportation tasks based on the utilization of visual information, via a stereo vision system, for object detection and tracking of manufacturing entities. Moreover, in order to achieve multi-robot cooperation, we implement centralized architecture where all communication is carried out through a central unit - workstation. The proposed centralized control architecture is shown in Figure 1.

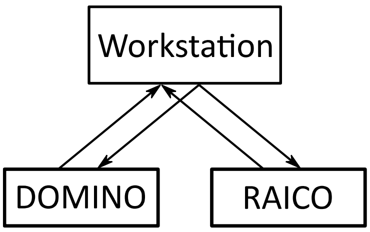

Figure 1. Centralized control architecture

MRs communicate pose coordinates evaluated based on their kinematic models and send image data for processing to the workstation via a wireless network protocol (Wi-Fi). Intelligent MRs shown in Figure 2, are considered heterogeneous due to their different way of achieving movement in a laboratory model of a manufacturing environment, as well as distinct gripping mechanisms.

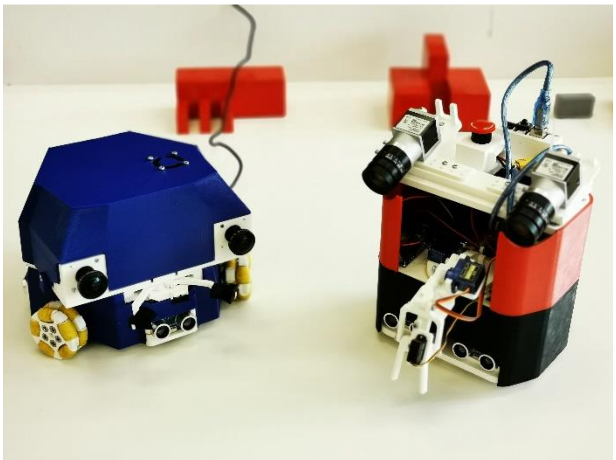

Figure 2. Intelligent MRs DOMINO (left) and RAICO (right)

Original intelligent MRs RAICO (Robot with Artificial Intelligence based COgnition) and DOMINO (Deep learning-based Omnidirectional Mobile robot with INtelligent cOntrol) were developed in 2019 and 2020, respectively, at the Faculty of Mechanical Engineering in Belgrade within the Laboratory for Industrial Robotics and Artificial Intelligence (ROBOTICS & AI).

The remainder of this paper is structured as follows. Section 2 introduces two kinematic models for two-wheeled nonholonomic and three-wheeled holonomic MRs. In Section 3, the process of training CNN for object detection is explained and results are presented. Section 4 presents experimental results, while Section 5 offers concluding remarks.

2. KINEMATIC MODELS

Two heterogeneous intelligent MRs, DOMINO (holonomic) and RAICO (nonholonomic) have different kinematics models because of their different locomotion abilities.

Holonomic MRs can directly reach any desired pose (i.e., position and orientation) due to the ability to move in any direction in a horizontal plane [5]. In order to achieve this holonomic motion, a MR platform needs to be equipped with specialized wheels (omnidirectional or mecanum wheels), and the most common holonomic MR platforms are equipped with three omnidirectional or four mecanum wheels. Consequently, holonomic MRs utilize additional DC servo motor, which requires more electrical power. Also, with additional wheel velocity that affects the evaluation of MR pose, kinematical models are more complex.

The pose of MR in the two-dimensional plane can be fully defined by a vector with three elements given in Eq. 1:

$$\boldsymbol{\xi}(t)=\begin{bmatrix} x & y & \theta \end{bmatrix}^{\mathrm{T}} \tag{1}$$

where coordinates x and y define a position and θ represents orientation angle with respect to the *X* coordinate axis. Figures 3 and 4 present nonholonomic and holonomic MR configurations with two standard wheels and three omnidirectional wheels, respectively. Additionally, in Figures 3 and 4 all relevant velocities and geometric characteristics for the evaluation of kinematic models are shown.

To establish forward kinematic models, we will relate MR velocities in global reference system with wheels velocities based on wheels kinematic constraint, i.e., pure rolling condition given in Eq. 2:

$$\mathbf{J}_1\mathbf{R}(\theta)\dot{\boldsymbol{\xi}}-\mathbf{J}_2\dot{\boldsymbol{\phi}}=0 \tag{2}$$

where $\mathbf{J}_1$ and $\mathbf{J}_2$ are *n*x3 and *n*x*n* transformation matrices, respectively, while *n* represents a number of wheels. $\boldsymbol{\phi}$ is *n*x1 vector of the wheel's angular velocities. Rearranging Eq. 2, MR velocities can be expressed with Eq. 3:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}=\mathbf{R}(\theta)^{-1}\mathbf{J}_1^{-1}\mathbf{J}_2\dot{\boldsymbol{\phi}} \tag{3}$$

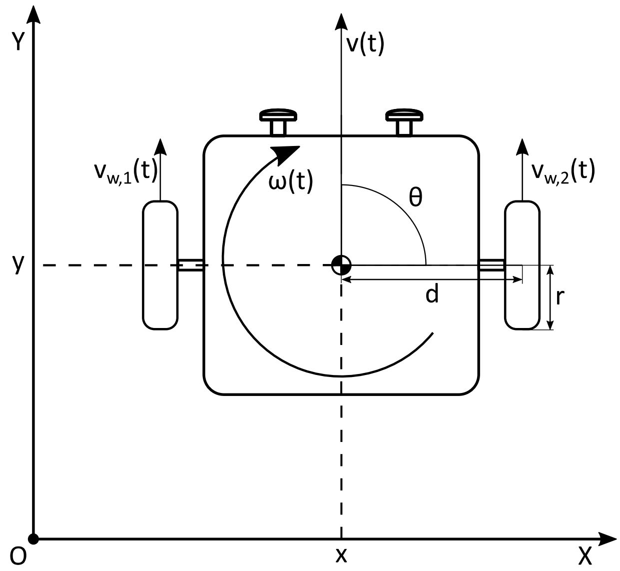

Figure 3. Nonholonomic MR with two standard wheels

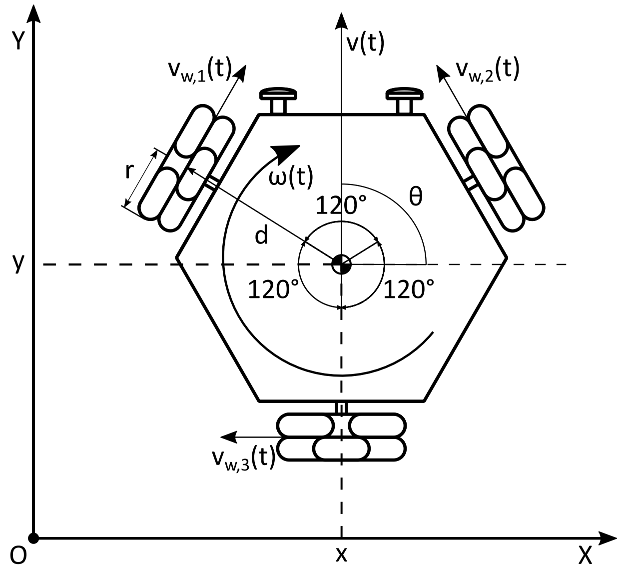

Figure 4. Holonomic MR with three omnidirectional wheels

Based on Eq. 3 and Figures 3 and 4, the kinematic model for a nonholonomic and holonomic MR can be mathematically formulated with Eq. 4 and Eq. 5, respectively.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}=\frac{1}{2}\begin{bmatrix} \cos\theta & \cos\theta \\ \sin\theta & \sin\theta \\ -\frac{1}{d} & \frac{1}{d} \end{bmatrix}\begin{bmatrix} v_{w,1} \\ v_{w,2} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \mathbf{R}(\theta)^{-1} \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & -\frac{1}{\sqrt{3}} \\ -\frac{1}{3} & \frac{2}{3} & -\frac{1}{3} \\ -\frac{d}{3} & -\frac{d}{3} & -\frac{d}{3} \end{bmatrix} \begin{bmatrix} v_{w,1} \\ v_{w,2} \\ v_{w,3} \end{bmatrix} \quad (5)$$

For further details about kinematic models, readers are referred to [6,7].

3. OBJECT DETECTION

In computer vision, object detection combines the classification and localization of objects within an image. Moreover, in a process of object detection Bounding Boxes (BBs) of detected objects are obtained. Based on tracking the change in dimensions of BBs, a system for collision avoidance can be developed.

For object detection task, a transfer learning technique is utilized and YOLOv5 [8] CNN architecture is implemented for training. Our own custom-made dataset for training contains 344 images obtained within a laboratory model of a manufacturing environment, acquired by DOMINO's stereo vision system. The stereo vision system consists of two parallelly placed Basler dart daA1600-60uc (S-Mount) area scan cameras. CNN is trained to detect seven different classes of manufacturing entities, presented in Table 1.

Table 1. Classification classes

Class 1	Class 2	Class 3	Class 4
Lathe	Vertical drill	Vertical mill	Machining center
Class 5	**Class 6**	**Class 7**	
MR RAICO	Press brake	Circular assembly table	

Classes 1-4 and 6 represent 3D printed models of machine tools, and class 7 is a wooden model of a circular assembly table. All 3D printed machine tools, seen in Figure 5, are produced with additive manufacturing technology using PLA material on Wanhao Duplicator i3 Plus 3D printer.

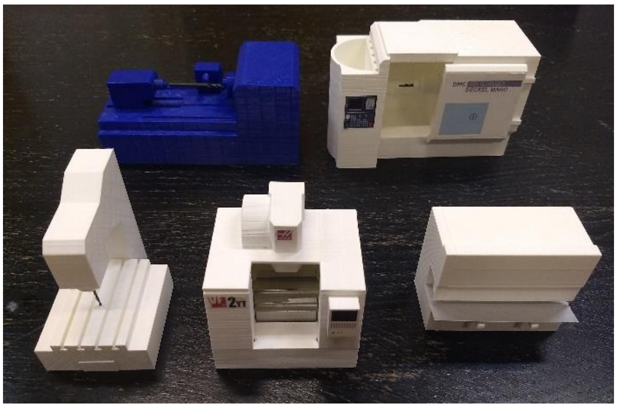

Figure 5. From left to right, first row: a) Lathe; b) Machining center; second row: c) Vertical drill; d) Vertical mill; e) Press brake;

The image dataset is randomly divided into training (296 images) and validation data (48 images), while the input image size is 800x600x3.

Chosen CNN model for training is yolov5s. This is the smallest and thus fastest model, especially suitable for real-time object tracking. The initial learning rate is 0.001 and as a learning algorithm Adam optimizer is utilized. CNN is trained for 30 epochs, mini-batch size is 8, and initial utilized weights are pretrained on COCO dataset.

Training is performed using PyTorch v1.9.0 in Python 3.8 software package running on the workstation with Nvidia Quadro RTX 6000 GPU with 24GB of RAM.

3.1 Training results

CNN training is performed successfully with the final mean Average Precision (mAP) of 95.3%. mAP per class is given in Table 2.

Table 2. Accuracy results

Class	1	2	3	4	5	6	7
mAP [%]	96.6	95.7	91.7	94.6	97.9	91.4	99.5

Furthermore, the confusion matrix seen in Figure 6 shows the reliability of the trained CNN model. Majority of classes are predicted with almost 100% accuracy, with the lowest score for Class 3 (Vertical mill) which is 89%. In Figure 6, FN and FP are abbreviations for false negative and false positive detection of background. As it can be seen from the confusion matrix, low values of predicted false positives for the background indicate good prediction results for all classes. On the other hand, false positive results indicate the probability of predicting background as one of the classes. This probability can be further reduced with an increase of the confidence threshold.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	FP
Class 1	0.93							0.08
Class 2		1.00				0.04		0.42
Class 3			0.89					0.07
Class 4			0.07	1.00				0.28
Class 5					0.98			0.03
Class 6						0.92		0.12
Class 7							1.00	
FN	0.07		0.04		0.02	0.04		

Figure 6. Confusion matrix

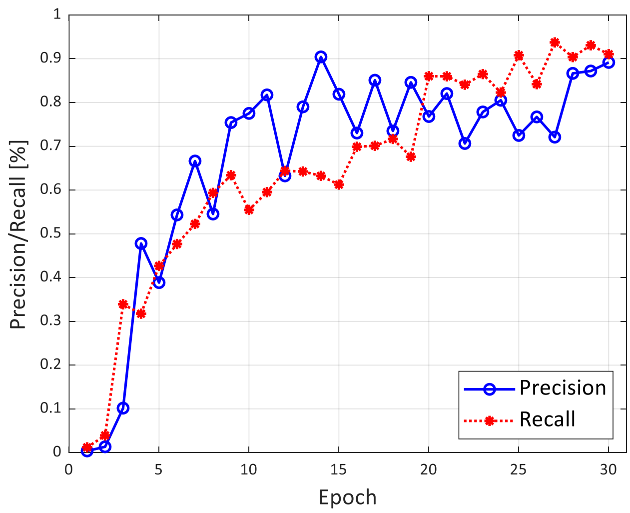

Figure 7. Change of precision and recall values throughout training epochs

Precision and recall, shown in Figure 7, are also good metrics for measuring the performance of the trained CNN model. Values of precision and recall were increasing throughout epochs and in the final epoch are 89.1% and 91%, respectively.

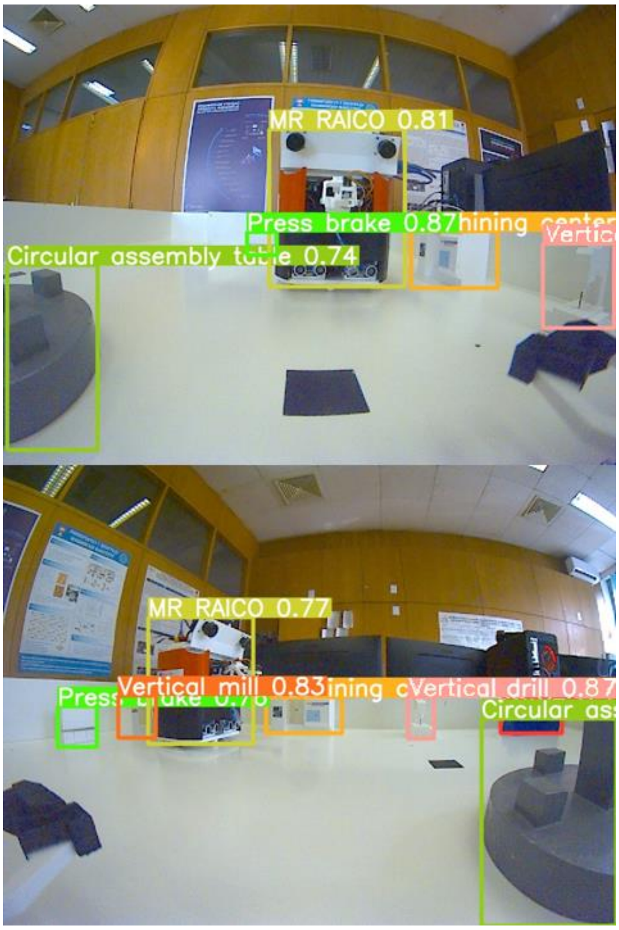

Figure 8. Prediction results with confidence values

Figure 8 shows predicted BBs of detected manufacturing entities with the value of confidence in the made prediction.

4. EXPERIMENTAL RESULTS

In order to verify and evaluate the proposed centralized control architecture and developed object detection and tracking system, the experiment is conducted on two heterogeneous MRs DOMINO and RAICO in a laboratory model of a manufacturing environment. For both MRs starting and goal pose are defined, and possess in between will be monitored and evaluated based on their respective kinematic models. Intelligent MR DOMINO will utilize trained CNN to detect and track the movement of intelligent MR RAICO within environment. Moreover, the BB size of the detected dynamic obstacle, which MR RAICO represents, will be evaluated. Based on the height and width of BB, MR DOMINO will take adequate action. If the height or width of BB exceeds the predefined threshold (Eq. 6) MR

DOMINO will temporarily stop and wait for the obstacle to be removed or back up if height or width of BB continues to increase. Threshold values of BB height and width, given in Eq. 6, are normalized.

$$BB\ height \geq 0.7, BB\ width \geq 0.5 \qquad (6)$$

The starting and target posses are given in Table 3. MR RAICO starting and target pose will be close to each other due to his predefined forward and backward movement. This movement is chosen in order to intersect the path defined for MR DOMINO.

Table 3. MRs starting, intermediate, and target posses

DOMINO	**starting pose**	[65, 20, 90]
	target pose	[65, 110, 90]
RAICO	**starting pose**	[10, 60, 0]
	intermediate pose	[70, 60, 0]
	target pose	[20, 60, 0]

The schematics of a laboratory model of a manufacturing environment and paths generated by kinematic models can be seen in Figure 9.

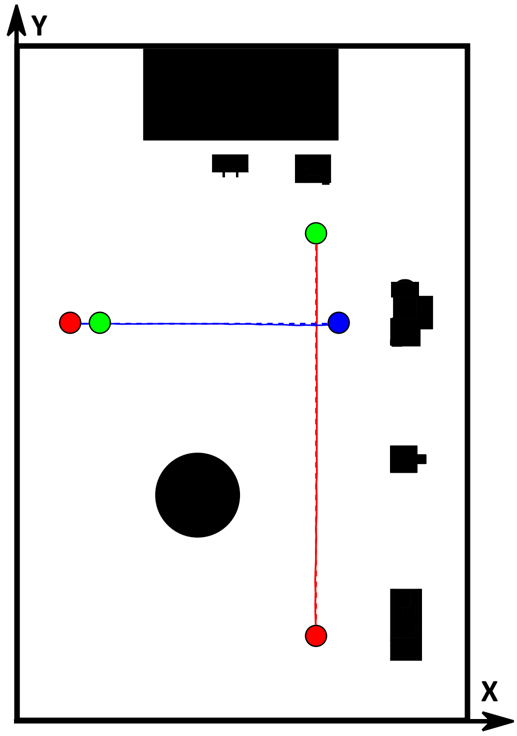

Figure 9. MRs paths within a laboratory model of manufacturing environment

Red and green circles in Figure 9 represent starting and target posses, respectively, while blue circle represent intermediate pose of MR RAICO. With intermittent and full lines are shown predefined paths and paths evaluated by kinematic models, respectively. Blue lines are paths of MR RAICO and red lines are paths of MR DOMINO. During the experiment, pose estimations are continually sent to the workstation, via established communication protocols. Furthermore, images obtained by MR DOMINO stereo vision system are sent and successfully processed on the workstation. BB height and width are evaluated for each image of stereo pair, and when the condition defined in Eq. 6 is meet, the workstation sends information to MR DOMINO to stop in order to avoid collision with MR RAICO.

In both left and right image of stereo pair, height of BB exceeds predefined threshold and MR DOMINO movement is stopped. The moment when MR RAICO is detected in left and right images of stereo pair is shown in Figure 10 and 11, respectively. Values of BB height and width for left and right image of stereo pair is shown in Table 4.

Table 4. Height and width of BBs in the moment when movement is stopped

Image	Height	Width
Left	**0.78**	0.32
Right	**0.72**	0.27

Figure 10. Detection of MR RAICO in left stereo pair image

Figure 11. Detection of MR RAICO in right stereo pair image

5. CONCLUSION

The cooperation of two or more intelligent mobile robots and their integration into contemporary manufacturing systems represent a key requirement for achieving autonomous transportation of manufacturing systems within Industry 4.0. This paper presents the methodology based on convolutional neural networks utilized for the detection of manufacturing entities within a dynamic manufacturing environment. One of the manufacturing entities used to verify the proposed methodology is MR RAICO, which represents the dynamic object in a manufacturing environment. According to the experimental verification of the proposed framework, the mean average precision for detecting the dynamic object (i.e., MR RAICO) is 97.9%. Obtained experimental results show the successful application of the developed object detection system for collision avoidance during the execution of cooperative multi-robot transportation tasks.

ACKNOWLEDGEMENT

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LINKING CAD MODELER AND XR ENGINE FOR DIGITAL TWIN-BASED COLLABORATIVE ROBOTIC ASSEMBLY

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Abstract: *Production paradigm of mass customization and development of highly complex products impose the need for development and using xR technologies in manufacturing. Immersive technologies (xR) are currently the best solution for human-machine interfaces and as such are great candidate for further development and usage in industry. In this paper, a way of integration between CAD modeler and xR development engine will be shown. For CAD modeler, SolidWorks software is chosen, which is well known as one of the most widely used engineering design tools, and for the xR development system is used Unity. Even thou SolidWorks offers great capabilities it still lacks proper xR technologies interfaces which can connect HMD xR interfaces(e. g. Facebook Oculus Rift). Using Unity API library and SolidWorks SDK digital-twin system is created which allows remotely xR interaction between CAD and XR models.*

Keywords: *Smart Manufactoring, Virtual Reality, Digital Twin, CAD-xR Dynamic Linker, xR.*

1. INTRODUCTION

Although virtual and augmented reality technology [1] (collectively xR) is objectively far from mass and thus, routine application in the manufacturing industry, it is undoubtedly one of the technologies that has a huge transformative potential to significantly change the production technologies as we know them today. This potential lies in the fact that xR technologies represent the technological basis for building a new generation of human-machine interfaces [2] (HMI). It is impossible to realize the concept of intelligent manufacturing systems (regardless of what we really mean by intelligent and which we often use uncritically), or more broadly, cyber-physical production systems, without realizing such a communication channel that will enable natural, unconstrained human communication with the world of digitalized information. Human's system of visual perception is undoubtedly a key component of such a communication channel. But what is meant here is not simply the transmission of visual information, but technology that will allow man's natural ability to penetrate three-dimensional space and use it effectively, through the amazing and almost incredible cognitive abilities of his brain (we see with Our brain, not with our eyes!). This topic far exceeds the available space for this paper, and its elaboration will end with the view that it is undoubtedly one of the most challenging research directions in the field of production technologies at the moment. It has a number of subdomains. One of the most important is the concept of so-called digital twins [3], through which the integration of man into the concept of cyber-physical production systems on a holistic basis and in a structured way, which allows for further systematic research. In this context, the issue of integration of existing CAD tools for engineering design, ie their graphic kernels, and xR kernels of modern platforms for application development in the gaming industry is of special importance. The convergence of these two worlds, fundamentally differently shaped and focused on fundamentally different applications, may be a good response to the rapid and wider application of xR technologies in the near future. Especially on the tasks of programming robots using demonstrations, and quasi-physical interactions in virtual space. This paper presents the basic ideas how this problem could be practically solved through the realization of an appropriate system architecture for dynamic interaction of CAD graphics kernel and xR engine in real time, with performance that is relevant for practical application. This concept has been practically verified on the mockup example of the integration of SolidWorks 3D CAD modeler and UNITY xR engine.

2. SYSTEM ARCHITECTURE OF XR – CAD LINKER

One of the first problems in creating a system for XR interaction with a CAD modeler is the importing of CAD model by an XR development system. The CAD model is imported into the XR development system to allow the system to function as naturally as possible, in real-time operation. In this way, the interaction between the VR Headset and the CAD model takes place in the XR development system, and then that interaction is simultaneously mapped to the 3D CAD modeler in real time, if possible.

One way to transfer 3D models from one application to another (e.g. from a 3D CAD modeler to an XR development system) is using the glTF [4] format. glTF (GL Transmission Format) is an open source standard for efficient transfer of 3D models and scenes from one application to another. It was designed by the COLLADA working group in 2012 and published in October 2015. The glTF format enables the minimization of the required memory space for the transfer of 3D models. It also reduces the time required to unpack the model, which can take some time with sophisticated 3D models.

After transferring the 3D model from the 3D CAD modeler to the XR development system, it is necessary to write program codes that allow interaction between HMD and XR development system, then map this interaction to the CAD modeler in real time. As we have transferred the 3D model from the 3D CAD modeler using the glTF format, the functionality of the system can be divided into three unity.

The first unit deals with servicing supported XR interactions (features) over a 3D model in an XR development environment. Supported XR interactions in the XR development system are defined by program code that allows the HMD joystick to rotate objects (robotic segments in our example) with appropriate manipulation.

The second unit deals with the detection and processing of manipulations on the model in the 3D CAD modeler, which involves calculating the angles of the object. Manipulating a robot in a 3D CAD modeler is possible using the supported API for that 3D CAD modeler or simply by manipulating the computer cursor.

The third unit enables communication between the previous two units, ie synchronization of the model in the 3D CAD modeler and the model in the XR development system in real time, including data collision protection mechanisms, and thus system oscillation. System oscillation protection means maintaining the stability of the entire system while simultaneously manipulating both models at the same time. The UDP communication protocol is used.

By building a system that includes these three functional units, we have created a platform that allows bidirectional connection between CAD and XR models in real time.

Graphical representation of the XR-CAD linker architecture is shown in Figure 1.

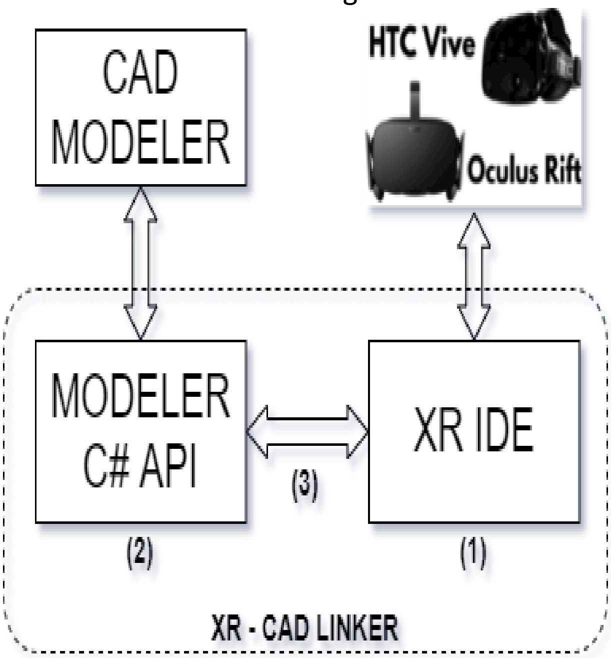

Figure 1. XR-CAD linker architecture

3. DEMONSTRATION OF THE XR-CAD REAL TIME LINKER

The practical implementation of the system described in the previous section will be presented on the SCARA mockup robot [5]. The SCARA mockup robot consists of three robotic segments, two mobile (R01_LINK_01 and R01_LINK_02) and one stationary (R01_LINK_00). It is a robot that has only two degrees of freedom, which made it easier to demonstrate the concept of system functioning in this paper, without losing generality.

The SolidWorks software package was used as a CAD modeler. The representation of the structure of the robot tree R01_ROBOT.sldasm and the representation of the 3D model in SolidWorks are shown in the Figure 2.

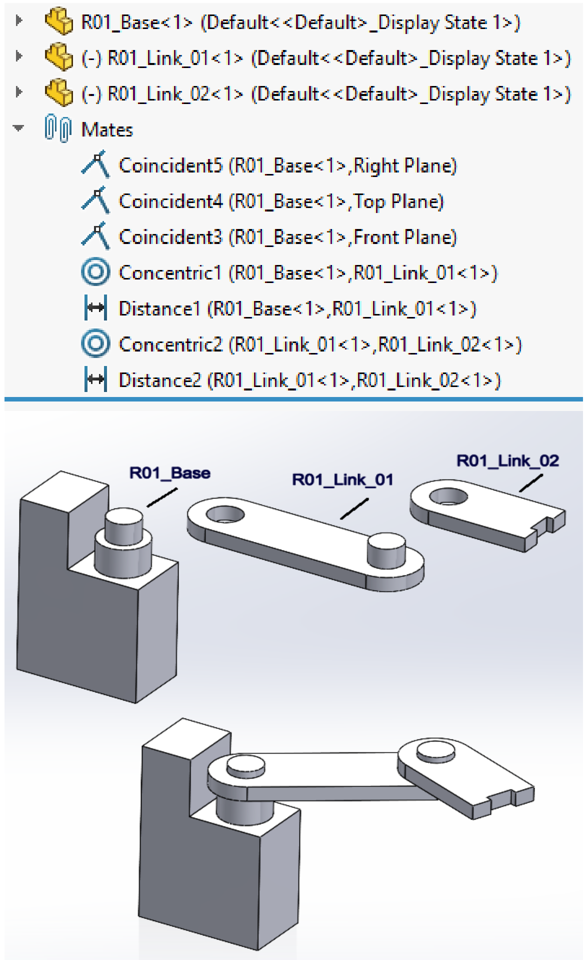

Figure 2. Design tree and 3D model of SCARA robot in SolidWorks

In order to export an assembly from SolidWorks to an XR development system, it is necessary to save the assembly R01_ROBOT.sldasm as an R01_ROBOT.gltf file. This is done by simply selecting an option from the SolidWorks drop-down menu.

The XR development system uses the Unity software package intended primarily for video game development. As XR technology is increasingly used in video games, this choice of XR development system seems right, due to the compatibility of different HMI Headsets. In Unity, by installing the appropriate package that allows the import of gltf files, we import the assembly from SolidWorks into Unity. The display of the tree structure as well as the 3D assembly, in Unity look exactly the same as in SolidWorks.

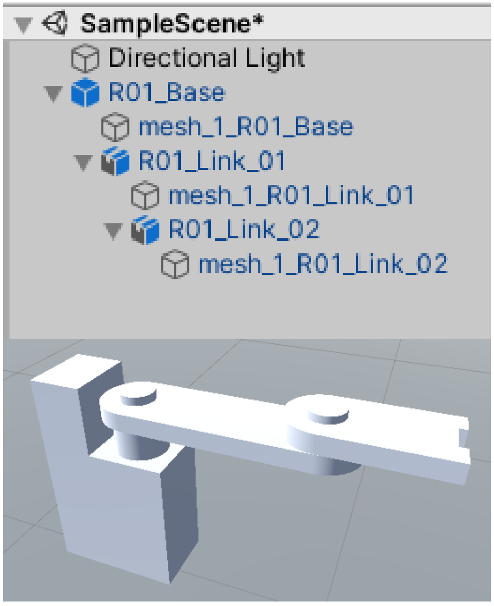

Figure 3. Design tree and 3D model of SCARA robot in Unity

The structure of the program code on the side of the 3D CAD model is the same as on the XR development system side. It consists of checking the requirements of mutual communication on the other side of the connection. If such a request exists, the data is accepted, parsed, and responded to by setting the angles of the 3D assembly to the values applied. In case there is no request to receive data, the program checks whether there is a change of angles on the 3D assembly. If it is, in that case an appropriate message is formed and sent to the other side of the connection.

```
while (true)
{
    if (udp_client.canRecieve() > 0)
    {
        angles = parserUDP.angles(udp_client.udpRead());
        set_angle.set_angles(angles[0], angles[1]);
        Array.Copy(uglovi, 0, old_angles, 0, angles.Length);
    }
    else
    {
        angles= get_angles.calc_angles();
        if (!Array_Sequence_Offset(angles, old_angles, 0.1))
        {
            Array.Copy(uglovi, 0, old_angles, 0, angles.Length);
            udp_client.udpSend("angle1:" + angles[0] + ";" +
                               "angle2:" + angles[1] + ";\n");
        }
    }
    XR_CAD();
}
```

Figure 4. Main code loop

4. CONCLUSION

In this paper, we have shown concept for development of interface between xR technologies and CAD platforms, such as SolidWorks, to be used as a tool for development of the Manufacturing Digital Twin concept, applicable in real industrial environment. The integration is done indirectly, by creating digital-twin in xR game development engine UNITY. Then a bidirectional synchronization of 3D models, between UNITY and SolidWorks is achieved. This type of, xR technologies and CAD systems integration, allows for development of many systems for practical application in advanced manufacturing, such as industrial robotics and many others.

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RECOGNITION OF GEOMETRIC INFORMATION IN A DXF FILE

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Abstract: *In a small manufacturing companies, the problem of impossibility of quick response to the customer request is often expressed. The reason for this is most often the inability to quickly create NC programs for CNC machines because the customer documentation is in various 2D raster or vector formats or the inability to have a large number of CAD CAM software to use 3D customer documentation. This paper discusses the possibility of automating the recognition of geometric information from a 3D DXF file and their recording and storage.*

Keywords: *DXF file, NC code, CAD/CAM systems*

1. INTRODUCTION

The degree of integration of CAD / CAM systems in small companies is increasingly affecting their competitiveness in the market. This is especially expressed in small companies that deal with production services according to the technical documentation of the customer. Nowadays, in production practice, three concepts of NC code generation are presented:

- the classic concept of NC code generating using CAM software when using geometric data obtained from CAD software. In the case when the customer orders parts according to his documentation, the company that provides the service must have a large number of the latest commercial CAD and CAM software, trained staff to work in these software, appropriate postprocessors, etc., where the price of these software is high and to work with them, a highly skilled workforce is needed.
- in case when the customer orders parts, according to the technical documentation in the form of drawings, ie 2D raster files or 2D vector files (jpg, pdf, tiff, dwg, dxf, etc.), for the needs of CAM software application, a new 3D model design is usually required. This prolongs the total time of the production cycle and makes the price of the production service uncompetitive.
- writing programs directly on a CNC machine, which requires highly professional operators with many years of experience, which are very difficult to find in the labour market. During the writing of the program, the CNC machine does not work, so the accumulated non-production time of the machine makes the price of the production service uncompetitive. Writing programs on a machine is not always possible due to the very complex geometry of the work piece.

In order to achieve a higher degree of automation, ie autonomy of the process of creating NC code based on the documentation of the customer, it is necessary to find a new model that would replace the existing concepts of NC code generation. Basically, the process of creating NC code includes the following steps:

- analysis of technical documentation,
- recognition of geometric information and their recording or storage,
- selection and optimization of tool paths and/or machining modes and their recording or storage and
- NC code generation based on previous information's.

The first problem is the recognition of geometric information. Technical documentation is a technical drawing, with all the necessary information for the production of the work piece, where the drawings are obtained from the customer, usually in different vector or raster formats. Such a documentation format cannot be used directly in the process of automated generation of NC code. Such a format needs to be translated and saved in a form that can be used to recognize geometric information. This format is usually in the form of a DXF file.

The second problem is the selection and optimization of the tool path and machining parameters and the formation of records that define the tool path in a form that can be used to generate NC code. All today's CAM systems, implement the tool path generation process through interaction with the knowledge of programmers or machine operators. Also, the programmer or operator on the machine enters the cutting depth, the number of revolutions of the main spindle, the speed of the auxiliary movement, the place where the tool starts moving as well as the place where the tool exits the machining zone, the clamping method, the position of clamping accessories and similar.

From the analysis of production flows in small enterprises it can be seen that the time from the reception of technical documentation to the implementation of the CNC program is 20% -30% of the total production cycle time required to produce one part. Reducing that time to 10% would bring significant savings and increase the competitiveness of such a company. Reducing this time is possible only by automating all or individual activities required to generate the NC code from the obtained documentation.

The aim of this paper is to describe the method of recognizing and extracting all necessary geometric information for defining the tool path from a 3D DXF file and their recording and storage in a suitable manner for the automatic generation of NC codes.

2. DEVELOPMENT OF MODULE FOR RECOGNITION AND EXTRACTION OF GEOMETRIC INFORMATION

From the available literature, it can be concluded that researchers are engaged in the process of recognizing and extracting geometric information from a DXF file for plane shapes. The authors most often [1, 2, 3] suggest automatic programming of CNC machines based on DXF file due to the compatibility of this format with most CAD software. The authors propose the recognition of geometry from a DXF file using object-oriented higher programming languages (e.g. C++), and use a genetic algorithm to optimize the tool path. These researches do not define the way of storing the recognized geometric information. Some research is limited to cylindrical parts [4, 5]. The authors cite as one of the basic problems the problem of the lack of a standard database structure for recording graphic information as an interspace between CAD and CAM.

In [7], the authors use an evolutionary algorithm to generate a continuous tool path as a new method for path optimization. The proposed model is unique because it allows changing the goal of optimization while maintaining the basic algorithm to obtain different goals, or different tool paths. The research refers to the milling processing of the geometric shapes in the plane.

Nowhere in the cited literature the way of storing the recognized geometric information it not defined, which should be independent in relation to the process of NC code generation. The authors are mostly limited to the recognition of geometric shapes in the plane, that is on generating NC code only for contours in the plane.

Figure 1 shows a block diagram of the concept of automatic generation of NC code containing:

- geometry recognition module,
- module for tool path optimization and selection of machining parameters and
- NC code generation module.

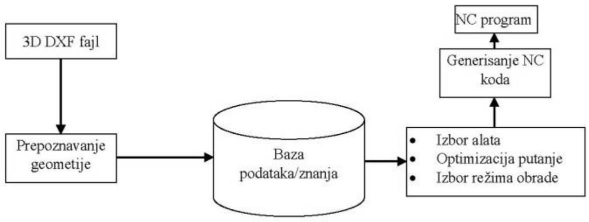

Figure 1. Block diagram of the concept of automatic generation of NC code

Knowing the structure of a DXF file, it can be approached to the development of an algorithm for extracting data from a DXF file and creating an algorithm for recognizing geometric shapes and their properties. The basis for the development of the model are the starting facts related to the DXF file [8, 9]:

- in the DXF file, the order of description of entities does not follow their connection in the graphic display,
- coordinate values depend on the position of the absolute coordinate system at the time the DXF file is formed and
- there is no possibility to simply read which entities represent the outer contour and which entities represent holes by simply reading the DXF file, i.e. it is not possible to recognize either the geometric shapes or their properties.

By analysing research [1-6] and many others from the available literature, it can be concluded that the processes of extracting data from a DXF file and recognizing geometric shapes are distinct processes. The authors describe the process of data extraction and the process of recognizing geometric shapes in plane parts almost identically. Within this paper, a combined algorithm is presented that extracts data from a 3D DXF file taking into account their position in space, recognizes geometric shapes and writes them to a database.

The geometric shapes to be recognized are: **line**, **circle** and **circular arc** or simply **arc**.

Line is described as a spatial form by its starting point $P1(x_1, y_1, z_1)$ and its ending point $P2\ (x_2, y_2, z_2)$. The equation of the line through two points in space is:

$$\frac{(x-x_1)}{(x_2-x_1)} = \frac{(y-y_1)}{(y_2-y_1)} = \frac{(z-z_1)}{(z_2-z_1)}$$

The length d of the line P1P2 is obtained by the formula

$$d = \sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}$$

The *Line* entity data defines one contour line that is completely determined by its start and end point as well as its length.

A **circle** as a plane shape is described by the its centre coordinates $O(x_1, y_1, z_1)$ and radius and can be described by the known formula:

$$(x-x_1)^2+(y-y_1)^2=r^2$$

where the length of the circle is equal to the circumference O and, according to the known formula, is $O=2r\pi$.

Circle entity data defines a circle that is completely determined by the its centre coordinates, radius and its length or circumference.

Arc as a plane shape is described by the its centre coordinates $O(x_1, y_1, z_1)$ and the radius, but also the initial angle (angle α_1 between the radius of the arc through the starting point and the positive direction of the x axis) and the end angle (angle α_2 between the radius of the arc through the end point and the positive direction of the x axis), measured in the positive mathematical direction. If $P(x, y)$ is a point on an arc and if the angle θ is the angle between the radius of the circle through the point P and the positive direction of the x axis, then the point P belongs to the arc if $\alpha_1 \leq \theta \leq \alpha_2$. However, for the complete definition of the arc, for the purposes of generating the NC code, the coordinates of the start and end points are also required. In this case, each point on the arc can also be given in polar coordinates:

$$x = r\cos\varphi \quad \text{and} \quad y = r\sin\varphi$$

where r is the radius of the circular arc and φ is the angle that encloses the radius at that point with the positive direction x of the axis passing through the centre of the arc. The coordinates of the point are obtained as $a=x+x_1$ i $b=y+y_1$ where x_1 i y_1 are the coordinates of the centre of the circular arc in relation to the coordinate system of the DXF file, *x* and *y* are the coordinates of the point in relation to the local or coordinate system passing through the centre of the arc. Also, it is necessary to know the length of the arc which is given with the known formula:

$$l = r\pi\alpha/180, \quad \text{and} \quad \alpha = \alpha_2 - \alpha_1.$$

Arc entity data defines a circular arc, which is completely determined by the its centre coordinates f, radius and its start and end angle, its length and its start and end point.

The contour of a piece is a set of lines and circular arcs. The contour can also consist of other geometric shapes (e.g. polylines) but in this model are not considered. Thus, the contour is a set $K = \{Li, Aj, zi\}$, i.e. it consists of Li lines where $i=1,...,n$ and of Aj circular arcs where $j=1,...,m$ which are on the same z coordinates or lie in the same plane. Data can be extracted from the DXF file that uniquely defines each entity *Li* and each entity *Aj*, but in the DXF file there is no data that can be extracted that defines the connection of these entities as well as their direction. The logic for determining the direction of lines located in one plane is simple and is shown in Table 1. Different authors in [1 - 4] use similar logic, but it should be noted that the data in Table 1 refer to the direction of the lines that make up one contour, that is, the geometric shape that lies in one plane. When it comes to an arc, it is always directed in a positive mathematical direction, that is, it is always directed from the start angle to the end angle

Table 1. The logic of determining the entity direction

Expression	Entity direction	Entity orientation	Mark	Description	Entity
if ($y_1=y_2$) i ($x_1<x_2$)	Horizontal	→	LDH	Right horizontal line	
if ($y_1=y_2$) i ($x_1>x_2$)	Horizontal	←	LLH	Left horizontal line	
if ($y_1<y_2$) i ($x_1=x_2$)	Vertical	↑	LVG	Vertical line up	
if ($y_1>y_2$) i ($x_1=x_2$)	Vertical	↓	LVD	Vertical line down	
if ($y_1<y_2$) i ($x_1<x_2$)	Under angle	↗	LGD	Line up right	LINE
if ($y_1>y_2$) i ($x_1>x_2$)	Under angle	↙	LDL	Line down left	
if ($y_1>y_2$) i ($x_1<x_2$)	Under angle	↘	LDD	Line down right	
if ($y_1<y_2$) i ($x_1>x_2$)	Under angle	↖	LGL	Line up left	
if ($y_1=y_2$) i ($x_1=x_2$) i ($z_1<>z_2$)	In the direction of the *Z* axis		LZ	Line in the direction of the Z axis	

It should be noted that the lines where C_i=*LZ* do not belong to any contour Ki but connect them in terms of the formation of spatial geometry. The direction of the entities is previously defined and the logic of extracting data from the DXF file is described. The next step is to define the logic that connects the lines and arcs into a closed polygonal contour that lies in one plane. Circles that are already defined as a closed geometric shape and lines where Ci =*LZ* are excluded from this analysis. It is clear that each element of the set K has its previous and its next element because it is a closed polygonal contour. It is necessary to determine only the next elements for each element of set A, having in mind that the next element of the penultimate member of set A will be the initial element of set A. The precondition for creating the algorithm is the existence of a DXF file in which:

- defined workpiece geometry,
- defined geometry of starting workpiece form and
- defined clamping accessories geometry

Figure 2 shows a wireframe model of a 3D

DXF file in which the geometries of the staring workpiece form, workpiece and clamping accessories are defined. Geometric shapes are denoted by different layers in the DXF file. One of the advantages of DXF files is that the entity can be described by its layer, to which it belongs, so the layer to which it belongs is added to the recognized entity as one of the attributes. In this way, the geometry of the starting workpiece form is very easily separated from the geometry of the workpiece or machine, etc. Figure 3, which is an isometric view of the workpiece of Figure 2, shows an example of the contours with marked contour entities. Having in mind that in the DXF file the neighbouring entities are not one above the other, but they are in a completely random arrangement, by random selection in the first *z* plane, one *k-th* line entity is chosen as the initial entity of one contour as shown in Figure 3. This entity is determined by $L_k=\{x_{1k}, y_{1k}, x_{2k}, y_{2k}, z_{1k}, z_{2k}, d_k, C_k\}$. Let the set $P=\{Li, KLj\}$ where *i=1,...,n* and *j=1,...,m*, and *i≠k*, a search set from which the initial entity is excluded. In order to connect the lines and circular arcs it is necessary:

1. Find the point *S (p, q)* such that $(p = x_{1k} \wedge q = y_{1k}) \vee (p = x_{2k} \wedge q = y_{2k})$.

The entity to which it belongs is the next entity of entity *Lk*. Join the set $L_k = \{x_{1k}, y_{1k}, x_{2k}, y_{2k}, z_{1k}, z_{2k}, d_k, C_k\}$ another member of the set that uniquely defines the next entity. This unique code belongs to the Group 5 Code of DXF file [8, 9]. Now the entity Lk is represented by the set $L_k = \{x_{1k}, y_{1k}, x_{2k}, y_{2k}, z_{1k}, z_{2k}, d_k, C_k, O\}$. In exactly the same way, another member is added to the set describing the entity arc, in case the next element is an arc. Let the next entity be marked Ep.

2. The set P is now $P = \{Li, KLj\}$ where *i=1, ..., n* and *j = 1, ..., m*, *i ≠ k*, and *i ≠ p*, ie the initial entity and its next entity are excluded from the search set and so on in each iteration entities connected up to current iteration are
3. $x_{1k}=x_{1p}$ i $y_{1k}=y_{1p}$ i $x_{2k}=x_{2p}$ i $y_{2k}=y_{2p}$; Ep=L_k; p=k;
4. Repeat steps 1) - 4) until $Ep \neq L_k$

Repeat steps 1) - 5) $\forall z$ for each change of z coordinate and for $z_{1k} = z_{2k}$ or for geometric shapes (lines, circles and circular arcs) lying in the same plane.

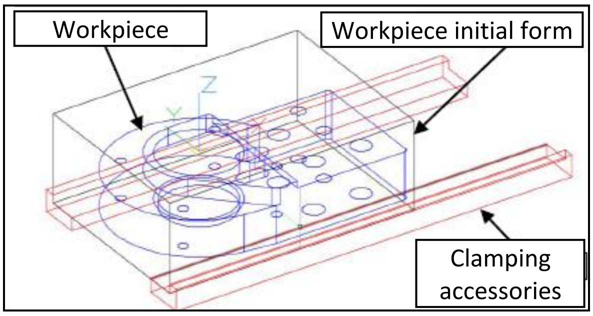

Figure 2. Wireframe model of 3D DXF file

From the previously presented algorithm, and looking at Figure 3, assuming that entity 1 is selected as the initial entity, the connection of the entities would be 1-4-6-5-2-3-7 and thus one contour is defined. This contour is located at z=*0*, in the plane in which the coordinate origin point is located. Entity 8 is not a member of that contour, because it is a hole. Also, if entity 10 is chosen as the initial entity, then the connection of the elements of the second contour is 10-12-11-9 and that contour lies in the plane z = 10.

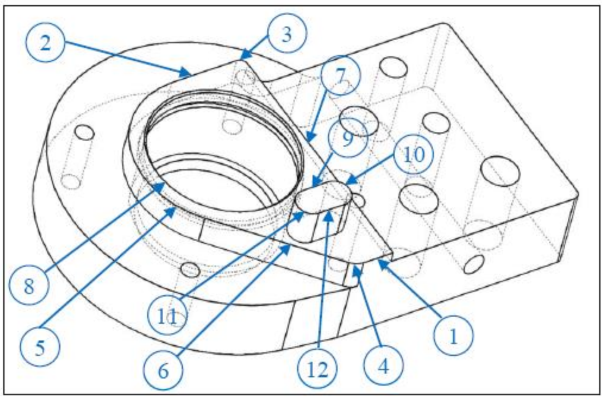

Figure 3. Workpiece with marked contours

In this way, two contours were obtained, where all entities and their mutual connection were defined, ie geometric shapes were formed, which are the subject of machining. However, the contours obtained by applying the previous algorithm are not yet fully defined. Namely, the contour recognized as a contour with entities 10-12-11-9 can be external (Figure 4) or internal (Figure 5) by looking at the workpiece as a geometric body. Also, the hole can represent both an outer and an inner contour. The outer contour does not have to be the boundary contour of the workpiece, ie it does not have to be the basis of the side surface of the workpiece because it can be an island as shown in Figure 4. From the point of view of NC code generation or tool path it is very important to determine whether the contour is external or internal because in the first case (Figure 4) the processing is performed outside the contour, and in the second case (Figure 5) inside the contour (pocket-type contour). In the available literature there is not an algorithm for determining the contour type (whether it is external or internal) from a wireframe 3D model.

The algorithm for determining the type of contour, which is based on the notation of the contour in the form Kp = {Li, KLj, zp, V, T} contains the following steps:

1) Determine z_{max} i z_{min}, i.e. the maximum and minimum z coordinate of the planes in which the contours lie,
2) Let r = z_{max} to z_{min}

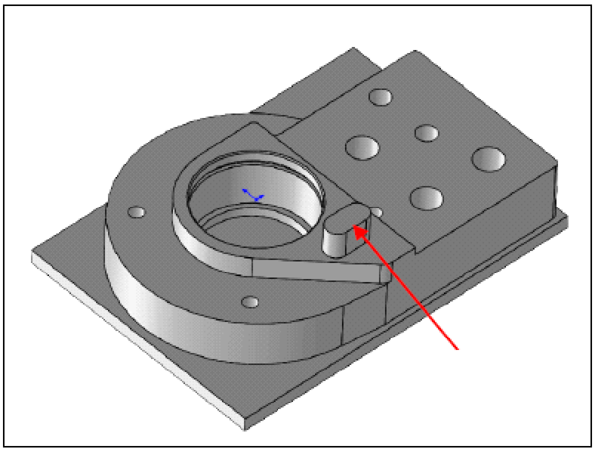

Figure 4. 3D model of a workpiece with an island type contour

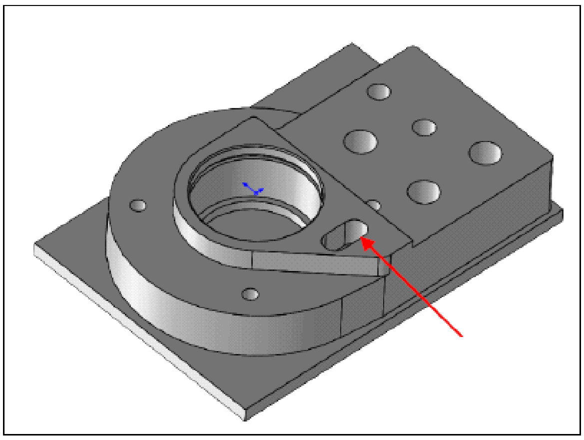

Figure 5. 3D model of a workpiece with a pocket type contour

3) If there is only one contour in the plane K_{z_r} then the contour $K_{z_r}=\{L_i, KL_j, z_r, V, T\}$ is external and then KZr = {Li, KLj, zr, H, S} and $K_{z_r} = \{L_i, KL_j, z_r, H, S\}$ and $K_{z_{r+1}}=\{L_i, KL_j, z_{r+1}, S\}$, the contour K_{z_r} and the contour K_{z_r}+ 1 are external and are excluded from further consideration and H=$z_{r+1} - z_r$where zr or H represents the height of the contour K_{z_r}
4) Step 3) is repeated for ∀r.
5) Let r = z_{max} to z_{min}
6) Let the set $K_r=\{K_{1r}, K_{2r}, \ldots, K_{lr}\}$ be the set of all contours lying in the plane z_r, and l the number of contours in the plane z_r.
7) Let m = 1 to l
8) Randomly select one point $P(x_p, y_p)$ that lies on the contour K_{mr}.
9) Let n = 1 to (number of contours in the plane z_r) −1
10) Calculate how many times the half-line p starting from the point P(xp, yp) and which is directed in the positive direction of the axis intersects the other contours in the plane z_r.
11) If this number is odd then the contour je is internal and is written as $K_{mr}=\{L_i, KL_j, z_r, U, D\}$ where $D=z_{r+1} - z_r$ and z_r or D represents the depth of the contour K_{mr} and in case when K_{mr} is the circle then $D=z_{2K_{mr}} - z_{1K_{mr}}$ that is, the depth of the hole is equal to the difference z of the coordinates of the circles representing the top and bottom of the hole.
12) If that number is even, then the contour je is external and is written as $K_{mr}=\{L_i, KL_j, z_r, S, H\}$ where $H=z_{r+1} - z_r$ or H represents the height of the contour K_{mr}.
13) Repeat steps 7) -12) until there is at least one contour K_{mr} for which no type has been determined.
14) Repeat steps 7) -13) ∀r.

It is clear that the circle entity will always have *depth* and that the previous algorithm also includes determining the type of contour for holes. Finally, after all previous considerations, the geometry recognition module can be expressed as follows:

1) The *line* entity denoted as $L_i=\{x_{1i}, y_{1i,} z_{1i} x_{2i,} y_{2i}, z_{2i} d_i, C_i, O\}$ where *i= 1, ..., n*, Ci∈A, O∈ of the set of hexadecimal numbers.
2) Entity *circular arc* denoted as $KL_j= \left\{\begin{matrix} x_{1j}, y_{1j,} z_{1j}, r_i, \alpha_{1j,} \alpha_{2j}, l_j, \\ a_{pj}, b_{pj}, a_{kj}, b_{kj}, D, O \end{matrix}\right\}$, where *D=0* if KL_j belongs to the contour *K, j = 1 , ...,* were D∈R, O∈ a set of hexadecimal numbers.
3) Circle entity denoted as $KC_k=\{x_{1k}, y_{1k,} z_{1k}, r_k, z_k, V, T\}$, $V=\{D, H\}$, $T=\{S, U\}$, *k=1, ..., e i H, D ∈ R*
4) Entity contour denoted as $Kp=\{L_i, KL_{j,}, z_p, V, T\}$, $V=\{D, H\}$, $T=\{S, U\}$, *k=1, ..., e and H, D ∈ R, p=1, ..., s.*
5) Geometric shape, or the workpiece denoted as $G=\{K_p, KC_{k,} KL_j\}$ *whereby* $KL_j \notin K_p$.

The elements of the sets shown from 1) - 5) are defined in the previous analysis, and i, j, k and p belong to the set of natural numbers.

3. CONCLUSION

The classic method of NC program development requires qualified operators, complex and often expensive software CAD and CAM packages, program development time is relatively long and there is no guarantee that the part creation time will be the smallest, ie that production costs will be minimized, because the effectiveness of NC programs largely depends on the knowledge or experience of the programmer or operator. This paper considers the possibility of complete autonomy and automation of the NC code generation process by recognizing the geometry from a 3D DXF file. For this purpose, a new algorithm for extracting and recognizing geometric information was created. This information cannot be found in the literature, as many authors mainly deal with 2D geometric shapes.

ACKNOWLEDGEMENT

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SPECIFICITY OF ENGRAVING WITH FIBER LASER MARKING SYSTEMS

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Abstract: *Laser processing is a technology that has quickly become necessary in many manufacturing industries. It is a very precise and economical finishing of parts. The most common application is for laser cutting and engraving. The term laser engraving is often used instead of laser etching and laser marking. However, there is a significant difference between these procedures, primarily in the depth of processing, and thus their application. In this paper, the influence of laser processing parameters on the characteristics of the processing trace was examined. The tests were performed using a TYKMA's (USA) laser marking machine "ZetalaseTM XL" .*

Keywords: *laser engraving, laser etching, laser marking, surface topography, polishing.*

1. INTRODUCTION

Engraving is the technical process of carving lines, ornaments, signs or figures into a hard, usually flat surface by making grooves in it.

Throughout history, engraving has been an important method of creating images on paper, metal, wood, stone, both by artists and for practical application.

Traditional hand engraving with a carving chisel or the use of machines was continued by gunsmiths, goldsmiths and others. Modern industrial techniques such as the use of CNC machines, photoengraving and laser engraving are increasingly used [3].

Hand engraving is used for personalization or decoration of weapons, trophies, knives or other products made of different materials, primarily for personal use, Figure 1 [3].

Figure1. Hand engraving on weapon [5]

In addition to manual engraving, there is engraving with pneumatic, vibrating and other devices, engraving with stamps, etc. Figure 2 shows an example of pneumatic engraving equipment.

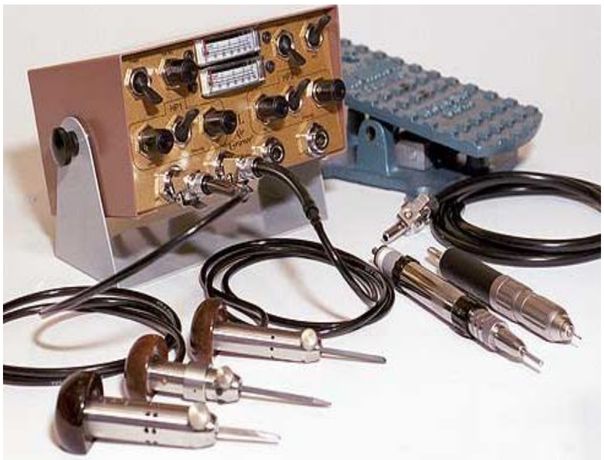


Figure 2. Pneumatic engraving equipment

Hand engraving is less and less used today. It is most often used for personalization or decoration of jewelry, weapons, trophies, knives and other products, usually made of precious metals or wood. Hunting and sports weapons, carbines, pistols for personal use and other weapons with the "signature" of the engraver of the weapons factory are owned by famous world statesmen, artists, politicians, athletes, famous collectors from all over the world. The combination of precious metals with steel creates relief paintings, most often motifs from hunting.

2. ENGRAVING PROCEDURES

In addition to manual engraving, today engraving is done with the help of various machines, namely pantographs with electric tool drive, CNC engraving machine and machine with laser engraving.

The pantographic engraving system originated in the second half of the 19th century. He suppressed manual engraving, just as he was suppressed by the use of CNC engraving machines at the end of the 20th century. Figure 3 shows an example of a pantograph. Engraving is performed by manually guiding the copying probe per copier [4].

The technology of engraving using CNC machines is widely used in today's industry. Today, CNC machines are used in all production activities, where engraving is only one operation in a series of operations of making a product [7].

The most common areas of application of CNC engraving machines are processing of wood, metal, plastic, etc. [7]. Figure 4 shows a CNC engraving machine.

Figure 3. Pantograph with electric drive

Figure 4. CNC engraving machine

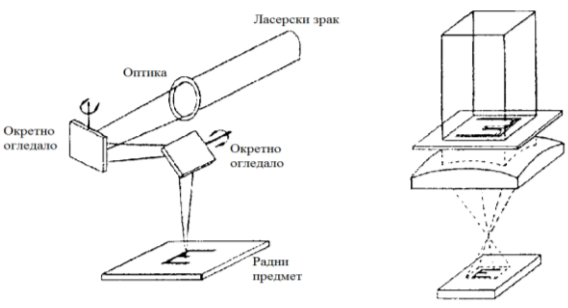
CNC technologies and machines are very reliable because the possibilities of errors are reduced, the influence of the human factor is minimal. The application of CNC engraving technologies aims to imitate manual engraving.

Laser engraving is the process of using a laser to engrave or mark an inscription. The laser can engrave glass, wood, metal, polymer and other materials. Special laser machines are used for engraving, and laser processing varies depending on the reflection and absorption of the processed material and the parameters of the laser beam [6].

Each laser machine consists of three parts: the laser beam source, the control system that allows the laser beam to be directed, the intensity, speed and focus of the laser beam to the surface and the stationary workbench on which the object is placed [1, 2].

The three basic engraving procedures are:

1. the object is stationary and placed on a desk, so that the laser beam is directed by a mirror to its surface, Figure 5a,
2. the object is stationary on a desk of larger dimensions, the laser beam is directed by mirrors and lenses from the source along the X and Y axes to the desired surface. This process has the greatest application for cutting material with a laser, Figure 6,
3. The template is placed between the source of the laser beam and the stationary object. By switching the laser beam source on and off, it pulsates and forms the desired image, engraving or marking the surface of the object, Figure 5b.



a) b)

Figure 5. Schematic representation of laser engraving a) by means of rotating mirrors, b) by a mask

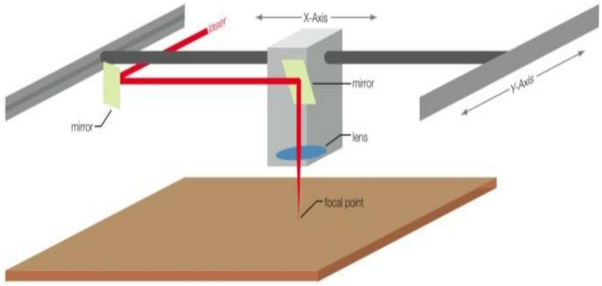


Figure 6. Schematic representation of a laser that performs engraving by moving the laser head in the xy plane

The advantages of using a laser are numerous:

1. high processing speed;
2. there is no mechanical contact with the object of processing, so mechanical damage and dirt are avoided;
3. possibility of processing on inaccessible surfaces (hard and uneven surfaces);
4. the ability to connect to a remote computer system, etc.

The biggest disadvantage of laser application is the relatively expensive equipment. However, the application of this equipment achieves high productivity, flexibility and quality.

3. LASER ENGRAVING, LASER ETCHING, AND LASER MARKING

The terms *laser engraving*, *laser etching*, and *laser marking* are commonly used interchangeably, figure 7. They are similar at the fact that a beam of light is amplified and concentrated at a single focal point. The surface of the metal is heated and its surface is altered. But where they differ is depth of penetration into the metal [9, 10, 11].

- ***Laser Engraving*** physically removes material from the metal by heating the surface and vaporizing the material. This is ideal for high wear environments (physically or highly corrosive). Visibility of the impression is very resistant to abuse because many more layers of the surface have to be removed in order to get to the bottom of the engraving depth.

- ***Laser Etching*** is a subset of engraving also removing material but vaporizes only the surface level. This process is like cutting, except only the top layer of material is being affected. This results in a very shallow indentation (< 0.03 mm) and a highly contrasted marking is produced. Laser etching works particularly well on materials that have two or more layers, like coated metals, anodised aluminium and industrial marking plastics. This is a less durable impression than laser engraving.
- ***Laser Marking*** does not remove material. It creates a marking by heating the surface of the metal resulting in oxidation of the material immediately under the surface layer. This changes the color of the material and creates a high contrast mark leaving the surface intact. This is ideal for identification and safety critical applications where removal of material would compromise its structural integrity. But since laser marking only alters the surface, the marking will disappear once the top layer is removed. It is not ideal for high wear environments if visibility is a concern.

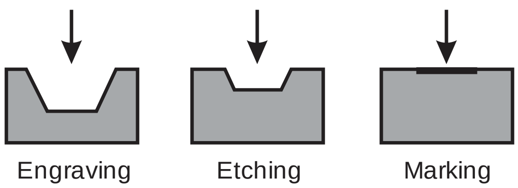


Figure 7. Laser engraving, etching and marking [8]

4. EXPERIMENTAL TESTING

Within this work, the influence of the parameters of laser engraving conditions (laser power, engraving speed and number of passes) on the obtained trace on steel was examined. The depth and height of the resulting engraving and the width of the obtained trace at different heights were measured. The obtained results showed that the parameters of the laser engraving conditions significantly affect the parameters of the obtained trace.

Lines 0.1 mm wide and 10 mm long are engraved on the test plates. Different parameter values were used:

- laser power: 55%, 80% and 100% of the maximum power of 70 W,
- engraving speed 20 mm / s, 100 mm / s, 250 mm / s and 500 mm / s,
- number of passes: 1, 2 and 3..

Engraving yielded 6 of the same parallel lines at a distance of 0.75 mm.

The tests were carried out in the company "Institute for testing weapons and ammunition" in Kragujevac on a USA TYKMA’s laser machine "ZetalaseTM XL", Figure 8. This company specializes in the production of laser machines for marking and engraving. The workspace is large and is used to the maximum.

The device "ISR-C002" INSIZE was used for profiling the obtained engraving traces. During the measurements, the parameters of the topography were not determined, but the height and length parameters of the obtained trace. Figure 9 shows the engraved plate and the method of profiling the engraving traces.

Figure 8. Laser machine “*ZetalaseTM XL*“

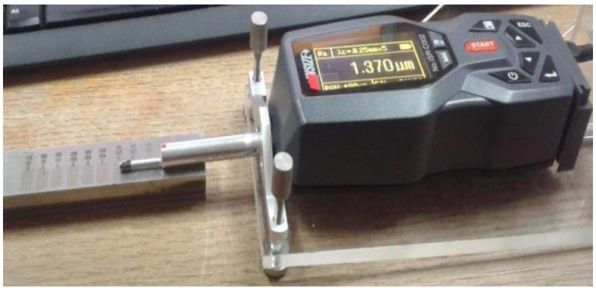


Figure 9. "*ISR-C002*" device and engraving traces profiling

The length of the profiling was 1.25 mm, and two traces of engraving were measured. The measured values at the engraving trace were:

- *Max - maximum height of the engraving trace,*
- *Min - maximum depth of engraving trace,*
- *s1 - width of the indentation trace on the base surface,*
- *s2 - maximum track width on the elevation,*
- *s3 - maximum width at the base of the track*.

Figure 10 shows the characteristic shape of the engraving trace. It can be seen that the material was removed in the central part, but that elevations were made laterally from the removed material. The reason for this trace of engraving is because engraving is performed without the use of working gas, the role of which is the intensive removal of molten material and cooling of the engraved surface.

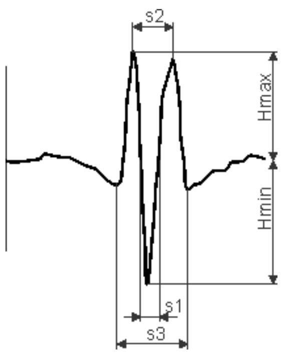


Figure 10. A characteristic shape of a laser engraving trace

Analyzing the results of measuring the widths s1, s2 and s3 (Figure 12), it was concluded that the engraving conditions do not have a significant effect on s1 and s2, while they have an effect on s3. Table 1 shows the results of measuring the traces of engraving on steel plates.

Table 1. Engraving test results

Serial number	num. of passes	V mm/s	P %	Hmin mm	Hmax mm	s1 mm	s3 mm
1	1	500	55	3,45	2,71	0,03	0,08
2	2	500	55	7,45	6,27	0,03	0,08
3	3	500	55	11,8	9,63	0,03	0,08
4	1	250	80	10,66	6,86	0,03	0,08
5	2	250	80	17,13	11,4	0,03	0,09
6	3	250	80	16,24	13,78	0,03	0,11
7	1	100	100	23,8	18,81	0,03	0,14
8	2	100	100	19,85	23,31	0,03	0,14
9	3	100	100	16,99	25,48	0,02	0,17
10	1	20	100	12,84	22,32	0	0,09
11	2	20	100	13,23	25,33	0	0,1
12	3	20	100	14,17	20,1	0	0,11

Based on the table, Figure 11 shows a diagram of the influence of laser engraving parameters on the maximum depth of engraving. As the engraving speed decreases and the power increases, the maximum depth of the engraving increases. As the engraving speed decreases further, the depth of the engraving decreases. At high engraving speeds and lower forces, the maximum depth of engraving increases with increasing number of passes, while at lower speeds at maximum power, the depth of engraving decreases with increasing number of passes. For a very low engraving speed, the number of passes has no effect on the maximum engraving depth.

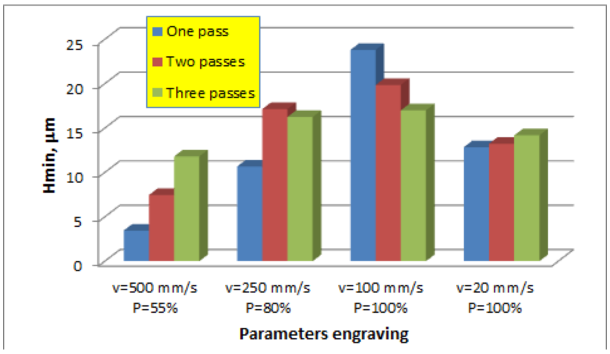


Figure 11. Maximum engraving depth

From the diagram in Figure 12, it can be seen that with increasing power and decreasing engraving speed, the maximum height of the engraving increases. At higher engraving speeds, regardless of strength, the maximum engraving height increases with increasing number of passes. At the lowest used engraving speed and maximum power, increasing the number of passes has no significant effect on the maximum engraving height.

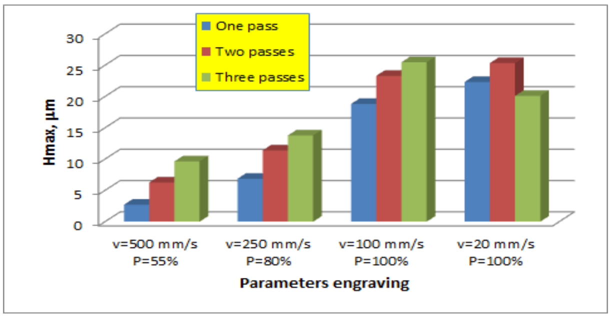
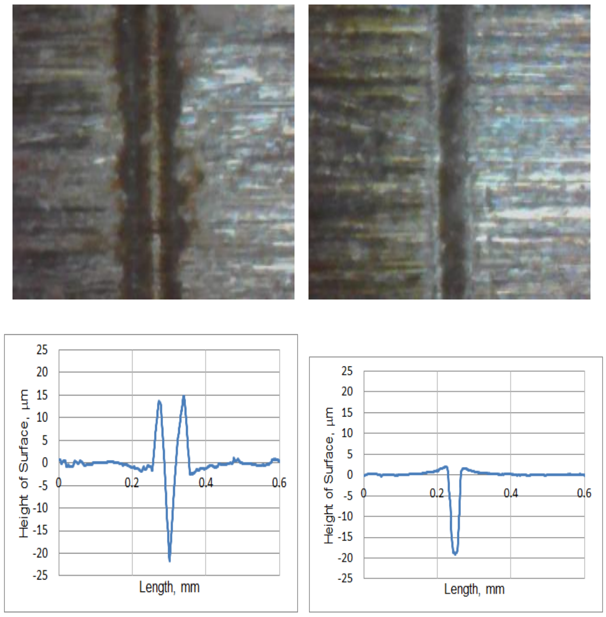


Figure 12. Maximum engraving height

It can be seen from Table 1 that the maximum width at the base of the engraving (s3) is approximately 0.1 mm, but that there are conditions when it can be significantly larger.

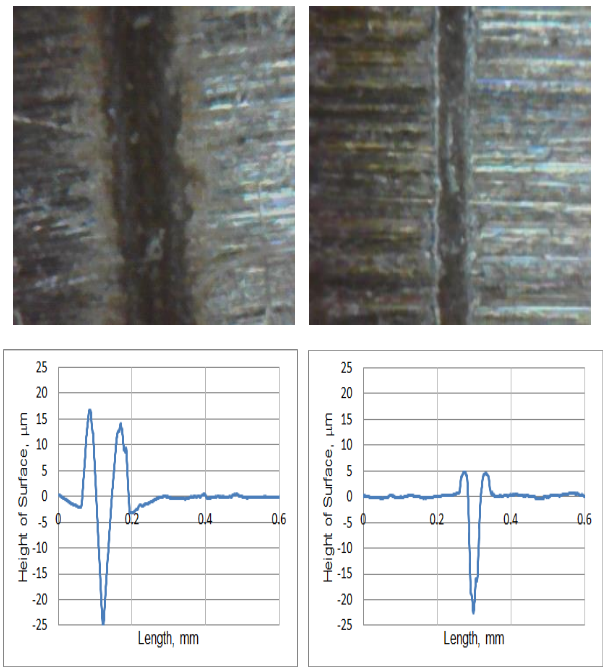
The obtained results showed that using the laser machine "ZetalaseTM XL" does not perform engraving but etching (laser Etching), the depth of the trace is less than 0.03 mm.

The following tests were performed in order to determine the appearance of the engraved surface after removing the surface layer by polishing. P400 sandpaper was used for manual polishing. Figures 13, 14 and 15 show part of the results of this test. Photographs of engraved surfaces and their topography before polishing a) and after polishing b) are shown.



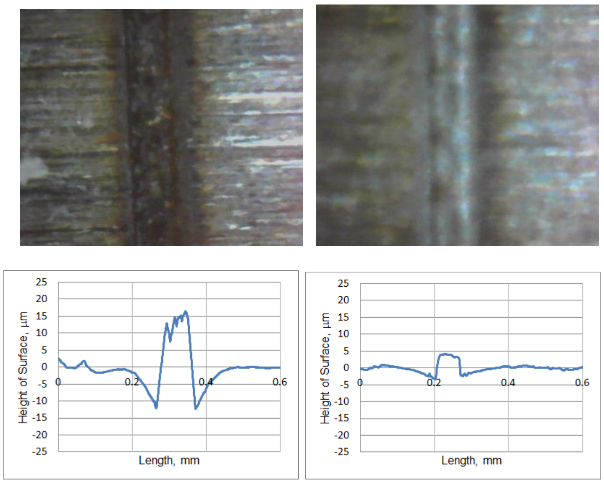
a) b)

Figure 13. Engraving profile on steel (3 passes, power 80%, speed 250 mm / s)



a) b)

Figure 14. Engraving profile on steel (1 pass, power 100%, speed 100 mm / s)



a) b)

Figure 15. Engraving profile on steel (3 passes, power 100%, speed 20 mm / s)

From these images it can be seen that after polishing, when removing a small surface layer (only a few microns), the trace of engraving becomes much smaller in width (width s1) and small in depth. Also, it can be concluded that at a very low engraving speed, there was no formation of a depression (groove) but an elevation, which was mostly removed by polishing.

5. CONCLUSION

Conventional technologies application in manufacturing companies with the aim of increasing efficiency of use, product quality, reduce of costs and save energy and materials".

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Realized tests have shown that laser etching is performed by applying laser marking equipment and selecting appropriate mode parameters. The obtained engraving trace is of very small depth, up to 0.025 mm, whereby elevations are also created, up to 0.025 mm high. The engraved surface obtained in this way is not suitable for parts exposed to wear and aggressive environment because it can easily damage or destroy the engraving. It is necessary to continue research in this area in order to determine the processing conditions under which it is possible to achieve greater depths of engraving. Also, the tests should include the corrosion resistance of surfaces obtained by laser etching and changes in the structure of the material.

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EXPERIMENTAL RESEARCH OF MATERIAL REMOVAL RATE IN POWDER MIXED ELECTRIC DISCHARGE MACHINING

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Abstract: *In order to improve the efficiency of electric discharge machining (EDM) of advanced engineering materials, existing EDM processes are constantly researched and developed. In recent times, possible technological improvement of the EDM process can be achieved by a modern method called EDM in dielectric with mixed powder (Powder Mixed Electrical Discharge Machining - PMEDM). The main goal of the research is to describe the influence of graphite powder as input parameter on material removal rate (MRR) during machining of titanium alloy. In addition, it is of primary importance to investigate the relationship between input factors, such as discharge current and pulse duration on MRR. The analysis of the results led to the conclusion that EDM with the addition of graphite powder significantly improves the MRR. The research is designed to achieve a comprehensive understanding that will provide guidance for future research in the field of PMEDM.*

Keywords: *PMEDM, graphite powder, titanium alloy, material removal rate, discharge current, pulse duration.*

1. INTRODUCTION

Over time, research into electrical discharge machining (EDM) intensified, and the first scientific papers on this machining appeared in the 1960s . Even then, the advantage of this technology was recognised in terms of its ability to machine difficult-to-machine materials . However, with the development and improvement of other machining processes, the application of EDM is limited in terms of productivity and surface quality , .

In the seventies of the last century, more precisely in 1967, Karafuzi presented the idea to improve the EDM process . He proved that by adding additives to the dielectric, an increase in processing productivity can be achieved. Guided by it, in 1971 Pal defined the fundamentals powder mixed EDM (PMEDM) in which the addition of graphite powder at a rate of 1.5 g/l resulted in a significant increase in machining productivity . However, this work does not mention the grain size of the powder, nor does it provide an explanation for the degree of increase in machining productivity.

Recognizing this fact, author Jeswani published a study in 1980 in which he clearly defined the processing conditions and detailed the results obtained . In the experiment, he used graphite powder with a grain size of 10 μm, which he mixed with kerosene at a ratio of 4 g/l. When analyzing the results obtained, the most striking observations are an increase in machining productivity of up to 60% and a reduction in tool wear of up to 15%.

Electrically conductive powder added to the dielectric reduces the insulating properties and causes an increase in the gap distance between the tool and the workpiece. Increasing the working distance means more efficient circulation of the dielectric, i.e. flushing of the working space between the tool and the workpiece, Figure 1. In this way, EDM becomes more stable, which improves the machining performances, such as material removal rate.

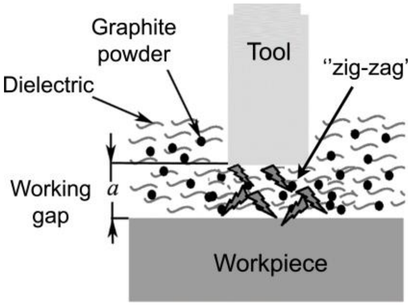

Figure 1. Powder Mixed Electrical Discharge Machining – PMEDM

The space between the tool and the workpiece, i.e. the gap distance, is filled with electrically conductive powder. Under the action of DC voltage, a strong electromagnetic field is created at the smallest local distance between the surface of the tool and the workpiece, i.e. at the point of least resistance to the passage of electric current. In the electric field, there is an intense accumulation of dust particles, which create a bridging effect, forming a kind of electrically conductive bridge, i.e. the so-called "zig-zag" shape. The increased bridge effect reduces the discharge voltage and the insulating properties of the dielectric.

At the same time, the powder change the properties of the discharge channel, which equalizes the distribution of sparks on the dust particles and thus reduces the current density. Due to this uniform distribution of the discharges, there is uniform erosion, i.e. shallow craters on the workpiece, which leads to a reduction in the roughness of the treated surface and thus to an increase in machining accuracy .

The process of electrical discharge machining in dielectric with mixed powder was mainly applied to fine machining, that is, the emphasis was placed only on the quality of the treated surface. Therefore, there is a need to study the effect of adding graphite powder on machining productivity. The present work is concerned with such an investigation. First, the limits of the most influential parameters such as discharge current and pulse length had to be investigated. Then, based on the assumed values of the input parameters, the influence of the addition of graphite powder on the productivity of processing was investigated.

2. EXPERIMENTAL SETUP

For the needs of material processing, a die sinking EDM, manufactured by Agia Charmille SP1-U was used. Experimental tests were carried out on a titanium alloy of $TiAl_6V_4$. The selected titanium alloy has found application in aerospace, biomedical and many other engineering fields due to its exceptional properties such as high temperature and corrosion resistance. Due to its inherent properties, the machinability of this material is not economically acceptable.

In the experimental studies, Dielectric Ilocut EDM 180 from Castrol was used. It is a low viscosity mineral oil that ensures successful flushing of the work area. This oil is recommended by the manufacturer of Agia Charmille machines for electroerosive machining of all non-ferrous and non-ferrous metals. Asbury PM19 graphite powder was used in machining of titanium alloy (PMEDM). This powder was chosen for its high electrical conductivity, which, when mixed with the dielectric, achieves an increase in the gap distance and efficient cleaning of the machining zone. The purity of this graphite powder is 95.5%, while the grain size is 19 µm (granulation). Surfactant Tween 20 $C_{58}H_{114}O_{26}$ is a clear liquid with high density. The role of surfactants is to prevent the accumulation and buildup of graphite powder particles to ensure a homogeneous mixture of powder and dielectric during PMEDM treatment. The recommended value of surfactant concentration ranges from 0.5 ÷ 15 g/l. According to the study, the addition of surfactant above 10 g/l has no effect on the processing effect. Figure 2 shows the experimental machining setting.

Figure 2. Experimental setting

The experiments used the negative polarity of the tool when eroding in a dielectric with a mixed titanium alloy powder. It is well known that when machining steel and other metallic materials, the positive polarity of the tool is mainly used, but this is not the case when machining titanium alloys. The reasons for this can be found in the results of individual studies. Klocke et al. conducted a comparative study on the influence of tool polarity on machining productivity in the machining of steels and titanium alloys . They concluded that the machining productivity is very low when machining this alloy with positive tool polarity. Moreover, the thickness of the defective layer of the workpiece material is greater than when machined with negative tool polarity.

3. RESULT AND DISCUSION

Based on the available literature sources and preliminary experimental investigations, appropriate conditions for the EDM were adopted $TiAl_6V_4$.

The value of the discharge current is limited by the dimensions of the electrode, that is, by the current density. According to the recommendation of the electrode manufacturer Toyo Tanso and literature sources, the maximum current density for graphite TTK50 for rough machining is in the range of 10 ÷ 20 A/cm^2, depending on the type of paired materials. Therefore, in this experimental study, when eroding titanium alloys without mixing graphite powder with dielectric, a discharge current in the range of 1.5 ÷ 7.5 A was used, taking into account the variations possible at the machine tool.

According to the research published in the works on titanium alloy machining, the upper limit of pulse duration was 200 ÷ 500 µs. From the literature, it was concluded that as the pulse duration increases, there is an increase in machining productivity. However, there is an optimum value of pulse length that corresponds to the maximum machining productivity. For the purpose of this test, a pulse length of up to 240 µs was used.

Increasing the pulse duration, at a constant discharge current of 7.5 A, increases the productivity to a pulse duration value of 56 µs. Further increasing the pulse duration to 180 µs decreases the machining productivity. No change in productivity was observed in the range of 180 ÷ 240 µs. For a discharge current of 3.2 A, there is no significant change in machining productivity with increasing pulse duration. Figure 3.

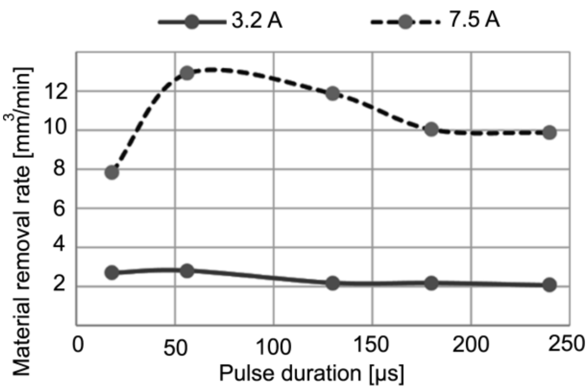

Figure 3. Dependence of MRR on discharge current and pulse duration

A review of the literature revealed that the concentration of graphite powder is generally in the range of 0 ÷ 20 g/l for various evaporated tool and workpiece materials. After determining the upper limit of powder concentration, three experiments were performed with different concentrations of graphite powder in the dielectric. The influence of graphite powder concentration on the productivity of PMEDM of titanium alloy is shown in Figure 4.

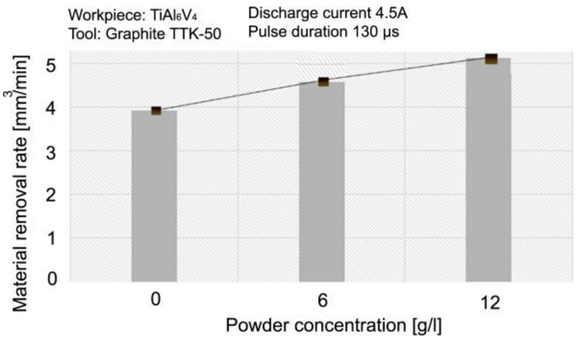

Figure 4. The influence of graphite powder concentration on MRR

The addition of graphite powder in a concentration of 6 g/l at the set processing conditions increases the processing productivity by about 20%. The reason for this is that the addition of graphite powder causes an increase in the working gap between the tool and the workpiece. This results in more efficient dielectric circulation, i.e. flushing of the working space is improved.

4. CONCLUSION

Based on the theoretical and experimental research conducted, as well as the analyzes performed, conclusions and directions of future research can be reported. In order to prove the established hypotheses, experimental studies were carried out in the EDM of titanium alloy ($TiAl_6V_4$) in a dielectric with mixed powder. The greatest increase in material removal rate was obtained at a graphite powder concentration of 6 g/l at a current of 4.5 A. Future research will focus on testing the PMEDM process for titanium alloys considering a larger number and wider intervals of input factors, as well as performing investigations for different erosion depths.

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ELECTROSPINNING AS THE FABRICATION TECHNOLOGY FOR THE ENERGY HARVESTING COMPOSITES

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Abstract: *This paper presents the electrospinning technology as used for the fabrication of the energy harvesting composites, including the review of ceramic-based and polymer-based piezoelectric composites and their electrical outputs for the energy harvesting applications. Energy harvesting is a method for obtaining electrical energy from the environment to be used for powering autonomous electronic devices. Current trend of reducing the size of the devices has led to the increasing number of new energy harvesting materials. Basic principles of fiber fabrication via electrospinning were presented, as well as material characterization methods. The special focus was given to the electrical properties of energy harvesting composites with a review of methods for detecting and measuring electrical outputs of these materials. Electrical performance of the electrospun piezoelectric nanogenerators was discussed.*

Keywords: *Energy Harvesting, Electrospinning, Piezoelectric Composites, Kinetic Energy Harvesting, Piezoelectricity.*

1. INTRODUCTION

Piezoelectric properties of the electrospun materials have been studied for applications in nanogenerators [1], [2], different sensors [3], including smart and wearable sensors and devices [4]–[8], for the monitoring of mechanical and acoustic signals [9], self-powered tissue cultures [10], or novel treatments [1], [11], [12], that is, in diverse biomedical applications [13].

Piezoelectric nanogenerators can exhibit high energy conversion efficiency [14]–[16]. Development of the efficient devices for energy harvesting is of the utmost importance for the development of micro-electro-mechanical systems (MEMS) [7], [8], [17], and especially related to the biomechanical and biochemical energy harvesting [18], [19].

There are different production technologies for piezoelectric materials [20], but the electrospinning is low cost and rather simple technology that can efficiently fabricate vast variety of materials and related structures, including piezoelectric materials [20], [21].

Unlike traditional methods of preparing the piezoelectric materials, which required additional steps to improve the piezoelectricity, the electrospinning method, that was first patented in 1934 by Anton Formhals [22], [23], is now extensively used for production of the piezoelectric nanofibers. Original electro-spinning process was further improved through the change in collectors, distance between polymer jet and collector and differences in voltage supply, thus creating new, near- and far-field electrospinning technologies [17], [24]–[26]. Initially, instead of the plate-like collectors, a revolving collector was introduced as a collector [26], [27]. Further control improvements were investigated with the use of fast-spinning collectors in the shape of drums [26], [28], wheel-like disks [29], and wire drums [30], with varying degrees of effectiveness.

In this paper, the review of electrospinning technology for the fabrication of piezoelectric materials is presented, including the mostly used composites. Material properties, especially electric properties and the dependence on the fabrication method are discussed. Advanced material characterization techniques, FTIR, XRD, PFM, are described. Different approaches in characterization of piezoelectric properties are evaluated, including artifacts used in output signal measuring. Electrical performance of the electrospun piezoelectric nanogenerators is discussed.

2. ELECTROSPINNING PRINCIPLE

The process of electrospinning was long discovered with first polymer filaments utilizing electrostatic force [22], [23]. In its most basic version, the electrospinning process consisted of a pipette to contain the polymer solution, two electrodes, and a DC voltage source in the kV range. Because of the high voltage, a polymer drop from the tip of the pipette was pulled into a fiber. The jet was electrically charged, and the charge caused the fibers to bend in such a way that the diameter of the polymer fiber decreased with each loop. The fibers were gathered in the form of a web of fibers on the surface of a grounded target. This is represented in Figure 1 [23].

Here, a syringe pump maintains a constant flow rate of polymer solution which is dispensed through a needle connected to a high voltage supply and acts as a cathode, whereas collector acts as an electrode that collects electrospun nanofibers.

Like other technologies, electrospinning does not have only one principle. For example, collector shown in Figure 1 does not have to be a plate. It can also be a drum collector as shown in [26]. In general, there are two types of electrospinning: near-field (NFES) and far-field electrospinning (FFES).

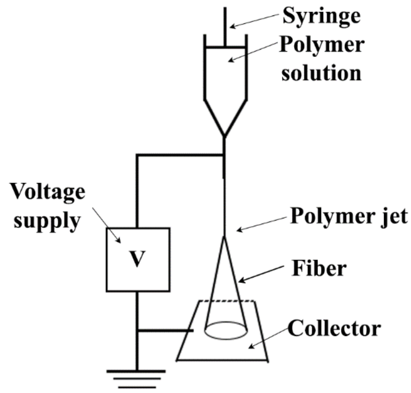

Figure 1. Schematic diagram of electrospinning process [23]

2.1 Far-field electrospinning

As it was already mentioned, a typical electrospinning setup includes a syringe pump, polymer solution, a dispense needle, high voltage supply unit and a collector [17], [24], [25]. A strong electrostatic field is formed between the needle tip and the collector electrode when a high voltage is applied. The electrostatic force draws the polymer melt from the needle and is balanced by the fluid's surface tension force. This produces a droplet with a conical form, known as a Taylor cone. When the electrostatic force exceeds the surface tension force, the droplet ejects a thin liquid/melt jet toward the collecting electrode. If the collection electrode is situated far enough away from the needle tip (tens of centimeters), the jet will undergo a whipping and chaotic process to deposit nanofibers randomly on the collector electrode, as is the case with traditional far-field electrospinning (Figure 2).

The average inner diameter of the dispense needle for far-field electrospinning is a few hundred micrometers, the applied voltage is several tens of kilovolts, and the needle-to-collector distance (*h*) is tens of centimeters. Main characteristic of the far-field electrospinning is the chaotic and random distribution of nanofibers on collector.

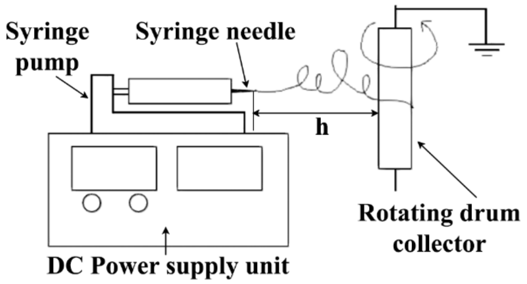

Figure 2. Schematic diagram of the electrospinning setup

The deposition of the nanofibers has significant influence on the energy generation efficiencies of the nanofiber nanogenerators. Thus, many attempts were made in order to control the deposition of nanofibers. At first, a rotating collector was added as a collector instead of a plate-like collectors, as shown in Figure 2 [26], [27]. Further enhancements of the control were examined with the use of fast-spinning collectors in the shape of drums [26], [28], wheel like disks [29] and wire drums [30], which had a various levels of success.

2.2 Near-field electrospinning

Another approach for controlling the deposition of nanofibers is near-field electrospinning, in which the needle-to-collector distance (parameter *h* shown in Figure 2) is decreased to improve the controllability of a fiber deposition. The needle-to-collector distance is decreased to a few millimeters, and the applied voltage is reduced to around 1 kV. By exploiting the stable liquid jet area, the reduced distance and enhanced electric field (as a result of considerably shorter distances), controlled nanofiber deposition on the collector is enabled. A dip-pen method was used in the early stages of the near-field electrospinning process, as illustrated in the experimental findings [31].

To refill the system in this scenario, repeated dips into a polymer solution were required. Continuous near-field electrospinning was later developed utilizing a syringe rather of a probe, as illustrated in [32], so that polymer solution could be fed constantly to deposit continuous nanofibers. These novel changes enable NFES to retain the continuous features of traditional FFES while providing greater control over deposition sites. These and other related NFES techniques can be used to build nanofiber nanogenerators previously unattainable by FFES, such as parallel arrays of nanofibers for nanogenerators [17].

3. MATERIAL AND STRUCTURAL CHARACTERIZATIONS

As piezoelectric properties strongly rely on the material structure, tools and techniques for its analysis are necessary to characterize the crystal/molecular structure for optimal parameters. Instruments such as Fourier transform infrared spectroscopy (FTIR), X-ray diffraction analysis (XRD) and piezoresponse force microscopy (PFM) have been used for this purpose and will be briefly described in this chapter.

3.1 FTIR

FTIR Fourier transform infrared spectroscopy (FTIR) can be used to characterize both the dipole orientation and crystallographic structure of nanofibers. Mandal et al. [26] used FTIR to examine the dipole orientation of electrospun P(VDF-TrFE) nanofibers. They have discovered that the dipoles were aligned in the direction of the electrical field during the electrospinning process. A comparison between the FTIR spectra of an as-spun fiber and a heat treated (above the Curie temperature to assure the random dipole alignment) electrospun fiber resulted in a different absorbance of perpendicularly polarized light. Baji et al. [33] also confirmed the presence of the crystal beta-phase using FTIR.

3.2 XRD

The X-ray diffraction (XRD) technique is commonly used to examine the crystalline structure of materials. Using XRD, Baji et al. [33] observed PVDF fibers fabricated by far field electrospinning. The beta-phase was found to be the most prevalent in electrospun PVDF nanofibers, while other crystalline forms were also detected. Smaller diameter nanofibers, fabricated via electrospinning, were found to have higher contents of beta-phase probably as a consequence of the stretching effect. McCann et al. [34] have also utilized XRD to analyze the structure of polycrystalline barium titanate nanofibers.
For PZT fiber based piezoelectric composites, XRD can be used to detect the presence of the perovskite phase of the material, being essential for the piezoelectric effect [35].

3.3 PFM

Piezoelectric force microscopy (PFM) is based on the detection of a voltage induced deformation of the piezoelectric structure. The PFM principle can be compared to AFM (atomic force microscopy), bringing a micro tip in contact with the surface while applying a sinusoidal voltage. In the case of a piezoelectric material, direction parallel to the PFM voltage direction, leads to a detectable deformation of the material due to the piezoelectric response [17]. PFM, compared to other characterization tools, is well suited for the investigation of individual nanofibers, as it allows piezoelectric measurements at the local level. Isakov et al., 2010 [36] used PFM to generate images of triglycine sulfate based nanofibers. Similar analyses were conducted by Baji et al. for electrospun PVDF nanofibers [33]. PFM has also been used for the characterization of PZT fibers, for example to characterize the polarization domains of the electrospun PZT fibers [37].

4. ELECTRICAL PROPERTIES OF ENERGY HARVESTING COMPOSITES PRODUCED BY ELECTROSPINNING

When a mechanical stress is applied to the piezoelectric materials, it causes transitory surface charge fluctuations and, as a result, electrical potential variations in the material. The output voltages can vary in the range of hundreds of mV and up to a hundreds of V, with the peak currents usually in nA ranges and power delivered by the device in mW [17], [38]. Besides the open-circuit output voltage, short-circuit current and power measurements, a significant criterion for selecting the proper piezoelectric nanofiber nanogenerators for energy harvesting applications is the piezoelectric energy conversion efficiency. This may be determined as the ratio between the measured output electrical power, calculated as the product of measured open-circuit voltage and closed-circuit current, and the estimated generated mechanical energy from the applied strain [17]. Furthermore, it is important to quantify several other characteristics of the piezoelectric materials as relevant for their application. These include impedance, permittivity, dielectric properties at different frequencies, piezoelectric displacement, resonance, and piezoelectric coefficients d_{33} and d_{31}.

4.1 Typical methods for measuring the electrical properties of piezoelectric materials

Generally, the properties of piezoelectric materials may be characterized using commercially available measurement equipment. For example, the dielectric constant and dielectric loss of nanogenerators were measured by an impedance analyzer (Alpha-A High Performance Frequency Analyzer, Novocontrol) between 102 and 106 Hz [39]. The impedance and dielectric constant of the nanocomposite fibers in [40] were measured by an impedance analyzer (Agilent 4194A) between 0.1 Hz and 10 kHz. Other commercial impedance analyzers, Solartron 1296, HP/Keysight 4294A and N4L PSM3750, were also used in the works of Cain et al. [41], Briscoe et al. [42] and Chen et al. [43] respectively. Moreover, a custom built impedance analyzer was used in [44] to measure the impedance of PVDF nanofiber mats as a function of the frequency between 70 Hz to 4 kHz at the room temperature. The method and measuring circuit for *in situ* measurements of the piezoelectric voltage coefficient, g_{31}, which shows the voltage generated by a piezoelectric under applied force, along with measurements of g_{32} were described in [45]. Furthermore, the frequently reported d_{33} and d_{31} piezoelectric coefficients can be determined using the well-known Berlincourt method comprehensively described by Stewart et al. [46]. The other measuring protocols and practices for characterization of piezoelectric materials are summarized in [47] and include testing at high temperatures, electromechanical coupling factor, relative permittivity, dielectric loss, ferroelectric hysteresis and material degradation.

Additionally, recent publication by Alexander et al. [48] showed that the atomic force microscopy (AFM), depending on the different forces between the probe tip and sample, can also be used for extracting electrical properties from the piezoelectric materials. The AFM electrical modes, which are all based on probing of the electrical force, may be used to measure variations of electrostatic forces, surface potentials and dielectric permittivity. They include non-contact electrostatic force microscopy (EFM), piezo response force microscopy (PFM), Kelvin force microscopy (KFM), probing of capacitance gradients as well as Maxwell stress microscopy.

Furthermore, energy harvester experiment setups are mostly custom-built combination of several devices and measuring instruments. They usually include signal generators, synthesized function generators, amplifiers, electrodynamic shakers, dynamic mechanical analyzers (DMA), accelerometers, digital voltmeters, ammeters, charge amplifiers, electrometers, digital oscilloscopes, rheostats, and laser-vibration meters [16] [49] [40] [47]. In addition, the control of these experimental rigs is usually done manually by taping the piezoelectric device [44] [16] or with a custom LabView [50] code or the proprietary software of the Keithley measurement system [51].

4.2 Artifacts in measured output signals

Electrical outputs generated by piezoelectric nanogenerators are usually extremely small and may have very low signal-to-noise ratio. This is particularly challenging when working with the small single nanofiber constructions [17]. For example, while measuring output signals from the nanogenerators, changes in the capacitance could result from a distance between the contact electrodes and potential electrical coupling of the measuring device. These changes may be larger than the actual nanofiber signal. Furthermore, the noise from the surrounding experimental environment and different resistances of the measuring equipment, can introduce artifacts in the signal. As a result, a measured signal must be filtered to remove the noise. Moreover, it is a good practice to conduct the additional tests while measuring the output signals. One of the tests is the switching polarity test, which shows if the polarity of the nanogenerator is fixed, i.e., connecting the measuring instrument's wires shouldn't influence the direction flow of the electrons. When altering the polarity of the measuring equipment, it should result in the output signals being reversed. Additionally, it is important to check the linear superposition principle, which should result in voltage response as the sum of the devices connected in series with the same polarity or a zero-voltage response if the devices are with opposite polarity [17].

The current "gold standard" is "*BS EN 62830-3:2017*" that describes the measurement protocols for electrical characterization of flexible energy harvesters. It includes tests for short circuit current (I_{SC}), open circuit voltage (V_{OC}), power delivered to a resistive load, and optimal electrical load. Additionally, a universal and easy-to-use standard for the voltage measurement of piezoelectric devices was recently proposed by Su et al. [52]. In their work, the inner resistance of voltmeter was set to be larger than a critical value in terms of impedance, loading frequency and accuracy requirement of measured voltage, thus making it a resistance-independent voltage measurement method.

4.3 Electrical performance of electrospun piezoelectric nanogenerators

According to some reports, electrospun nanofibers have the potential to exhibit high energy conversion efficiency in nanogenerator applications such as PVDF [14], [53] or PZT nanofibers [16]. Overview of the commonly used piezoelectric materials and their electrical outputs for energy harvesting applications is given in Table 1.

In the experiments conducted by Chang et al. [14] PVDF nanofiber nanogenerators were tested by varying a diameter from 600 nm to 6.5 mm and a length from 100 to 600 mm. The average conversion efficiency was calculated to be 12.5%, although the maximum voltages were ~30 mV. Even higher conversion efficiency of 13.62% was reported in [54] for a membrane device of randomly oriented electrospun PVDF nanofibers with the area of 2 cm^2 at a compression frequency of 10 Hz while generating up to 2.21 V. This is a considerably higher value than the conventional devices made from piezoelectric PVDF thin films (0.5–4%) or commercial PVDF thin films (0.5–2.6%) tested under the same conditions [17]. In general, nanogenerators with the smaller diameters have higher energy conversion efficiency even if the piezoelectric properties change due to the slight differences in the processing conditions. Recent work of Fang et al. [55] showed that using the needle electrospinning method to produce the nanofiber web from 16% PVDF solution can increase the conversion efficiency by 14% compared to nanofibers produced by disc electrospinning but the voltage and current dropped from 2.6 V to 2.05 V and 4.5 µA to 3.12 µA. Also, increasing PDVF solution to 20% led to a similar electrical output. Some of the nanogenerators with the highest voltage outputs were produced by Shi et al. [53] and Guo et al. [56]. They demonstrated that by combining the 15wt% of $BaTiO_3$ nanoparticles with 0.15wt% of graphene nanosheets the generated open-circuit voltage was 11 V and electric power 4.1 µW under a compression frequency of 2 Hz and 4 mm strain. However, during the finger pressing, the nanogenerator managed to produce a peak voltage of 112 V. Moreover, the hybrid nanogenerator produced by pairing the two components: electrospun silk nanofibers and PVDF [56], managed to generate the open-circuit voltage of 500 V, short-circuit current of 12 µA, and power density of 0.31 mW cm^{-2}, respectively. The list of other electrical outputs of nanogenerators with various material combinations is given in Table 1.

Electrical performance of the piezoelectric materials is of the utmost importance for several other applications, besides energy harvesting. Their possibility to influence a healing process of the tissues has been proven, even though this approach is still largely in its research phases. For example, bone healing process under the influence of the electric stimulations has been long proven. Such approach is already widely used in regenerative clinical medicine, but only by using externally applied devices that stimulate the tissues over the skin. Novel piezoelectric materials has opened up new directions in these treatments, due to the possibility to harness the energy stored within the material itself and use it for some type of treatments that otherwise would engage some externally powered device. Further research in the development and application of the piezoelectric materials will surely enable significant advancements in several fields, including medical treatments in regenerative medicine.

Table 1. Overview of the commonly used piezoelectric materials and their electrical outputs for energy harvesting applications

Fabrication method	Material combination	Typical applications	Output power/voltage/current	Ref
Disk electrospinning needle electrospinning	PVDF in DMF-acetone solvent	Nanogenerators for microelectronic devices, powering LEDs, photodetectors, smart textiles	Voltage: 1 – 3 V Currents: 1.4 – 4.5 μA	[55]
Electrospinning	BNT-ST embedded into PVDF-TrFE	Power for wearable devices or sensors for health monitoring	Voltage: up to 3 V	[57]
	Coated zinc oxide/PVDF	Human motion tracking	Voltage: 83.3 mV/(m/s) Power: 134 nW	[4]
	BaTiO3/PVDF	Human motion monitoring, wearable electronics	Voltage: 0.1 V Current: up to 300 nA	[58]
	Polycarbone acrylate di-epoxide (PCADE)/PVDF	Energy harvesting, biosensors	Not reported	[59]
	GK Graphite powder/PVDF	Biosensors	Voltage: 1.5 V, Current: 100 nA, Power: up to 5.5 nW	[60]
	PVDF/PZT	Nanogenerators		[17]
	NFC, NFCh, CNC, MFS	Human motion monitoring, nanogenerators, smart materials	Voltages: up to 500V, Current: up to 12 μA Power: up to 0.31 $mWcm^{-2}$	[56], [61]
	Ag/PVDF	Sensors	Not reported	[62]
	TiO2	Solar cells, Li-ion batteries, supercapacitors, fuel cells	Not reported	[63]
	PLLA	Strain sensors, human motion energy harvesting	Voltage: 0.55 V Current: 230 pA Power: 19.5 nW	[64]
Far-field electrospinning	PZT	Biosensors, medical treatments with small currents	Voltage: up to 1.6 V	[16], [50], [51]
Electrospinning (far or near field)	PVDF	Harvesting energy from human movements, biosensors	Voltages: 2.21 V [54], 30 mV [14], 24.6 V [49], 11 V to 112 V [53]	[14], [31], [38], [49], [53], [54], [65], [66]
Electrospinning	CNT/PVDF	Mechanical motion control	Voltage: 9 V Current: 0.01 A	[67]

5. CONCLUSION

In this paper the electrospinning principle is briefly described and its application in energy harvesting, as the method for obtaining energy from environment. Furthermore, the material characterization techniques, FTIR, XRD, PFM, commonly used for determining the composite structures, are described. Brief review of piezoelectric composite materials, their application and electrical characteristics was given. The review of typical methods for detecting and measuring the electrical outputs and electrical performance of electrospun piezoelectric nanogenerators were presented, with artifacts used in output signal measuring.

Unlike traditional methods of preparing the piezoelectric materials, which required additional steps to improve the piezoelectricity, the electrospinning method can be efficiently used for production of the piezoelectric nanofibers. Through mechanical stretching and poling of the polymer solution, this method leads to an increase in the electrical potential of the material due to the higher content of β-phase. Modern electrospun piezoelectric nanofiber devices have been vastly improved by modifying polymers and forming of composite structures, in order to enhance their piezoelectric properties.

Advanced characterization techniques such as standard or customized FTIR, XRD, PFM technologies can provide valuable directions for improvements of the piezoelectric materials and their properties, as well as for the design of novel composites with piezoelectric properties.

Further research is important, related to piezoelectric materials, their fabrication technologies and characterisation methods, considering that the need for energy in the world constantly grows, especially for self-sustaining devices, also including energy generation and storage systems.

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RESEARCH ON LASER TREATMENT IN MECHATRONICS

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Abstract: *The report presents a study on laser beam treatment, oriented to application in mechatronics. A historical overview of the discovery of the laser is made, the basic concepts and types of lasers are considered. The manufacturing process in the various laser beam operations is explained. Special attention is paid to the most modern operations such as laser stereo-lithography, holography, combinations of operations in micro- and nanotechnology, determining the state of laser processing at the moment. Specific examples of details are given and the machinability of different materials is analyzed. The results can be used in the teaching and research process in higher education, as well as by specialists in practice.*

Keywords: *laser beam treatment, types of lasers, stereo-lithography, holography, operations in micro- and nanotechnology, machinability of different materials*

1. INTRODUCTION

1.1. Historical review

The theoretical foundations for the development of quantum mechanics were laid in the twentieth century, 1917 by Einstein with the development of the theory of relativity. Here Einstein lays the foundations forthe phenomenon of “Stimulated Emission,” which is the basis of all laser research. The term LASER is an acronym for the expression "Light Amplification by Stimulated Emission of Radiation". In 1959, the Russian scientists Prokhorov and Basov, together with the American Towns, began developing the first laser based on a ruby solid, for which they received the Nobel Prize in 1964. Technical implementation of various types of lasers was carried out in practice from 1959-60 and in the USA with the development of a ruby laser by Theodore Maiman in the company Hughes Aircraft Comp. Malibu and helium - neon gas laser from the Bell laboratory. The first gas laser (helium-neon) was invented by Ali Javan in 1960, and the Excimer laser - again by Basov in 1970. The production of lasers for technological purposes began in 1964-66, after which the laser beam treatment took place reality.

Alexander Prokhorov (1916-2002), Nikolai Basov (1922-2001), Charles Towns (1915-2015), Albert Einstein (1879-1955), (Theodore Maiman (1927-2007), Ali Javan (1926-2016)

2. MAIN HEADING

2.1. Basic concepts

The laser is a source of monochromatic coherent light beam with constant wavelength, constant phase and brightness. Its principle of operation is a combination of quantum mechanical and thermodynamic processes. The following terms are used:

Absorption: A light source, acting on an atom, causes or induces an oscillating dipole, which receives energy from the radiant field and the atom goes into an excited state (F.1).

Excited state,
Emitting dipole,Basic state

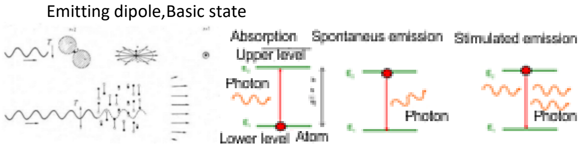


Figure 1. Application of abnormal absorption in a dielectric. Absorption and emission of photons

The laser consists of three main components: an active medium, an external power source or another source, called a pump and a resonator (Fig. 2).

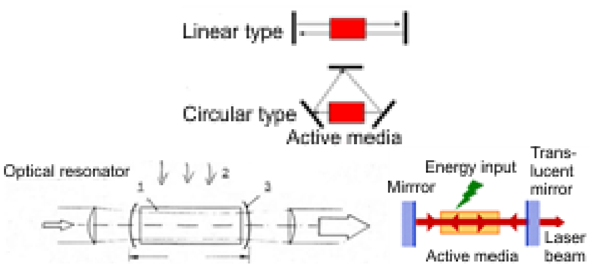


Figure 2. Optical resonator - linear and circular type **Legend:** 1-active media, 2-power supply, 3-translucent mirror

Induced emission: Apart from spontaneous emission, the excited atom can also pass into a normal state under the influence of a light quantum falling on it, which is referred to as induced or stimulated emission. The most important result is, that it amplifies the intensity of the incident light. The number of induced emission cycles over a period of time (s) is determined:

$$Zi = n_2 . u . B_{21} . f (w), \qquad (1)$$

where n_2 is the amount of excited atoms, pcs.; u - radiant energy density, W / cm^2; B_{21}-Einstein's coefficient, f(w)-dependence on the frequency of probability of transition to the excited state.

In order for amplification to prevail, an inversion state must be reached, more atoms must be in a higher trajectory or excited state than in a normal state (n_2 greater than n_1). This condition cannot be achieved directly by irradiating with light, but is only an approach to reaching higher energy levels.

Inversion in a three-level system: If the atom is in the excited state E_3 after irradiation with light, it has two possibilities to return to its normal state:

1. By spontaneous emission directly in the normal position;

2. By passing through a lower energy level (orbit) E_2.

Amplification by feedback and self-excitation: A significant increase in amplification is achieved if the optical medium (medium) is located in an optical resonator. The length of the laser medium is increased by reflection. The optical resonator consists of at least two interconnected, interferometric mirrors, between which a standing light wave can be formed. The gain (1.10^4 - 1.10^9) determines the oscillations of the amplifier (Fig. 3)

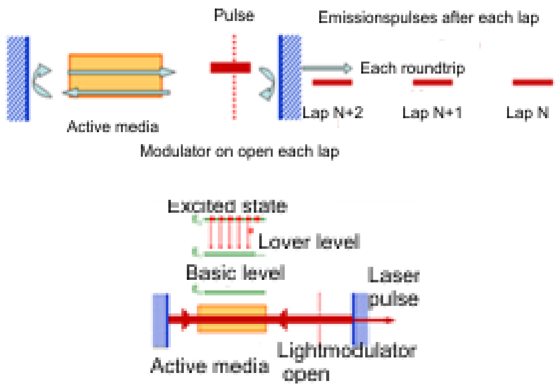


Figure 3. Methods: Feedback mode, Lock mode

For technological use, the output laser beam is focused using a system of lenses, all energy is concentrated on a very small area (up to 3.10^{-3} mm^2) and a beam with a high energy density (up to 1.10^5 kW /cm^2) is achieved. The more important types of resonators and ways of focusing the beam are (Fig. 4):

- plane-parallel;
- confocal (most advantageous for small refractive losses); $r_F = \lambda/\pi \ f/r$, (2)
- hemispherical;

$$r_F = \lambda/\pi \ f/r \ (2p + l + 1), \qquad (3)$$

- with two mirrors with a large radius of curvature (at high gain).

$r_F = \lambda/\pi \; f/r \; (2m + 1)\,(2n + 1)$,(4)

where f is the focal length, mm; r - the radius of the lens, mm, wavelength, nm; r_F - radius of the monochromatic, coherent laser beam.

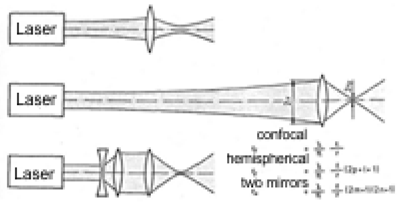


Figure 4. Focusing schemes

2.2. Types of lasers

Currently, about 150 types of laser systems based on various active media are used (the most modern so far are the so-called atomic lasers), the most important of which and their distribution by function are shown in Tables 1 and 2 [1, 2, 3, 5]:

Gas lasers:

- molecular (ArF, λ = 193 nm; KrF, λ = 249nm; XeCl, λ = 308 nm);
- argon-ion - Ar (in blue and green: λ = 450 ÷ 500 nm);
- helium-neon - HeNe (λ = 632.8 nm, λ = 543.3 nm, λ = 1.15 μm, λ = 3.39 μm) [4];
- carbon dioxide - CO_2 (λ = 9.6 ÷ 10.6 μm);
- "Excimer."

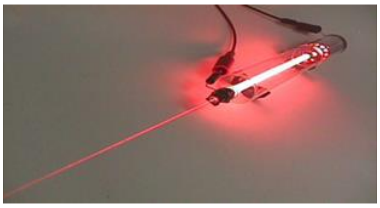
Earlier generations of devices used lasers to produce light directly. According to the orientation of the discharge and the velocity of the gas, they are subdivided into two main basic constructions: with a longitudinal beam parallel to the resonator and with a transverse beam perpendicular to the resonator, shown in Figure 5. By design, lasers are also for projection and direct lithography [1, 7].

Table 1. Laser systems and their typical data

Laser system	Active media	Type of arousal	Typical length, cm	Constant output power,W	Pulsating power, W
gas laser	noble, molecule. gases metal vapor	chemically, gas discharge	50	1.10^{-3} - 1.10^{4}	1.10^{3} - 1.10^{5}
liquid based laser	organic paints in solvents	flash, laser light	5	1.10^{-1}	1.10^{4}
semiconductor laser	semiconductor elements doped with Zn / Se	electricity	0,1	1.10^{-1}	1.10^{4}
solid state lasers: - ruby; -Ne-glass; - Ne-$Y_3Al_5O_{12}$; - Ga-arsenide; - laser diodes.	crystals and glasses with metal atoms or rare metals	flash, gas discharge lamps or Wf-wires	5	1.10^{-2} - 1.10^{2}	1.10^{4} - 1.10^{9}

Table 2. Distribution of lasers by functions, application and types

By application	By material processing operations	By species
Metalworking 28% Mechanical Engineering and Electronics 20% Medicine 13% Graphic 8% Optical memories 15% Communication equipment 10% Measuring equipment 3% Other 3%	Cutting 33.7% Marking, engraving 24.4% Welding 20.2% Drilling, Perforation 11.9% Microprocessing 11.4% Surface treatment 2.3% Soldering 1.0% Chemical methods 0.5% Other 3.1%	Gas lasers: CO_2 24% Ion lasers 15% Helium-neodymium 8% Excimer 4% Helium-cadmium 1% Solid state lasers 16% Laser diodes 29% Liquid-based lasers 3%



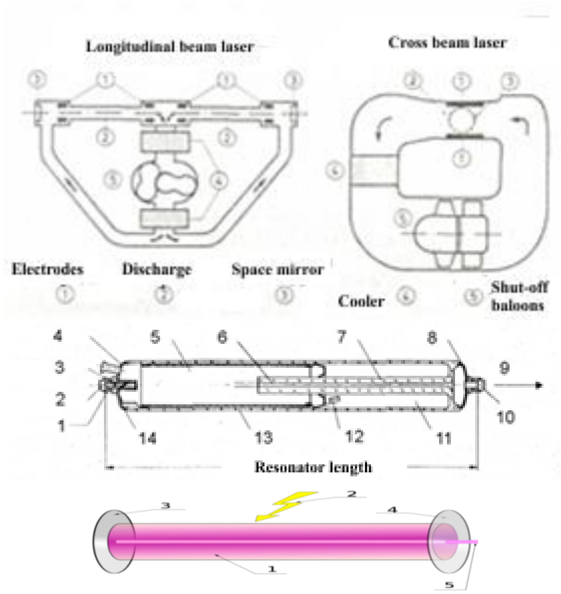


Figure 5. Technical concepts of CO_2 powerful lasers for different laser beam processing (left) and construction of gas helium-neon laser with beam length for lithography

Legend: 1-holder for the mirror; 2-fully reflective mirror; 3-eyepiece for observation (only for polarized lasers); 4-cathode connection; 5-cathode; 6-capillary hole; 7-capillary; 8-anode connection; 9-emitting rays; 10-semi-reflective mirror; 11-helium-neon-gasmedium; 12-aperture; 13-glass tube; 14-glass-metal coating. Below: 1-active medium, 2-pumping source, 3-100% mirror, 4-translucent mirror, 5-laser beam

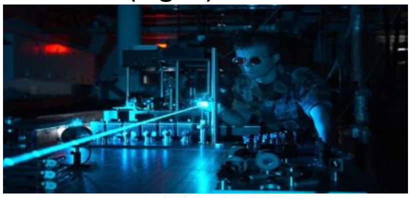
Liquid lasers:

- organic molecules (λ = 380 ÷ 750 nm) - one molecule covers 50 nm from the light ultraviolet to the infrared spectrum.

The liquid is poured into a bath between the mirrors, and a gas or ruby laser can be used instead of a lamp. The beam is obtained monochromatic with filters.

Semiconductor lasers

In semiconductor-based lasers, the emission of laser light from the semiconductor is the result of the stimulated recombination of the excited electrons in the conductive layer with the holes in the valence layer. At a current above the threshold of self-excitation, light with a coherent wave is formed and the semiconductor element begins to work as a laser (Fig. 6).



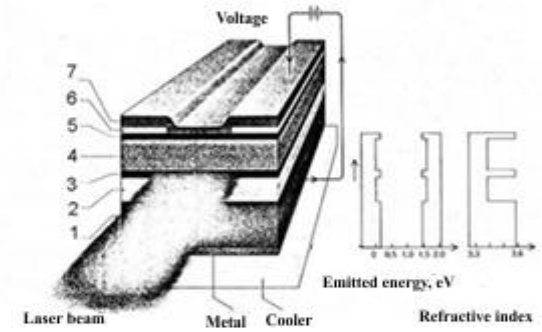


Figure 6. Multilayer semiconductor laser and its performance characteristics

Legend: 1-strongly n-doped gallium arsenide; 2-n-doped gallium-aluminum arsenide; 3-gallium arsenide; 4-p-doped gallium-aluminum arsenide; 5-strongly p-doped gallium arsenide; 6-silicon dioxide; 7-metal

Solid state lasers:

- Diodes: GaN, GaAlInP, AlGaAs. Wavelength according to the material (λ = 350 ÷ 1030 nm). Efficiency 60%.

- Crystalline: Nd_3 +: YAG ($Y_3AL_5O_{12}$) λ = 1064 nm. They use matric doped with ions. Glass, ruby, sapphire.

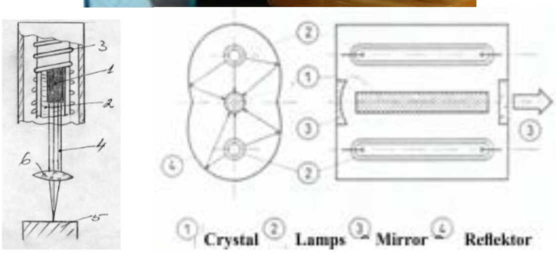


Figure 7. Ruby laser

Legend: 1-ruby stick; 2-liquid nitrogen; 3-xenon flash; 4-luminous flux; 5-detail; 6-optical system

Figure 7 shows a diagram of a laser head based on a solid body - ruby. The position of the mirror can be as shown above on the right, and also directly on the polished mirror surfaces of the crystal, obtained by evaporation (on the left).

2.3. Laser processing

The process of laser beam treatment involves the local melting of the material at the point of irradiation, which results in partial evaporation due to the absorption of the monochromatic, coherent laser beam. The transformation of laser energy into heat (5500-9000^0 C) is carried out by absorbing the radiation in the part. Figure 8. shows the state of the material under laser irradiation. The absorption of laser radiation increases with increasing temperature, the part heats up and the absorbed power increases.

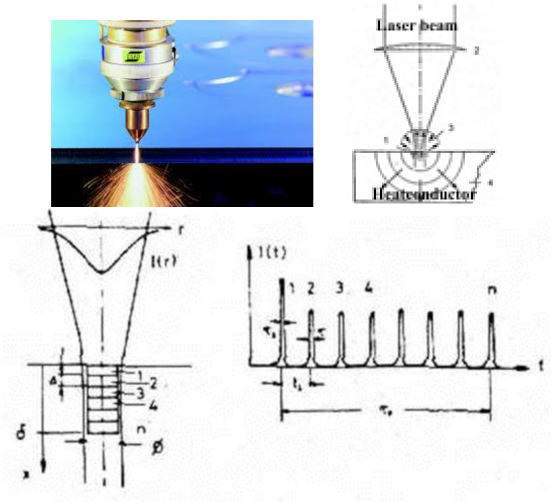


Figure 8. Drilling process with controlled laser radiation

Legend: 1-evaporated volume; 2-focusing optics; 3-coming cloud of vapor; 4-detail

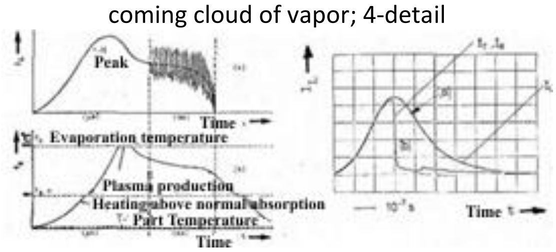


Figure 9. The energy is controlled by the shape of the laser pulse, change of intensity in time, temperature and reaching abnormal absorption during welding

There is a process of evaporation of the material in the focused processing spot, which proceeds very quickly and an explosive removal of material from the part takes place. By appropriate selection of the energy-pulse duration ratio, better radiation absorption can be achieved. The type of treatment is determined by the amplitude (shape), change in pulse intensity over time (frequency) and temperature (Fig. 8, 9) [6].

2.4. Types of laser beam operations

The operations for laser beam processing depending on their basic parameters are presented in Figure 10.

Intensity Pulse duration

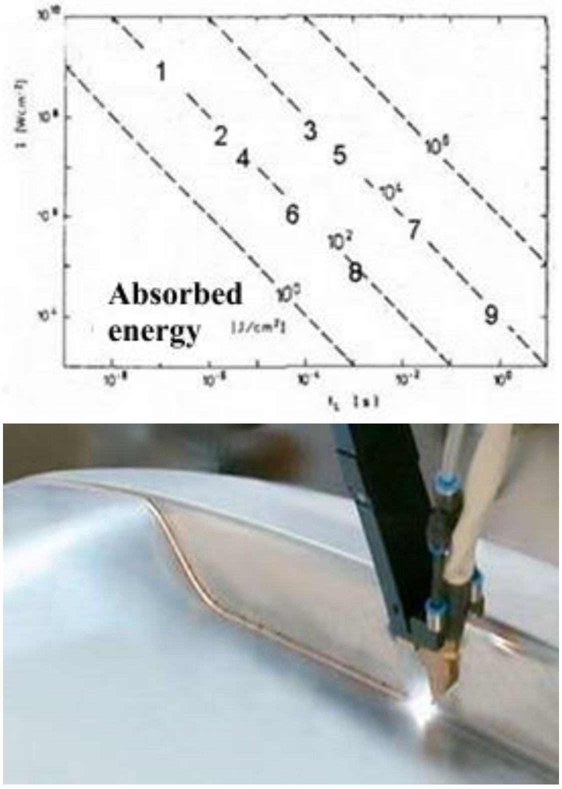


Figure 10. Laser beam operations

Legend: 1-change the properties of the surface layer; 2-drilling; 3-cutting; 4-engraving and coloring; 5-deep welding; 6-melting; 7-welding; 8-tempering; 9-hardening

- ✓ **Laser beam treatment by material removal**
  - **Cutting and Drilling**

During the cutting operation, pulses of different durations are applied. In Figure11. the schematic diagram of a gas CO_2 laser for cutting, which is typical for industrial applications, is shown. The laser radiation is excited by an electric glow discharge, which is maintained in a laser medium (mixture of helium, oxygen and carbon dioxide) at a pressure of about 40 mbar. Laser cutting machines are discus-sed in detail in [11].

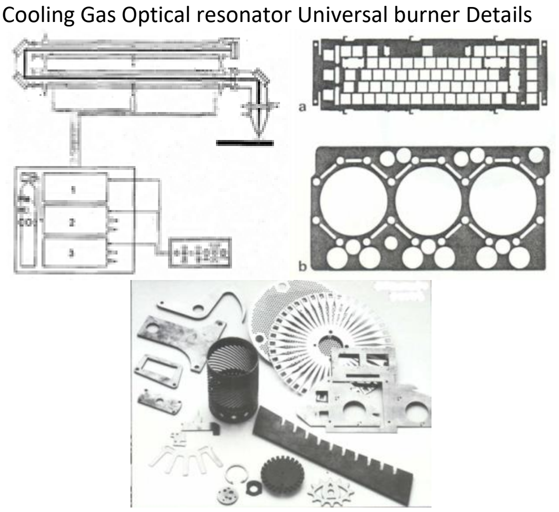


Figure 11. Gas CO_2 laser for cutting. Details (Companies Metafot, Trumpf, Germany)
Legend: 1-high voltage generator, 2-vacuum pump, 3-cooling

In practice, the following parameters of cutting with gas CO_2-lasers of different materials have been achieved - Table 3.

- **Welding**

For drilling and welding operations, pulsed lasers based on a solid body (neodymium-glass or neodymium-yttrium-$Y_3Al_5O_{12}$) with excitation by two flashes are used (Fig. 12). When drilling, short pulses are used, which are repeated after evaporation and blowing of the material. The parameters that affect the process are: the intensity and diameter of the beam, the pulse shape, the depth of processing, the material (melting and evaporation temperature, thermal conductivity, coefficient of thermal expansion), the geometry of the details, the properties of the surface layer (absorption, reflection , foreign inclusions such as oxides, varnishes, galvanic and zinc coatings) [8, 9].

Laser drilling is used in mechatronics for

Table 3. Cutting parameters for gas CO_2 lasers

Material	Thickness, mm	Cutting speed, mm/min	Cutting width, mm
unalloyed structural steels	0,205	6000	0,1
unalloyed tempered steels	0,3	6000	0,1
rolled sheet metal	1,5	2500	0,1
spring steels	4	600	0,3
alloy steels	0,24	6000	0,1
high alloy steels	1	3000	0,1
chemically improved steels	3 - 3,5	600	0,2
titanium and its alloys	3	13000	0,4
lead	2 - 3	1800 - 2500	0,2
rubber (gummy)	5	1600	0,3
cardboard	3	600	0,2
quartz glass	1,9	600	0,2
ceramic-alumina	1	3000	0,1
polyamide fabrics	0,1	2.10^5	0,1
polystyrene	4	1600	0,5
polypropylene	4	2000	0,4
polypropylene with 20% glass	4	1250	0,3
polypropylene with 30% glass	4	950	0,3
polyethylene - soft	4	1200	0,4
polyethylene - hard	4	1050	0,7
spectacle lenses of artificial material	1,6	3500	0,2
textile fabrics	20	-	-

precision holes in the stones of watches, diamonds and hard metals, rasters from holes (mainly with solid-state lasers), as well as for perforation and marking of foil or data carriers.

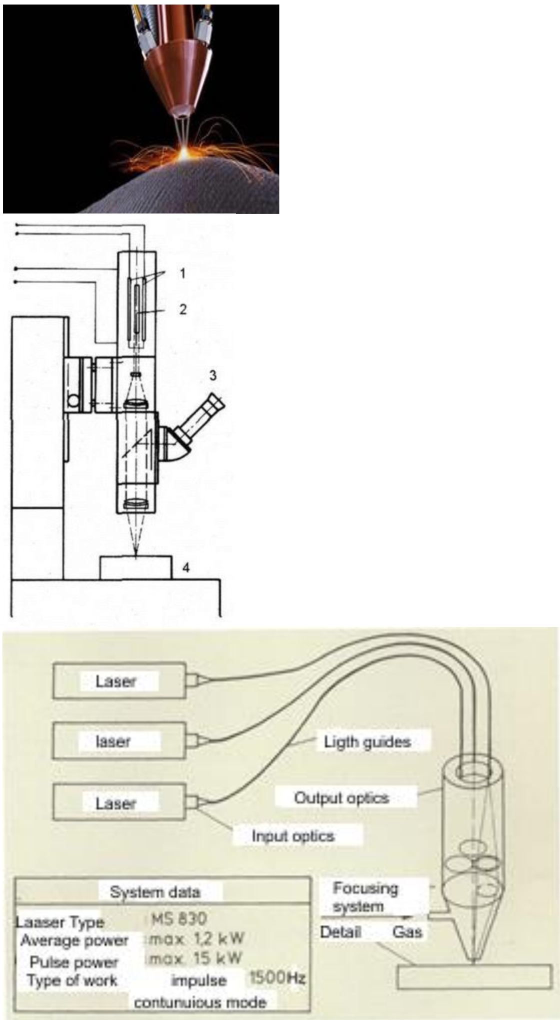


Figure 12. Laser for drilling and welding. Schematic and visual representation of the "3 in 1" laser drilling system. Laser type MS 830, average power max 1,2kW, impulse power max 15kW, pulse mode 1500 Hz

Legend: 1-flashes; 2-neodymium laser media; 3-eyepiece for observation; 4-detail

The characteristic features of laser welding are: long machining distance (up to 200 mm), non-contact energy transfer, no deformation, minimum forces for fixing the parts in any position, simultaneous welding in different places by beam splitting, minimal heating and processing in a normal environment (atmosphere). The welding point is less than 1 mm in diameter and the seam width is also less than 1 mm at approximately the same depth [8]. Examples of details by welding are shown in fig. 15. and 16.

The advantages of laser beam welding are:

• very high energy density - up to $1,10^9$ W / cm^2;

• precise control of the radiated power and the introduced heat;

• welding of plastics;

• possibility for welding with shielding gas in chambers and hybrid

The disadvantages of laser beam welding are:

• large equipment-investments (Figures 13 and 14 below);

• welding of micro-parts only (at an intensity of several 100 Ws welding of larger parts with dimensions of the order of mm).

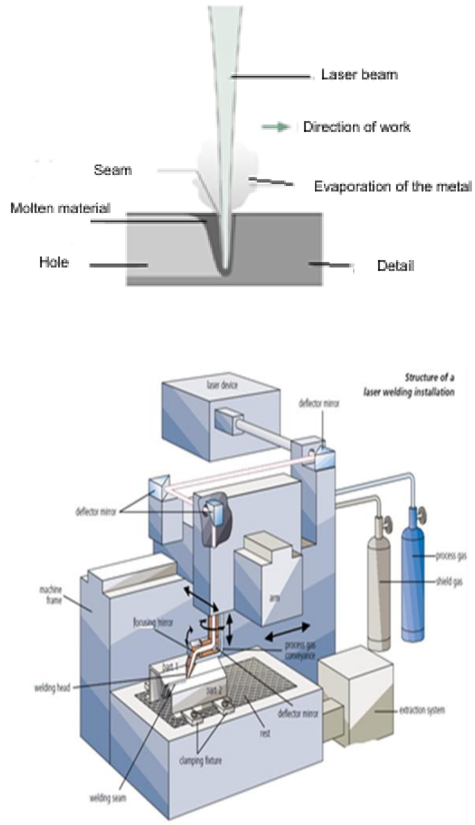


Figure 13. Deep welding. Structure of laser welding installation

Legend: laser device; reflective mirrors; two guides; shielding gas; gas to support the process; focusing lens, welding head, two pieces of mat. fixed in place, weld, separation system

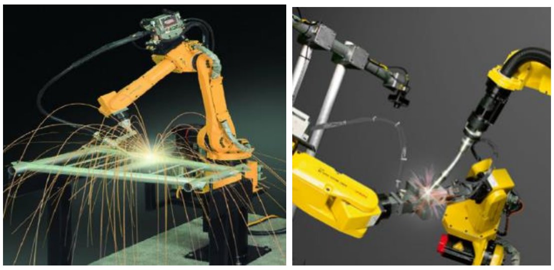


Figure 14. FANUC robotic welding systems [10]

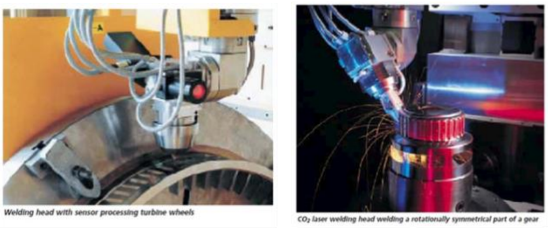


Figure 15. Gas laser welding of turbine and gear

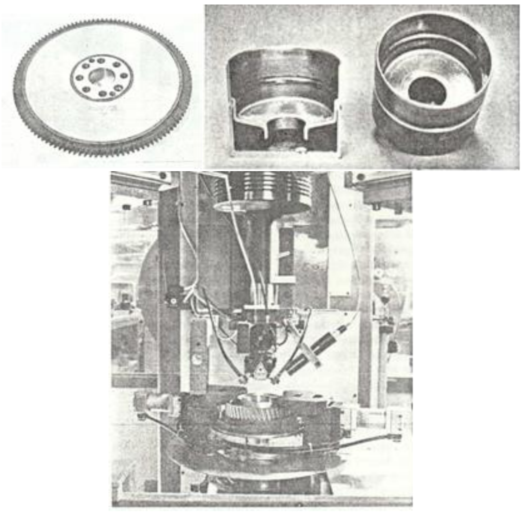


Figure 16. Details, welded with laser beam (companies Daimler-Benz, ZF, Leybold) [7]

Hybrid laser welding with pulsed light arc and metal-inert gas is shown in fig. 17 [9]. The latter is carried out by a CO_2 laser system with a total power of 4 kW and a current arc of 250A (Fronius Austria) and is used for welding the tank of material S235JR at a thickness of 9mm with radial-round seams in the car AUDI A2.

Micro-welding of details and elements from the electronic industry and spot welding of the moment springs for winding the watches are also applied.

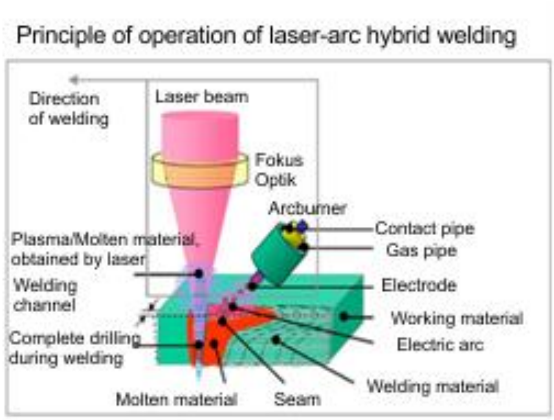


Figure 17. Hybrid laser - arc welding

- ✓ **Structuring and modifying the surface layer**

It is necessary to specifically note the use of the laser beam for micro-structuring. For the operations of micromachining, marking, engraving and surface treatment of metals, glass, artificial and organic materials, the pulsed ultraviolet gas laser LAMBDA PHYSIK Excimer is used, which has a significantly better degree of absorption (Fig. 18). It uses a gas mixture of the noble gases xenon and argon and the halogen gases chlorine and fluorine. Reaction:

$$Xe + HCl = Xee\text{-}Cl + H = Xe + Cl + H \qquad (5)$$

With the help of a parallel coherent laser beam, microstructures with high quality and a form factor of 10 : 1 are obtained. The most commonly used lasers are: Nd: YAG (wavelength λ equal to 1.06μm), CO_2 (λ equal to 10.6 μm) and Excimer laser (λ equal to 0.2 ... 0 , 3 μm).

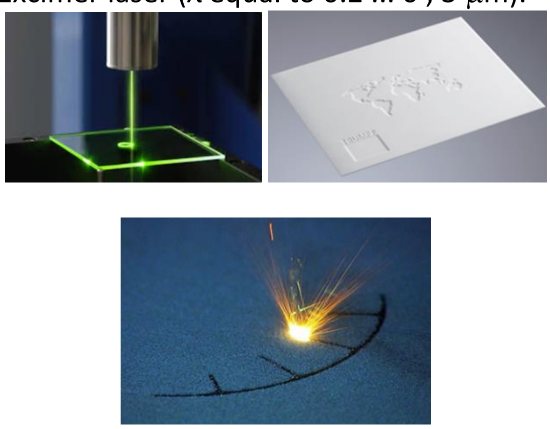


Figure 18. Marking, micromachining, surface formation during sintering

In laser holography, the concept of operation connects the principle of a rotating disk, which is used as a CD (compact), MD (mini) or DV (digital) disk, with the holographic method of volumetric storage. The data are recorded on a photopolymer layer in the form of a microscopically reflected hologram, and the holographic multiplication method allows the arrangement of the variety of microholograms. The reading of the data on the disk is also performed with the help of a focused laser beam and in case of compatibility with the protection of the various compact, digital or mini-optical types of disks (audio / video equipment). Similarly, holograms are applied to important documents and banknotes, or modernist works of art are engraved on foil or thin metal sheets. Figure 19 explains the principle of operation in laser microholography [12].

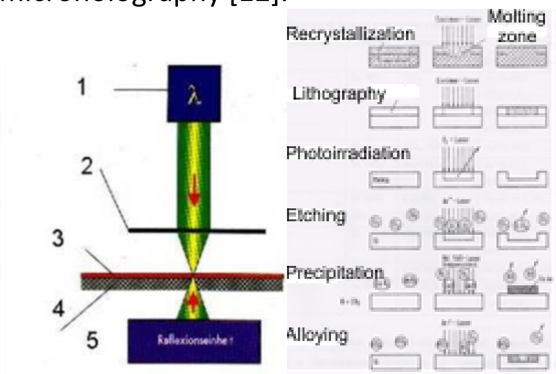


Figure 19. Principle of laser holography Laser-induced processes in micro- and nanomechatronics [15]

Legend: 1-laser source; 2-optical focusing system; 3-sensitive layer; 4-carrier; 5-reflector

- **Laser processing in nanotechnology**

Regarding the modification with laser irradiation in micro- and nanoscale directions, physical and chemical methods are used. In the physical we have a direct effect on the change or on the basis of the purely thermal nature of the process on the surface of the solid. In chemical methods, it is based on the effect of laser photons, the atoms in the surface layer and the molecules of a liquid or gaseous medium. An example is the laser-induced chemical modification of Teflon (PTFE) with UV and laser irradiation. Nanometric laser structuring is performed by focusing close to the probe blade in scanning tunneling microscopes [1].

- ✓ **Laser-induced processes**

Laser-induced processes in micromechanics are also: recrystallization (method for obtaining monocrystalline silicon ingots), laser lithography (with Excimer-laser structures smaller than 0.5-2μm are realized), exposure with the help of ultraviolet laser beam from F_2), etching or deposition of gas phase without layer - mask, alloying, stereolithography in combination with galvanoplating. An important application is the correction of masks for photolithography. By local deposition or evaporation of an absorbent material (eg chromium) from a gas phase with a laser beam from NdYAG-laser clear defects on the masks are removed, quartz resonators, silicon bridges and beams are adjusted, layer resistors and capacitors are adjusted to nominal value , the resistances of the different layers in single- and multilayer boards are equalized.

Examples of laser beam-induced deposition and etching are given in Table 4 [13]. The depth of the removed or microprocessed layer for one laser pulse for brittle materials is about 1.10^{-3} mm. Re-irradiation at the same treatment site results in new material removal at the same depth. The required processing depth is achieved by selecting the number of pulses with higher precision and repeatability than 1.10^{-3} mm. Material - polycarbonate, aspect ratio 50, application in cellular systems. The Excimer laser with a wavelength λ=248 nm is also used in magnetron sputtering for layering in the conditions of a glow discharge and application of inhomogeneous electric and magnetic fields [1].

Lithography using laser radiation is widely used to develop the latest optical technologies. With the sophisticated optical system, the sample is reduced, focused and printed on a thin layer of silicon coated with a light-sensitive resistor. This is repeated dozens of times, layer by layer, leaving a network of hundreds of chips on a single silicon substrate. It is discussed in detail in [14].

Stereo-lithography is the most modern application of electroplating in combination with laser treatment. In this case, the model is constructed automatically on a computer and the data is fed to the control system of the system for receiving the laser beam.

Table 4. Laser-induced deposition and etching

Sediment layer Substrate Reaction gas Laser

Sediment layer	Substrate	Reaction gas	Laserwavelength [μm])
Si	Si, SiO_2	SiH_4	Ar^+(0,488) CO_2(10,6) Kr^+(0,531) KrF(0,248)
SiO_2	Si	SiH_4, N_2O	ArF(0,193)
Al	Si, SiO_2	$Al_2(CH_3)_6$	Ar^+(0,257) ArF(0,193)
Cr	Si, SiO_2 SiO_2	$Cr(CO)_6$ $Cr(C_xO_x)_y$	Dye(0,28-0,35) Ar^+(0,488)
Al_2O_3	Si	$Al_2(CH_3)_6$, N_2O	ArF(0,193) KrF(0,248)
GaAs	GaAs, Si	$Ga(CH_3)_3$, AsH_3	Ar^+(0,458-0,515)
ZnO	Si, SiO_2	$Zn(CH_3)_2$, N_2O	ArF(0,193) KrF(0,248)

Etched material Etching gas Laserwavelength

Etched material	Etching gas	Laser wavelength [μm])
Al	Cl_2	XeCl(0,308), N_2(0,337)
Al_2O_3	CF_4	XeCl(0,308)
GaAs	Cl_2	Ar^+(0,515)
Ni	Cl_2	N_2(0,337)
Si	Cl_2 SF_6	XeCl(0,308), N_2(0,337) CO_2(10,6)
SiO_2	CF_2Cl_2 Cl_2	KrF(0,248) Ar^+(0,458)

The combination of two technologies or LIGA-method + microlaser stereolithography allows for the production of structures with vertical and non-vertical conical and profile surfaces, tools and others.

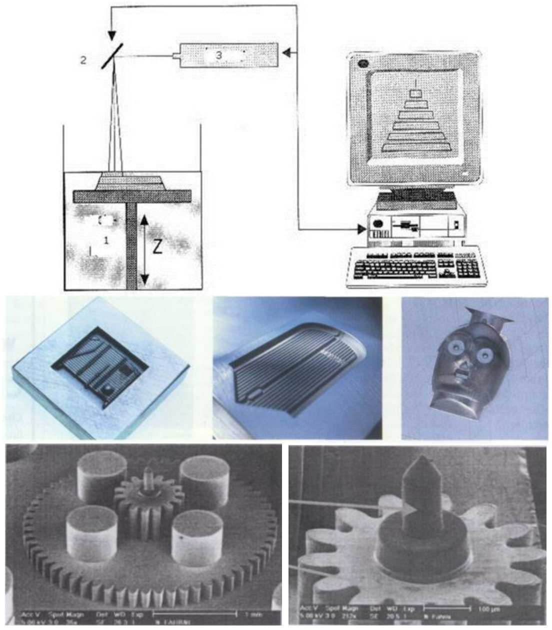


Figure 20. Elaboration of detail by stereo-lithography. Profile structures of different materials obtained by laser beam treatment by stereo-lithography and combined technology. **Legend:** 1-photoreactive resin, 2-refraction and X-Y axis control, 3-laser

- ✓ **Hardening and processing by plastic deformation**

Examples of hardened machined parts are given in Figure 21. The most typical example of an Excimer laser machined part are the razor blades, woodworking tools. Hardening is also used to increase the stiffness of springs and parts in cameras.

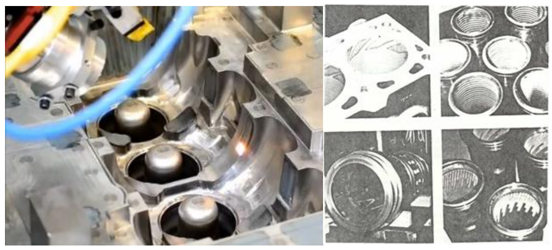


Figure 21. Cylinder bushings for diesel engines with hardening (MAN, German)

• Plastic deformation with laser beam

It is carried out by targeted application of induced thermal voltage by a laser beam. The stages of the process are:

- Local heating to expand the material and remove internal stresses;
- Plastic deformation;

- Cooling for springing and final deformation of the part.

The principle of laser beam deformation is explained in Figure 22. [16].

Deformation by targeted application of laser-induced thermal stress

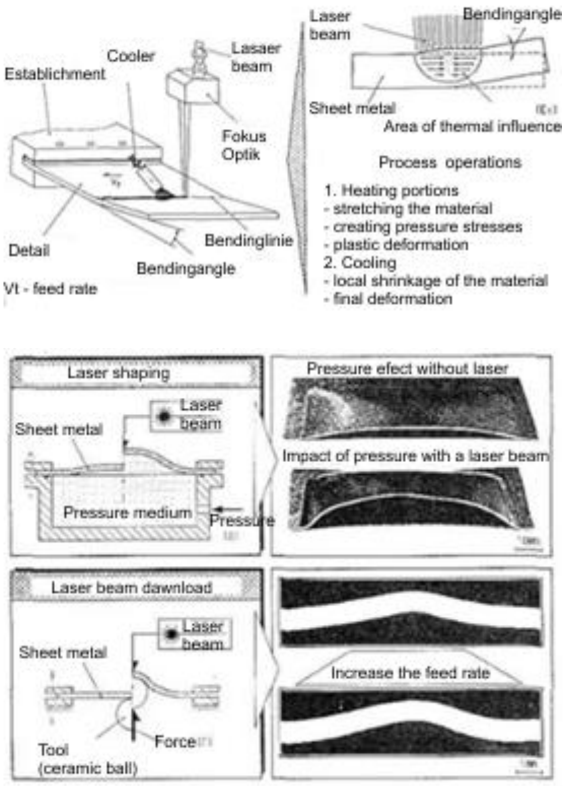


Figure 22. Principle of deformation with a laser beam. Principle of drawing (shaping) with a laser beam (down)

• Laser-assisted download

Plastic deformation of the metal occurs simultaneously by the pulling force (respectively the pressure) and the laser beam. The two variants of Figure 22. explain the principle of drawing and forming with the help of a laser beam, as on the right are the difference between conventional impact and interaction with a laser beam, as well as the increase of the feed rate [16]. The last two operations are applied to microelements of the switching technique.

- **Laser lithography technologies**

With the introduction of laser lithography in 1993, the size of the structures fell below the wavelength of light to develop. The mass application of laser lithography is around 2000. Nanoprinted lithography (NPL) is an effective approach to producing cheaper products. In this case, the image is formed at the expense of the physical deformation of the resist of the mold (stamp), and not at the expense of the modification of its chemical structure after irradiation, as in conventional lithography. The pulse energy is obtained by the methods:

• mechanical - up to 100 Hz through an oscillating system;

- up to 1 MHz by rotating prisms and apertures with openings;

- by means of an ultraviolet beam to change the refractive index of the laser crystal or by introducing a certain medium in the course of the beam (modern).

• electro-optical (predominantly) - by applying nitrobenzene nuclei for double refraction of the beam, a repeatability of 1.10^{-6}s is achieved.

- by rapidly changing the state of the resonator by the previous method, combined with two highly reflective mirrors.

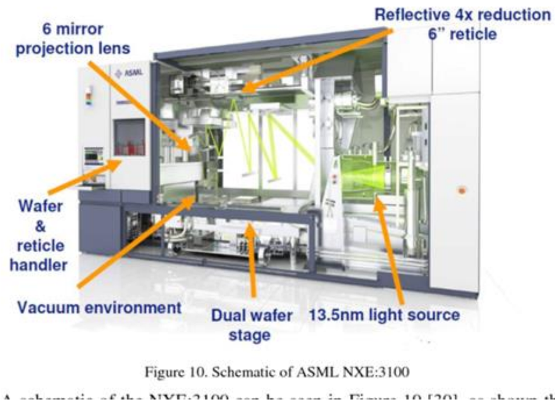


Figure 23. ASML-installation (Netherlands)

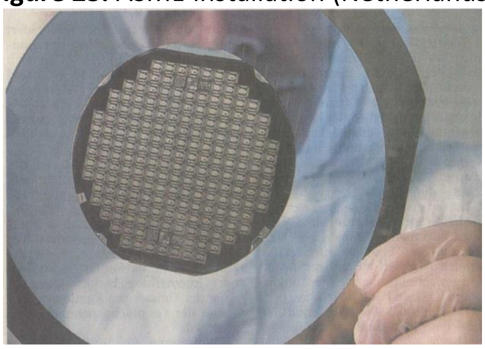


Figure 24. Separation of the chips from a silicon substrate by laser scribing (Philips, Netherlands)

The largest company for the production of equipment is ASML (Netherlands), founded in 1984. Competing are Japan's Canon and Nikon (which have not developed EUV technology), Samsung from South Korea, Global Foundries and TSMC (Taiwan Semiconductor Manufacturing Co.) Taiwan, AMD has been using 7 nm EUV technology since mid-2020, and Intel - currently it is based on 14 nm and at the end of 2021 - at 7 nm. With the sophisticated optical system, the sample is reduced, focused and printed on a thin layer of silicon coated with a light-sensitive resistor. This is repeated dozens of times, layer by layer, leaving a network of hundreds of chips on a single silicon substrate (fig. 23, 24) [17, 18, 19].

✓ **Machinability of materials with laser beam**

Based on the properties of the processed materials, Table 5 shows the specific parameters for this purpose. The susceptibility to machining in metals and to shear in non-metals increases in the direction of increasing the machinability coefficient [20].

1. The heat diffusion coefficient β is determined by the formula:

$\beta = - K / c / V,$ (6)

where c is the heat factor; V - volume, cm^3; K - thermal conductivity, cal/cm.s, ^oC.

2. The machinability factor (laser number) N is determined by the formula assuming the following larger integer:

$N = int [T_V^2 / 100 (G+1)^3].$ (7)

3. Temperature T_V at which a needle is inserted to a depth of 1 mm, area 1 mm^2 by force 10 N after heating in the part.

Table 5. Machinability of materials with laser beam

(on the left - metals, on the right - plastics, paper, leather)

Parameter / Material	Thermal conductivity, Kcal / cm. s, ^oC	Heat diffusion coefficient β, cm^2/s	Melting temperature Tstop., ^oC	Parameter / Material	Temperature Tv, ^0C	Modulus of elasticity during heat treatment G, N/mm^2	Machinability factor N, relative units
Gold	0,71	1,20	1063	Getinax, Textolite	200	4	3
Silver	1	1,70	960	Leather	200	3	6
Cuprum	0,94	1,14	1083	PVC	80	1	8
Aluminum	0,53	0,91	1210	Polyurethane	100	1	12
Tungsten	0,40	0,62	3380	Wood	200	2	14
Molybdenum	0,34	0,51	2630	Paper	200	2	14
Tantalum	0,13	0,23	2850	Polyethylene	60	0	36
Chrome	0,16	0,22	1800	Polypropylene	90	0	81
Nickel	0,22	0,24	1452	polyamide	180	0,5	96
Iron	0,16	0,21	1530	Teflon	110	0	121
Zinc	0,15	0,38	232	Plexiglass	120	0	144
				Polycarbonate	150 160	0 0	225 256

3. CONCLUSION

A historical overview is given, the physical bases of the laser technique, the types of lasers, the possibilities, the machinability of the materials and the application of the technological operations are considered. Currently, laser treatment dictates the level of products in mechatronics. The main conclusion is that the wavelength of the beam determines and is commensurate with the resolution, size and manufacturability of the components in mechatronics. The gas laser is most widely used in lithography. It is the first laser with continuous light and works on the principle of converting electrical energy into laser light power. Possible combinations of gas mixtures in terms of their application in laser systems have not yet been sufficiently studied. The demand for such equipment is growing successfully, forming a suitable areal in the market. The equipment in the nanoprinted laser lithography determines the level of development of the components in mechatronics.

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STATISTICAL ANALYSIS OF ISO/IEC AND IEEE STANDARDS IN THE FIELD OF ARTIFICIAL INTELLIGENCE, MACHINE LEARNING AND DATA MINING

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Abstract: *This paper presents standardized sources of knowledge (standards) and statistical analysis of published standards in the areas of: Artificial intelligence (AI), Machine learning and Data mining, both by ISO, the International Organization for Standardization and the IEEE (Institute of Electrical and Electronics Engineers), and by local organizations in the region. The aim of the research is to collect, qualitative and quantitative approach and statistical analysis of different knowledge sources from the mentioned areas by the T-test method. The results of the analysis indicate similarities and differences in price between the two groups of standards, namely ISO/IEC and IEEE. It was concluded that countries in the region should be more involved in the development of standards in these areas, to achieve maximum quality of future products and services developed in these areas, which contributes to better positioning and market placement.*

Keywords: *Standards, ISO, IEEE, Statistical analysis, Artificial intelligence, Machine learning, Data mining*

1. INTRODUCTION

Artificial intelligence (AI), as a scientific field, is gaining increasing primacy when it comes to everyday innovation and progress. AI is defined as the part of computer science that deals with the design of systems that have characteristics, ie. learning opportunities as in humans, language comprehension, reasoning, problem solving, etc.

Machine learning, as a branch of AI, deals with techniques and methods that enable computer systems, ie. machines to learn from experience, that is, to react to changes in the external environment, without explicit programming. One of the important applications of machine learning is in data research, ie in the field of data mining.

Data mining is a process of "mining" large databases and extracting new and useful information that can contribute to better and more successful business (if it is in this area) [1]. The goal is to use the collected data, ie information in the best possible way, and get results that will help in finding and recognizing certain patterns or predicting some outcomes or behaviors, and many other things in different spheres. Machine learning is often used in the first step, ie. data analysis and extracting hidden knowledge from “raw data”.

The aim of this paper is to collect, qualitative and quantitative approach and statistical analysis of various sources of knowledge in the field of Artificial Intelligence, machine learning and data mining, as factors of the same.

1.1 Related work

By studying reality, collecting different data and accessing different sources of knowledge, new information is created, and first of all, scientific knowledge is expanded in certain areas. There are a number of related studies that deal with standardization and analysis of standards in certain areas. In the paper [2], a statistical analysis of standards in the field of e-learning was performed, where the obtained comparison results indicate significant differences in terms of the number of published standards and their prices between the analyzed sets of standards, ie. between the national standards of Serbia and nearby countries such as: Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Albania, Hungary, Romania and Slovenia and international also.

A related research [3] presents an analysis of existing knowledge bases in the field of expert systems and AI, ie published standards, eKspertise2Go web pages, as well as standardized and non-standard dictionaries. The obtained results show that the International Organization for Standardization has published the largest number of standards, while the eKspertise2Go website is the most consistent website with information on the use and construction of expert systems.

The author in [4] presents a comparative analysis of ISO and local standards from countries in the region in the field of e-learning. The results after the survey indicate similarities and differences both in terms of publishing trends and in terms of the price of the standard.

The results in the conducted research [5] represent the current state and position of local standardization in the field of software development, ie Information Technologies in relation to neighbouring countries.

The following chapters will present standardization organizations as well as sources of knowledge in the fields of AI, machine learning and data mining.

2. ORGANIZATIONS FOR STANDARDIZATION AND INITIATIVES IN THE AI AREA

Standardization is defined as the activity of establishing provisions for general and multiple use, which refer to existing or possible problems, to achieve the optimal degree of regulation in a given area. Three basic levels of standardization by geographical scope are defined, namely: international, regional (European) and national level of standardization. In addition, the following will be listed for standardization organizations by levels [6]:

1. International standardization organization:

- ISO-International Organization for Standardization,
- IEC-International Electrotechnical Commission,
- ITU - International Telecommunication Union.

2. European organization for standardization:

- CEN-European Committee for Standardization,
- CENELEC-European Committee for Electrical Engineering,
- ETSI-European Institute of Telecommunications.

3. State organizations for standardization:

- ISS - Institute for Standardization of Serbia,
- BAS-Institute for Standardization of Bosnia and Herzegovina,
- DIN-German Institute for Standardization,
- BSI - English Institute for Standardization,
- AFNOR-French Institute for Standardization,
- NEN-Dutch Institute for Standardization,
- ON- Austrian Institute for Standardization,
- SIST-Slovenian Institute for Standardization,
- HZN-Croatian Institute for Standardization.

AI is an area that was significantly less represented in the previous period, and therefore the representation of standards in that area was small. However, rapid development, a large increase in interest and activities around AI in recent years leads to the need, ie. standards development initiative. As a consequence, the international organizations ISO and IEC established the first board, ie. committee and subcommittee of JTC 1 SC 42 for AI area standardization in November, 2017. The first plenary meeting of the subcommittee was held in Beijing in 2018, where the greatest emphasis was on fundamental AI standards, big data, AI security, use cases, applications, computational AI approaches, ethical and social issues in the AI field [7].

The European Telecommunications Institute ETSI has launched a number of initiatives since April 25, 2018 on AI, especially in the field of AI security [8] [9]. The IEEE professional association is also very important in proposing new standards for AI, especially in the field of ethics of autonomous and intelligent systems.

As AI develops, the requirements for new standards and revision of existing ones will be more pronounced.

3. KNOWLEDGE SOURCES

Sources of information can be formal and informal, ie. scientific information is obtained through formal and informal channels of communication. Standards, scientific journals, textbooks, monographs, dictionaries, etc. are part of formal sources of information, ie. knowledge. In addition, the following is a list of all international ISO / IEC standards (Table 1- Table 3).

Table 1 shows the international ISO / IEC standards in the field of AI, of which there are 24. Some standards are no longer active, but have been withdrawn.

Table 1. Overview of published international ISO / IEC standards in the field of AI

No.	Standard number and title
1.	ISO/IEC TR 20547-2:2018, Information Technology – Big Data Reference Architecture - Part2: Use Cases And Derived Requirements
2.	ISO/IEC TR 20547-5:2018, Information Technology - Big Data Reference Architecture - Part 5: Standards Roadmap
3.	ISO/IEC TR 24028:2020, Information Technology - Artificial Intelligence - Overview Of Trustworthiness In Artificial Intelligence
4.	ISO/IEC TR 24029-1, Artificial Intelligence (AI) - Assessment Of The Robustness Of Neural Networks - Part 1: Overview [Under Development]
5.	ISO/IEC AWI TR 5469, Artificial Intelligence - Functional Safety And AI Systems [Under Development]
6.	ISO/IEC AWI 22989, Artificial Intelligence Concepts And Terminology
7.	ISO/IEC AWI 23053, Framework For Artificial Intelligence Systems Using Machine Learning
8.	ISO/IEC AWI 24029-2, Artificial Intelligence (AI) - Assessment Of The Robustness Of Neural Networks - Part 2: Methodology For The Use Of Formal Methods [Under Development]
9.	ISO/IEC AWI TR 24368, Information Technology - Artificial Intelligence -Overview Of Ethical And Societal Concerns [Under Development]
10.	ISO/IEC AWI 38507, Information Technology - Governance Of It - Governance Implications Of The Use Of AI By Organizations
11.	ISO/IEC AWI 42001, Information Technology - Artificial Intelligence - Management System [Under Development]
12.	ISO/IEC AWI TS 6254, Information Technology - Artificial Intelligence - Objectives And Methods For Explainability OFML Models And AI Systems [Under Development]
13.	ISO/IEC CD 22989.2, Artificial Intelligence - Concepts And Terminology [Under Development]
14.	ISO/IEC CD 24668, Information Technology - Artificial Intelligence - Process Management Framework For Big Data Analytics [Under Development]
15.	ISO/IEC DTR 24027, Information Technology - Artificial Intelligence (AI) - Bias In AI Systems And AI Aided Decision Making [Under Development]
16.	ISO/IEC DTR 24372, Information Technology - AI - Overview Of Computational Approaches For AI Systems [Under Development]
17.	ISO/IEC WD TS 4213, Information Technology - Artificial Intelligence - Assessment Of

	Machine Learning Classification Performance [Under Development]
18.	ISO/IEC WD 5338, Information Technology - Artificial Intelligence - AI System Life Cycle Processes [Under Development]
19.	ISO/IEC WD 5339, Information Technology - Artificial Intelligence - Guidelines For AI Applications [Under Development]
20.	ISO/IEC WD 5392, Information Technology - Artificial Intelligence - Reference Architecture Of Knowledge Engineering [Under Development]
21.	ISO/IEC CD 23053.2, Framework For Artificial Intelligence (AI) Systems Using Machine Learning (Ml) [Under Development]
22.	ISO/IEC CD 23894, Information Technology - Artificial Intelligence - Risk Management [Under Development]
23.	ISO/IEC CD TR 24030, Information Technology - Artificial Intelligence (AI) - Use Cases [Under Development]
24.	ISO/IEC 20546, Information Technology - Big Data - Overview and Vocabulary

Table 2 shows the international ISO / IEC standards in the field of machine learning, of which there are 4. Some standards have been withdrawn, while even one standard is under development.

Table 2. Review of published international ISO / IEC standards in the field of machine learning

No.	Standard number and title
1.	ISO/IEC CD 23053.2, Framework For Artificial Intelligence (AI) Systems Using Machine Learning (Ml) [Under Development]
2.	ISO/IEC 2382-31:1997, Information Technology - Vocabulary - Part 31: Artificial Intelligence - Machine Learning [Withdrawn]
3.	ISO/TR 22100-5:2021, Safety Of Machinery, Relationship With ISO 12100-Part 5: Implications Of AI Machine Learning
4.	ISO/IEC WD TS 4213, Information Technology - Artificial Intelligence - Assessment Of Machine Learning Classification Performance [Under Development]

Table 3 shows the international ISO / IEC standards in the field of Data mining, of which there are 2.

Table 3. Review of published international ISO / IEC standards in the field of Data mining

No.	Standard number and title
1.	ISO/IEC 13249-6:2002, Information Technology - Database Languages - SQL Multimedia And Application Packages -Part 6: Data Mining
2.	ISO/IEC 13249-6:2006, Information Technology - Database Languages - SQL Multimedia And Application Packages-Part 6: Data Mining [11]

European standards (ETSI) in the field of AI are presented in Table 4 [12]:

Table 4. Overview of published European standards in the field of AI

No.	Standard number and title
1.	ETSI GR ENI 004 V2.1.1 (2019-10), Experiential Networked Intelligence (ENI); Terminology For Main Concepts In ENI [Published]
2.	ETSI GR SAI 004 V1.1.1 (2020-12), Securing Artificial Intelligence (SAI); Problem Statement [Published]
3.	ETSI TR 103 674 V1.1.1 (2021-02), Smartm2m; Artificial Intelligence And The ONEM2M Architecture [Published]

Institute of Electrical and Electronics Engineers (IEEE) is a leading standardization and development organization that develops and maintains standards through the IEEE Standards Association (IEEE - SA). It has a dual structure - regional and technical, with organizational units based on geographical location and consists of 38 associations with more than 300 local organizations, which meet regularly. IEEE - SA is responsible for IEEE standardization activities. As pointed out in the previous chapter, the IEEE is a very important organization in proposing new standards for AI, especially in the field of ethics of autonomous and intelligent systems. In response, Table 5 lists the IEEE standards [13] in the field of AI, of which there are 17.

Table 4. Review of published IEEE standards in the field of AI

No.	Standard number and title
1.	IEEE SA - Artificial Intelligence Systems (AIS)
2.	IEEE 1232-1995, IEEE Standard For Artificial Intelligence And Expert System Tie To Automatic Test Equipment (AI-ESTATE): Overview And Architecture
3.	IEEE 1232.1-1997, IEEE Standard For Artificial Intelligence Exchange And Service Tie To All Test Environments (AI-ESTATE): Data And Knowledge Specification
4.	IEEE 1232.2-1998, IEEE Standard For Artificial Intelligence Exchange And Service Tie To All Test Environments (AI-ESTATE): Service Specification
5.	IEEE 1232-2002, IEEE Standard For Artificial Intelligence Exchange And Service Tie To All Test Environments (AI- ESTATE)
6.	IEEE 1232-2010, IEEE Standard For Artificial Intelligence Exchange And Service TIE To All Test Environments (AI-ESTATE)
7.	IEEE 62243-2010, IEC 62243:2012(E) (IEEE STD 1232-2010): Artificial Intelligence Exchange And Service Tie To All Test Environments (AI-ESTATE)
8.	IEEE 1232.3-2014, IEEE Guide For The Use Of Artificial Intelligence Exchange And Service Tie To All Test Environments (AI-ESTATE)
9.	P2801, Recommended Practice For The Quality Management Of Datasets For Medical Artificial Intelligence
10.	P2802, Standard For The Performance And Safety Evaluation Of Artificial Intelligence Based Medical Device: Terminology
11.	P2976, Standard For XAI – Explainable Artificial Intelligence - For Achieving Clarity And Interoperability Of AI Systems Design
12.	P2247.4, Recommended Practice For Ethically Aligned Design Of Artificial Intelligence (AI) In Adaptive Instructional Systems
13.	P2975, Standard For Industrial Artificial Intelligence (AI) Data Attributes
14.	IEEE P7004TM, Standard For Child And Student Data Governance [14]
15.	IEEE P7005TM, Standard For Transparent Employer Data Governance
16.	IEEE P7006TM, Standard For Personal Data Artificial Intelligence (AI) Agent
17.	P7006, Standard For Personal Data Artificial Intelligence (AI) Agent

BAS, as a state organization for standardization in Bosnia and Herzegovina, stands out as one of the few in our environment that deals with standardization and publication of standards in the field of AI [15], where the standard should be singled out:

• BAS IEC 62243: 2010, Artificial Intelligence Exchange And Service TIE To All Test Environments (AL-ESTATE).

Domestic dictionaries (according to the SRPS standard), as formal sources of knowledge that have basic terms and definitions from these areas are:

• SRPS ISO / IEC 2382-1: 2007 - Information technology - Vocabulary - Part 1: Basic Terms [16].

4. RESEARCH METHODOLOGY

Standardized sources of knowledge, ie. standards are by comparing the values of certain characteristics such as price, status, date of publication, etc. they may differ according to the group of standards to which they belong, whether they are international ISO / IEC or IEEE standards. In addition, a statistical analysis of the two previously mentioned groups of standards was conducted. The standard analysis was performed in SPSS software.

SPSS is an IBM product. SPSS is a platform for statistical analysis, text analysis, open source scalability, big data integration and offers a huge library of machine learning algorithms [17].

The analysis of the standard was performed by the method of T-test a (independent samples). The T-test of independent samples is a test used to compare the mean value of a continuous variable in two different groups of subjects [18], ie. in this case the standard. In the analysis, a set of data (STD.sav) was used, ie. database of standards from the previously mentioned categories, namely: ISO / IEC and IEEE.

Figure 1 illustrates the representation of variables, ie. variables, where one variable is categorical (Group) and denotes a group of standards (1 - ISO / IEC or 2 - IEEE), two are continuous dependent variables - (Price) which denotes the price of the standard and (NumberOfPage) - denotes the number of pages, while the other variables are nominal.

Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
Group	Numeric	8	0	Grupa	{1, ISO/IEC}...	None	8	Left	Nominal	Input
Name	String	100	0	Naziv standarda	None	None	17	Left	Nominal	Input
Price	Numeric	8	2	Cena	None	None	8	Right	Scale	Input
Status	String	100	0	Status	None	None	16	Left	Nominal	Input
DateOfPublicated	String	10	0	Datum publikovanja	None	None	11	Left	Nominal	Input
ICS	String	100	0	ICS oblast	None	None	8	Left	Nominal	Input
NumberOfPage	Numeric	8	0	Broj strana	None	None	12	Right	Scale	Input

Figure 1. Review of variables used in standard analysis

Group	Name	Price	Status	DateOfPublicated	ICS	NumberOfPage
1	TR 20547-2:2018 INFORMATION TECHNOLOGY - BIG DATA REFERENCE AR...	198,00	PUBLISHED	2018-01	35.02...	252
1	TR 20547-5:2018 INFORMATION TECHNOLOGY — BIG DATA REFERENCE A...	88,00	PUBLISHED	2018-02	35.02...	17
1	TR 24028:2020 INFORMATION TECHNOLOGY — ARTIFICIAL INTELLIGENCE ...	158,00	PUBLISHED	2020-05	35.02...	43
1	TR 24029-1 ARTIFICIAL INTELLIGENCE (AI) ASSESSMENT OF THE ROBUST...	138,00	PUBLISHED	2021-03	35.02...	31
1	20546: INFORMATION TECHNOLOGY — BIG DATA — OVERVIEW AND VOC...	58,00	PUBLISHED	2019-02	35.02...	12
1	AWI 42001 INFORMATION TECHNOLOGY — ARTIFICIAL INTELLIGENCE — ...	.	UNDER DEVEL...	-	35.02...	.
1	AWI 38507 INFORMATION TECHNOLOGY - GOVERNANCE OF IT - GOVERN...	58,00	UNDER DEVEL...	-	35.02...	26
1	AWI 23053: FRAMEWORK FOR ARTIFICIAL INTELLIGENCE SYSTEMS USIN...	.	UNDER DEVEL...	-	35.02...	35
1	AWI 22989: ARTIFICIAL INTELLIGENCE CONCEPTS AND TERMINOLOGY	.	UNDER DEVEL...	-	35.02...	55
1	TR 22100-5:2021 SAFETY OF MACHINERY — RELATIONSHIP WITH ISO 121...	38,00	PUBLISHED	2021-01	13.11...	6
1	CD 23053.2 FRAMEWORK FOR ARTIFICIAL INTELLIGENCE (AI) SYSTEMS U...	.	UNDER DEVEL...	-	35.02...	35
1	2382-31:1997 INFORMATION TECHNOLOGY VOCABULARY — PART 31: AR...	.	WITHDRAWN	1997-12	01.04...	16
1	13249-6:2002 INFORMATION TECHNOLOGY — DATABASE LANGUAGES — ...	.	WITHDRAWN	2002-12	35.06...	196
1	13249-6:2006 INFORMATION TECHNOLOGY — DATABASE LANGUAGES — ...	198,00	PUBLISHED	2006-11	35.06...	282
2	1232.1-1997 - IEEE STANDARD FOR ARTIFICIAL INTELLIGENCE EXCHANGE...	137,55	SUPERSEDED	1997-09	35.08...	112
2	1232-1995 - IEEE STANDARD FOR ARTIFICIAL INTELLIGENCE AND EXPERT...	101,13	SUPERSEDED	1996-03	35.08...	25
2	1232.2-1998 - IEEE STANDARD FOR ARTIFICIAL INTELLIGENCE EXCHANGE...	153,95	SUPERSEDED	1999-02	35.08...	148
2	1232-2002 - IEEE STANDARD FOR ARTIFICIAL INTELLIGENCE EXCHANGE A...	284,29	SUPERSEDED	2002-11	35.08...	124
2	1232-2010 - IEEE STANDARD FOR ARTIFICIAL INTELLIGENCE EXCHANGE A...	261,52	WITHDRAWN	2011-03	35.08...	167
2	62243-2010 - IEC 62243:2012(E) (IEEE STD 1232-2010): ARTIFICIAL INTELLIG...	293,42	ACTIVE	2012-07	-	170
2	1232.3-2014 - IEEE GUIDE FOR THE USE OF ARTIFICIAL INTELLIGENCE EX...	174,95	ACTIVE	2014-10	35.08...	96
2	P7005TM - STANDARD FOR TRANSPARENT EMPLOYER DATA GOVERNAN...	36,00	ACTIVE	-	-	81

Figure 2. View a data set for analysis

Figure 2 shows the data prepared for analysis. This data set contains information (presented in the form of columns) on: group to which the standard belongs, name of the standard, price of the standard (in CHF currency), date of publication, status, ICS (International Classification for Standards) area to which it belongs, as well as information on the number side. Statistical analysis by the T-test method in this paper was conducted to determine the differences in price in these two groups of standards.

5. RESULTS AND DISCUSSION

This chapter provides a comparison of price test results for ISO / IEC and IEEE standards using the t-test method.

During the conducted T-test statistical analysis, a brief overview of the first T-test of independent samples is given, and a research question is asked: Is there a statistically significant difference in the price of standards in Group 1 (ISO / IEC) and Standard 2. groups (IEEE)?

The results of testing the price of ISO / IEC and IEEE standards were compared. What is needed for the analysis are two variables:

- One category (indicates a group of standards)
- One continuous dependent variable (indicates the price of the standard)

Assumptions and hypotheses set during the analysis are:

- **H_0:** The difference between the two groups of standards in price is not statistically significant.
- **H_1:** The difference between the two groups of standards in price is statistically significant.

T-Test

[DataSet1] C:\Users\Korisnik\Desktop\STD.sav

Group Statistics

	Grupa	N	Mean	Std. Deviation	Std. Error Mean
Cena	ISO/IEC	8	116,7500	64,68329	22,86900
	IEEE	8	180,3513	92,46436	32,69109

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Cena	Equal variances assumed	,968	,342	-1,594	14	,133	-63,60125	39,89609	-149,16986	21,96736
	Equal variances not assumed			-1,594	12,527	,136	-63,60125	39,89609	-150,12320	22,92070

Figure 3. T-test results - comparison of ISO / IEC and IEEE price testing

Figure 3 presents the results of the T-test, which compares the results of testing the price of ISO / IEC and IEEE standards. The first part of the "Independent Samples Test" table gives the results of Levene's Test for Equality of Variances. The first step is to examine the equality of variance (variability) of results in two groups (ISO / IEC standards and IEEE standards). The outcome of this test determines which t-value (of the two calculated by SPSS) should be considered correct and used. When the size of Sig. (in the section "Levene's Test for Equality of Variances") greater than 0.05, the first row of the table, calculated for the case of equal variances assumed, should be used, otherwise when the value is Sig. less than or equal to 0.05 the second order should be used (Equal variances not assumed). How is the significance level of the Levene test Sig. (0.342) greater than 0.05, it is concluded that the assumption of equality of variance was not violated and for the final conclusion is taken t value of the first order t (- 1,594). The second step is to determine significant differences between these two groups of standards in price based on the value of the Sig column. (2-tailed). How is the value of Sig. (2-tailed) (0.133) greater than 0.05, the difference between the two groups of standards is not significant, but random, thus confirming the null hypothesis - H_0.

The final conclusion is as follows: There is no statistically significant difference between the mean values in the price of the ISO / IEC (Mean = 116.75, Std. Deviation = 64.68) standard and the IEEE standard (Mean = 180.35, Std. Deviation = 92, 46), t (- 1,594), p (0, 13). The table also contains the mean value of the difference between the two groups (Mean difference = -63.60), as well as below (Lower = - 149.17) and the upper (Upper = 21.97) limit, which with a probability of 95% contains the actual magnitude of that difference.

6. CONCLUSION

Learning and which use the methods and techniques of AI and Data mining, the need for standardized sources of knowledge is inevitable. Data set, ie. the knowledge base used for the conducted statistical analysis in this paper contains international standardized sources of knowledge, ie. ISO / IEC standards in the areas of: AI, Machine learning and Data mining of which there are the most (30), then IEEE standards (17), as well as standardized European ETSI standards (3) in the field of AI, domestic SRPS dictionary (1) issued by Institute for Standardization of Serbia and BAS standard (1) issued by the Institute for Standardization of Bosnia and Herzegovina in the AI field.

Based on the research conducted in this paper, using statistical analysis using the T-test method, it was concluded that the differences in the prices of representatives of the standards published by ISO / IEC and IEEE organizations are not statistically significant.

Also, it can be concluded that the countries in the region should participate more and contribute to the development of standards in these areas, in order to achieve the maximum quality of future products and services developed in the already mentioned areas.

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SOFTVER ZA UPRAVLJANJE NEUSAGLAŠENOSTIMA U REALNOM VREMENU U MALIM I SREDNJIM PREDUZEĆIMA U OKVIRU KONCEPATA INDUSTRIJE 4.0 I KVALITETA 4.0

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Apstrakt: *Ovaj rad ima za cilj da predloži softversko rešenje za otkrivanje neusaglašenosti i definisanje preventivnih i korektivnih radnji koje proširuje upotrebu mobilnih uređaja u skladu sa paradigmama Industri 4.0 i Kualiti 4.0. Predstavljeni dizajn softverskog rešenja zasnovan je na programskom jeziku JavaScript i njegovoj sposobnosti da se implementira u sve nivoe softverskih rešenja kroz međusobno povezane okvire (MongoDB, Ekpress.js, Angular i Node.js) u MEAN okviru. Razvijeno rešenje implementirano je u tri mala i srednja preduzeća. Prvi rezultati pokazuju nekoliko prednosti u povećanju otkrivanja neusklađenosti i prijavljivanja. Sve neusklađenosti odnosile su se na posebne odeljke standarda ISO 9001: 2015, tako da su menadžeri kvaliteta i menadžeri u kompanijama mogli da imaju uvid u izvore problema i osnovu za definisanje različitih upravljačkih akcija. Glavni doprinos rada ogleda se u prezentaciji softverskog rešenja namenjenog pristupačnoj identifikaciji i izveštajima o velikom broju neusaglašenosti, integrisanom sa drugim softverskim modulima.*

Ključne reči: *Industrija 4.0, Kvalitet 4.0, izveštaj o neusaglašenostima, upravljanje neusaglašenostima, rešenje otvorenog koda.*

1. UVOD

Ovaj rad prvenstveno namerava da pokaže da se tehnologije iz skupa alata Industri 4.0 (I4.0) mogu primeniti u upravljanju kvalitetom (KM) i upravljanju neusklađenostima (NCM), čineći bitan korak ka I4.0 i kvalitetu 4.0 (K4.0) [1]. Da bi postigli ovaj cilj, autori su razvili i implementirali inovativno softversko rešenje sa nekoliko prednosti prihvatljivih za mala i srednja preduzeća (MSP). Razvijena softverska aplikacija za mobilne uređaje omogućiće svim zaposlenima da izveštavaju i upravljaju o neusaglašenostima koristeći korake i direktive iz ISO 9001: 2015 (otkrivanje, izveštavanje, donošenje odluka i definisanje preventivnih i korektivnih radnji). Glavni doprinos ogleda se u predstavljenom softverskom rešenju za pristupačnu identifikaciju i izveštavanje o nesaglasnostima (NC), integrisano sa drugim softverskim modulima za analizu i predviđanje kvaliteta. Na ovaj način moguće je postići horizontalnu skalabilnost i bogatstvo predloženog softverskog rešenja za pametna preduzeća usredsređena na proizvodnju svetske klase i Lean proizvodnju. Predstavljena upotreba rešenja doprinosi svim učesnicima koji su uključeni u organizaciju proizvodnje i samu proizvodnju kroz: (1) uključivanje svih zaposlenih; (2) digitalizaciju i poboljšanje postojećih sistema prijavljivanja neusklađenosti; (3) poboljšanje percepcije neusklađenosti; (4) poboljšanu svest i procenu doprinosa poslodavaca upravljanju neusklađenošću; (5) činjenjem tehnologije lakom za korišćenje jeftinom i pogodnom za širu industrijsku publiku.

U narednim odeljcima rada autori su predstavili koncept NCM -a u I4.0 (odeljak 2), sa predloženim opštim softverskim komponentama i njihovim odnosima (odeljak 2.1) i dijagramom toka procesa (odeljak 2.2). Pored toga, razmatrani su mobilni uređaji, trendovi aplikacija u oblaku i K4.0, rešenja zasnovana na JavaScript -u i Tipescript. Na kraju, autori su predstavili poseban slučaj razvijene softverske infrastrukture, sa mogućim prednostima rešenja (odeljci 3 i 4).

2. TEORIJSKA POZADINA I PREGLED LITERATURE

2.1 Koncepti industrije 4.0 i kvaliteta 4.0

I4.0 bi trebala da poboljša protok informacija kroz celu organizaciju, omogućavajući bolju kontrolu i prilagođavanje operacija u stvarnom vremenu [2] kako bi se odgovorilo na očekivanja zainteresovanih strama uz zadržavanje konkurentske prednosti.

U I4.0, koncept kvaliteta je proširen i uključuje personalizovani kvalitet usluge i personalizovanu proizvodnju. Ciljevi kvaliteta su evoluirali zajedno sa fazama revolucije u industrijalizaciji. Prema izvorima literature [3], ključni preduslovi za održivi ekonomski uspeh u savremenim proizvodnim kompanijama fokusirani su na KC, KM i KMS.

Osnovni koncept K4.0 obuhvata jedanaest osa (komponenti) prema Jacobu [4], uključujući: (1) velike podatke sa karakteristikama zapremine, raznolikosti, brzine, tačnosti i transparentnosti; (2) analitički okvir koji pruža opisnu, dijagnostičku, prediktivnu i preskriptivnu analizu; (3) povezivost koja može omogućiti skoro povratnu informaciju u stvarnom vremenu od povezanih ivičnih uređaja, ljudi i procesa; (4) saradnja putem digitalnih poruka, opis tokova aktivnosti (vizuelni) i društvenih (društvenih) medija; (5) razvoj aplikacija uključujući mobilne aplikacije, platforme, virtuelnu stvarnost, proširenu stvarnost, veb-klijent, pregledač i aplikacije za robote (merenje i manipulacija) i mašine (CNC, DNC, senzori itd.); (6) horizontalna skalabilnost predstavlja sposobnost podržavanja sve veće i veće količine podataka, korisnika, uređaja i analitike na globalnom nivou; (7) sistemi upravljanja koji prate autonomne i povezane procese; (8) usklađenost koja između ostalog uključuje elektronsko podnošenje izvještaja o usklađenosti/NC i automatizaciju tokova u području usklađenosti; (9) kultura kvaliteta koja predstavlja funkcionalno snažnu saradnju, kredibilitet i zajedničku odgovornost; (10) liderstvo izraženo kroz kvalitetne performanse, vlasništvo nad procesima i zakazivanje ciljeva; i (11) kompetencije koje obučavanje zaposlenih smatraju jednim od najvažnijih polja za poslovni napredak. Stoga su kroz K4.0 kritične nove tehnologije pristupačne i dostupne širem krugu poslovnih organizacija, sa pruženom mogućnošću za rešavanje dugoročnih izazova u kvalitetu i usvajanje novih rešenja. Prateći ove predložene ose, primarni cilj ovog rada je predstavljanje mobilnog rešenja za NCM koje se zasniva na prikupljanju velikih podataka, podršci menadžmenta, poboljšanoj komunikaciji među zaposlenima i poboljšanju kulture kvaliteta kao bitnih elemenata skupa alata u K4 .0 koncept.

2.2 Upravljanje neusaglašenostima

Zbog sve veće konkurencije na tržištu, organizacije su usvojile standarde kvaliteta poput ISO 9000: Serija međunarodnih standarda [5]. Uspostavljanje alata za sprečavanje NC-a i uklanjanje njihovih uzroka predstavlja obavezan zahtev standarda kvaliteta, pa kao takav NCM dobija funkciju podprocesa u opštem proizvodnom procesu [6]. NCM treba (prema ISO 9001: 2015) primeniti tokom realizacije svih organizacionih procesa, a organizacija treba da zadrži dokumentovane informacije o neusaglašenostima. Kao što je specificirano standardnim zahtevima, dokumentovane informacije mogu se formulisati kao izveštaj sa opisom neusaglašenosti, preduzetih radnji, dobijenih koncesija i identifikovanih ovlašćenja. Osim toga, standard zahteva dokumentovane informacije kao dokaz bilo kakvih rezultata korektivnih radnji, koje dopunjuju izveštaj, kao što je ranije pomenuto. Korišćenjem izveštaja preduzimaju se korektivne i preventivne mere za uklanjanje identifikovanih NC.

Ovaj rad se fokusira na upravljanje neusaglašenostima, sa namerom da se smanji broj neusaglašenosti kod proizvoda i procesa i efikasno primene proaktivne i korektivne mere adekvatne za poboljšanje kvaliteta proizvoda i procesa. U idealnom slučaju, neusaglašenosti i otpad bi trebalo eliminisati, čime bi se postigla proizvodnja bez nedostataka. Potrebno je implementirati kontrolu kvlaiteta u realnom vremenu, omogućavajući detekciju neusaglašenosti u ranoj fazi procesa i smanjujući otpad iz proizvodnje. Uopšteno govoreći, ovi zahtevi mogu biti izvedeni iz standarda, specifikacije, kupca ili zainteresovane strane.

Stoga bi se otkrivanje i izveštavanje o neusaglašenostima moglo dogoditi tokom revizije, inspekcije, pregleda dokumentacije, testiranja proizvoda, žalbi kupaca, povratnih informacija zainteresovanih strana i opšteg zapažanja zasnovanog na iskustvu [7]. Pored gore navedenog, NC mogu imati različite oblike i tipove, koji mogu varirati u zavisnosti od vrste industrije, tako da uobičajeni NC -i uključuju: neuspeh u identifikaciji problema, neuspešno definisanje procesa, planova i rasporeda, odstupanja procesa i nedostatke proizvoda , odstupanja od specifikacije karakteristika proizvoda, propušteni plan, povratak kupaca i dobavljača. Uzimajući u obzir navedene činjenice, NC podaci su rasuti po različitim organizacionim sistemima u heterogenim formatima. Specifična ICT rešenja sa skalabilnim mogućnostima mogla bi se primeniti za prevazilaženje raznolikosti i heterogenosti podataka, stvarajući okruženje za donošenje odluka u realnom vremenu za NCM stvaranjem homogenih digitalnih NC izveštaja.

2.3 Upravljanje neusaglašenostima

Početne pretpostavke, na osnovu kojih je sprovedeno istraživanje, su da je dovoljan protok informacija veoma naglašen za kontinuirano funkcionisanje naprednih proizvodnih procesa i da se, međutim, nepredviđene situacije i pitanja kvaliteta moraju često rešavati korišćenjem nepreciznih i nepotpunih informacije. Zbog toga je ključno obavljati česte sveobuhvatne i pouzdane kontrole kvaliteta kako bi se sproveli i isporučili procesi i proizvodi bez grešaka i visokog kvaliteta i bili konkurentni. Iako su tradicionalne tehnike i alati za analizu podataka široko i uspešno korišćeni za proveru kvaliteta, nove I4.0 tehnike se mogu primeniti na miniranje masovnih skupova podataka prikupljenih automatizovanom industrijskom arhitekturom.

Prateći gore navedene pretpostavke i zahteve K4.0, uključujući izveštavanje NC -a, primarna namera ovog istraživanja je usvajanje tehnologija iz skupa alata I4.0 (kao što su računarstvo u oblaku, veštačka inteligencija, mobilne platforme, napredne informacione tehnologije) kako bi se pokazao put do mogući prelazak kvaliteta na model K4.0. Autori će se u ovom istraživanju fokusirati na KM i NCM kao bitne elemente pristupa kvaliteta. Autori ovog rada pokazali su da pristupačna otvorena rešenja razvijena na osnovu tehnologija otvorenog koda mogu poboljšati NCM i osnovne principe KM-a. Autori pretpostavljaju da bi se razvoj pristupačnih cloud rešenja zasnovanih na MEAN steku mogao koristiti za NCM u realnom vremenu radi poboljšanja osnovnih principa KMS-a, kao što su angažovanje ljudi, poboljšanja i donošenje odluka zasnovanih na dokazima.

3. ARHITEKTURA I KARAKTERISTIKE RAZVIJENOG REŠENJA

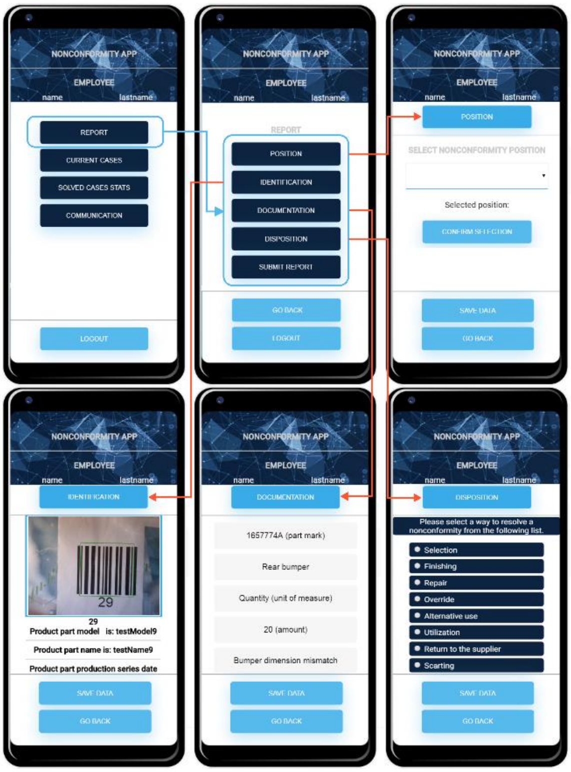
3.1 Opis aplikacija i njene prednosti za kvalitet 4.0 i upravljanje neusaglašenostima

Na osnovu navedenih pretpostavki i namera, zahtevi za softversko rešenje za izveštavanje o neusaglašenostima su sledeći: rešenje mora biti u stanju da prijave neusaglašenosti i da dodele neusaglašenosti određenom zaposlenom na upravljanje i rešavanje; da evidentiraju jednu ili više preventivnih/korektivnih radnji i da ih povežu sa prijavljenim neusaglašenostima; da se dodele odgovornosti za sprovođenje preventivnih/korektivnih akcija; da se istraže obaveštenja, sa podsetnicima, da se utvrde korelacije između performansi procesa i neusaglašenosti, u određenim periodima, koristeći metode statističke analize; da koristi skladištenje podataka i dalju kasniju upotrebu za formiranje potrebnog znanja u bazama znanja za buduće procese donošenja odluka. Shodno tome, softversko rešenje sadrži sledeće module: statističke i komunikacione module, modul za moguće otkrivanje bar koda proizvoda, modul za početno NC izveštavanje, modul za prepoznavanje uzoraka, modul za grafičku prezentaciju statističke analize. Rešenje se može uključiti u IoT arhitekturu organizacija i povezati sa drugim bazama podataka putem Web usluga. Prikupljeni podaci koji se odnose na definiciju neusaglašenosti, njeno upravljanje, identifikaciju proizvoda ili procesa u kojima je neusaglašenosti nastala, i predložene radnje za rešavanje neusaglašenosti mogu se koristiti za formiranje baze znanja koji se može naknadno koristiti, pored rekurentnih neuronskih mreža (RNN), za prepoznavanje obrazaca i davanje predloga odgovarajućih preventivnih/korektivnih radnji.

Slika 1 prikazuje interfejs predloženog rešenja zasnovanog na primeni JavaScript MEAN okvira. Izraz MEAN okvir predstavlja skup JavaScript zasnovanih tehnologija pogodnih za razvoj Web aplikacija. MEAN je skraćenica izvedena iz prvih slova korišćenih tehnologija, tj. MongoDB, EkpressJS, Angular i Node.js. MEAN je okvir otvorenog koda sa mogućnošću razvoja prilagodljivih i skalabilnih aplikacija, i kao takav je savršen kandidat za cloud hosting. Nivo prezentacije je razvijen kroz Angular okvir; nivo aplikacija je uveden kroz Ekpress.js i Node.js mogućnosti, pri čemu je MongoDB usvojen za definisanje baze podataka u oblaku. Shodno tome, izbor tehnologije može se smatrati bitnim aspektom, jer utiče na cenu, performanse i moguće funkcionalnosti rešenja za izveštavanje i kvalitet 4.0. Ako rešenje primenjuje više kompanija, prikupljeni i integrisani podaci mogli bi se koristiti za prepoznavanje obrazaca. U ovom slučaju, oni će učiti jedni od drugih i imati obrasce za priznavanje nacionalnih manjina i odabir mogućih inicijativa upravljanja.

Predložena metoda ima jasne prednosti jer koristi novi pristup u razvoju aplikacija kako bi ispunila principe KMS -a. Ovaj pristup sa dostupnošću i personalizacijom povećava učešće i uključenost zaposlenih i pruža širu osnovu za NCM i donošenje odluka zasnovanih na dokazima.

Sloj prezentacije se primenjuje preko JavaScript/TipeScript otvorenog koda Angular framevork-a. Povećana upotreba Angular okvira proizilazi iz činjenice da podržava koncept progresivnih veb aplikacija. Ovaj koncept ukazuje na to da je predstavljena aplikacija: trenutno učitana, nezavisna od mreže spora ili nestabilna veza, odzivna i, između ostalog, sa funkcijama, kao što je Veb Bluetooth API, što aplikaciju čini više izvornom. Node. Osim motora V8, Node.js sadrži biblioteku slojeva apstrakcije za rukovanje asinhronim događajima. Node.js objedinjuje razvoj aplikacija samo oko programskog jezika JavaScript. Podaci NC izveštavanja se šalju sa sloja prezentacije na poslovni sloj u laganom formatu JavaScript Object Notation (JSON) koji se međusobno menja.



Slika 1. Interfejs uspostavljenog softverskog rešenja

Sloj prezentacije se primenjuje preko JavaScript/TipeScript otvorenog koda Angular framevork-a. Povećana upotreba Angular okvira proizilazi iz činjenice da podržava koncept progresivnih veb aplikacija. Ovaj koncept ukazuje na to da je predstavljena aplikacija: trenutno učitana, nezavisna od mreže spora ili nestabilna veza, odzivna i, između ostalog, sa funkcijama, kao što je Veb Bluetooth API, što aplikaciju čini više izvornom. Node. Osim motora V8, Node.js sadrži biblioteku slojeva apstrakcije za rukovanje asinhronim događajima. Node.js objedinjuje razvoj aplikacija samo oko programskog jezika JavaScript. Podaci NC izveštavanja se šalju sa sloja prezentacije na poslovni sloj u laganom formatu JavaScript Object Notation (JSON) koji se međusobno menja. Ovaj format nije nezavisan od jezika i prilagođen je za razmenu podataka među međusobno povezanim klijentima. Kao kompaktan i jednostavan, JSON efikasno generišu i analiziraju mašine i lako ih čitaju ljudi. JSON je na osnovu pomenutih prednosti postao odgovarajuće rešenje za NoSKL bazu podataka u oblaku. MongoDB baze podataka pripadaju klasi baza podataka NoSKL, za razliku od SKL relacionih baza podataka, gde su kolone eliminisane, a redovi su dokumenti koji se koriste za skladištenje informacija o podacima i samim podacima. Pošto se podaci čuvaju u BSON formatu koji predstavlja binarni JSON dokument, MongoDB se pokazao kao razumno rešenje za razvoj aplikacija usmerenih na JavaScript. Ovaj modul dodaje čitav niz funkcija na vrh MongoDB -a koje omogućava definisanje i održavanje strukture podataka i modela podataka i njihovu upotrebu za uvođenje direktne interakcije od koda aplikacije do baze podataka.

3.2 Mogućnosti softverskog rešenja

Softversko rešenje ima za cilj da obezbedi izveštavanje u realnom vremenu o neusaglašenostima događajima uzrokovanim odstupanjima u procesima organizacije ili dobavljača. Odgovarajuće izveštavanje treba da obuhvati kritične elemente, kao što su pozicioniranje, identifikacija, dokumentacija i raspolaganje.

Rešenje može generalno da dobije podatke iz tri izvora: ručni unos od zaposlenih i podaci prikupljeni direktno pomoću senzora ugrađenih u proizvodnju i IoT. Preko ovih senzora, namenski softver uključuje funkcije spoljnih uređaja ili senzora povezanih na periferne U/I. Ova opcija zahteva prilagođavanje rešenja na obodu preduzeća, što uključuje postojeće senzore u sistemu.

U okviru predstavljenog rešenja moguće je koristiti Rekurentnu neuronsku mrežu (RNN) za otkrivanje mogućih obrazaca preventivnih/korektivnih mera [8]. RNN je klasa neuronske mreže (NN) koja proširuje konvencionalni NM unapred sa petljama u vezama [9]. RNN se razlikuju od naprednih NN jer mogu obraditi uzastopne ulazne podatke kroz ponavljajuće skriveno stanje čije aktiviranje u svakom narednom koraku zavisi od aktivacije prethodnog koraka. Na ovaj način, RNN može izložiti dinamičko ponašanje.

Za prepoznavanje uzoraka NC -a i korektivnih radnji, data sekvenca je je $nc = (nc^1, nc^2, \ldots, nc^k)$ predstavlja opise pojavljivanja neusaglašenosti, tako da okvir RNN može izračunati skriveni vektor niz kao $h =$

$(h^1, h^2, \ldots, h^K)$ ponavljanjem sledeće jednačine od k= 1 do K:

$$h^k = \varphi(w_{ih} nc^k + W_{hh} h^{k-1} + b_h). \quad (1)$$

Gde w_{ih} označava ulazni skriveni vektor težine, dok W_{hh} označava kontekstnu matricu težine skrivenog sloja, b_h je bias vektor u skrivenom sloju i $\varphi()$ je funkcija aktivacije skrivenog sloja (moguće sigmoidna ili tan-sigmoidna funkcija). Konačno, predviđena korektivna akcija ka mogla bi se izračunati na sledeći način::

$$q_a = W_{oh} h^K + b_o \quad (2)$$

gde W_{oh} označava matricu težine skrivenu na izlazu, i b_o je bias vektor izlaznog sloja. Motivacija je da se različiti događaji neusaglašenosti i korektivne radnje predstave kao sekvencijalni podaci, tako da se RNN može usvojiti za modeliranje prepoznavanja obrazaca.

3.3 Studija slučaja i rezultati implementacije

Razvijeno rešenje je korišćeno u tri mala i srednja preduzeća u proizvodnji plastičnih i gumenih delova namenjenih automobilskoj industriji. Neusaglašenosti plastičnih i gumenih proizvoda mogu biti različitie, teško ih je odrediti i prijaviti.

Primenom rešenja, zaposleni može da dokumentuje i prijavi neusaglašenosti. Moguće je obezbediti merenje ili koristiti korelirane podatke bar koda za praćenje neusaglašenosti kod prethodno realizovanih sličnih proizvoda, za sticanje znanja neophodnog za pretpostavku šta treba učiniti sa ovom vrstom neusaglašenosti. Softverski sistem koji koristi RNN modul pruža pomenutu odluku i radnju.

Autori su pratili implementaciju i početne rezultate zastupljenog softvera u tri mala i srednja preduzeća. Podaci su se prikupljali šest meseci. Imajući u vidu da kompanije imaju različite proizvodne programe i količine proizvodnje i različite proizvode, moglo bi se zaključiti da primena i korišćenje takvog sistema poboljšava uključivanje zaposlenih u proces i kulturu kvaliteta. S druge strane, omogućava lakše otkrivanje, izveštavanje i digitalizaciju uočenih NC -ova i smanjuje periode izveštavanja i preduzimanja radnji.

Autori su otkrili da bi prepoznavanje obrazaca pomoću RNN -a moglo pomoći u preduzimanju upravljačkih radnji u upravljanju neusaglašenostima. Iz dobijenih i prezentovanih podataka evidentno je da je povećan broj otkrivenih i prijavljenih neusaglašenosti i broj preduzetih korektivnih i preventivnih radnji. Od suštinskog je značaja uzeti u obzir da su mnoge preduzete mere zasnovane na sugestijama razvijenim o prepoznavanju obrazaca. Osim toga, ovaj softver prilagođen korisniku, sa inovativnim modulima, poboljšava učešće zaposlenih u NC izveštavanju. Može se zaključiti da ovo rešenje omogućava važne principe KM-a: učešće zaposlenih i donošenje odluka zasnovanih na dokazima za menadžere kvaliteta.

Sve kompanije su uvele, implementirale i sertifikovale QMS prema ISO 9001: 2015. Podaci u kojima je uspostavljena korelacija između NC -a i odeljaka standarda ISO 9001: 2015 (Tabela 1). Ova korelacijska tabela omogućava menadžerima kvaliteta da prate sve NC i imaju jasne menadžerske implikacije za buduće interne i eksterne revizije.

Tabela 1. Broj neusaglašenosti otkrivenih šest meseci pre implementacije softvera i šest meseci nakon korišćenja softvera povezan je sa posebnim odeljcima ISO 9001: 2015

Sekcija ISO 9001:2015 standarda	Pre upotrebe softvera			Nakon upotrebe softvera		
	SME 1	SME 2	SME 3	SME 1	SME 2	SME 3
4.1	0	0	0	0	0	0
4.2	0	0	1	2	1	3
4.3	2	2	2	3	3	3
4.4	2	1	2	1	2	3
5.1	0	0	0	0	0	0
5.2	0	0	0	0	0	0
5.3	2	2	3	3	3	4

6.1	2	2	3	3	3	4
6.2	3	3	2	4	4	3
6.3	0	0	0	0	0	0
7.1	0	0	0	0	0	0
7.1.1	0	0	0	0	0	0
7.1.2	0	0	0	0	0	0
7.1.3	2	3	3	4	3	4
7.1.4	0	0	0	0	0	0
7.1.5	1	1	2	3	2	3
7.1.6	0	0	0	0	0	0
7.2	1	1	3	2	2	2
7.3	0	0	0	0	0	0
7.4	0	0	1	0	0	0
7.5	2	2	1	0	0	0
8.1	0	0	0	0	0	0
8.2	2	2	0	0	0	0
8.3	0	0	2	0	0	0
8.4	2	3	1	4	3	6
8.5	4	7	4	8	8	7
8.6	2	1	1	2	1	0
8.7	4	4	3	7	6	5
9.1	2	2	2	1	2	2
9.2	1	2	2	2	2	1
9.3	2	2	3	2	2	2
10.1	0	0	0	0	1	0
10.2	2	1	2	0	0	0
10.3	0	0	0	0	0	0
UKUPNO	38	41	43	51	48	52

Primena softvera omogućava povezivanje neusaglašenosti sa posebnim odeljcima standarda ISO 9001: 2015. Svaka kompanija bi mogla imati dokaze o svojim podacima i definisati upravljačke akcije prema otkrivenim primarnim izvorima neusaglašenosti. Prema Tabeli 4, moglo se primetiti da se većina neusaglašenosti može povezati sa odeljcima 8.7 i 8.5, ali i značajan broj neusaglašenosti se odnosi na 6.2.

Da bi se dodatno proširila studija slučaja i uzeli u obzir performanse razvijenog rešenja, izvršeni su testovi za upoređivanje razvijenog rešenja sa mogućim rešenjima zasnovanim na pristupačnim tehnologijama, uključujući PHP, Apache server, MySQL i MariaDB. Autori su testirali rešenja na identičnoj infrastrukturi, koja je uključivala servere za skladištenje podataka sa strukturama zasnovanim na tehnologijama MySQL/Apache/PHP, MariaDB/Apache/PHP i MongoDB/Node.js/Ekpress.js, i slojevima prezentacije udaljenih korisnika sa strukture zasnovane na primeni HTML/CSS, HTML/CSS i Angular. Testiranja su odražavala najrealnije moguće scenarije za utvrđivanje koje tehnologije imaju najbolje performanse u smislu prosljeđivanja upita i preuzimanja podataka iz baza podataka.

Stvorena su različita radna opterećenja neusaglašenosti kako bi se testirale baze podataka prethodno korišćenih rešenja i odziv trenutnih rešenja. Svaki benčmark test izveden je pod istim korisničkim podacima menadžera kvaliteta, primenjujući podrazumevane postavke baze podataka.

Prije svega, postojala su tri scenarija, uključujući umetanje podataka, izmjenu i odabir. Prvi scenario se koristi za testiranje agilnosti umetanja za opsežniji skup objekata podataka u određenom zahtevu, drugi scenario za testiranje agilnosti za modifikaciju i treći scenario za testiranje agilnosti pri izboru. Svaki scenarij testa izveden je pet puta za različite količine upita, tako da je srednja vrijednost izračunata za svaki tip testa. Postupak je ponovljen zbog varijacija koje se mogu pojaviti tokom izvođenja testova. Testovi su sadržali sintaksu i strukturu, kao što je prikazano u Tabeli 2.

Tabela 2. Insert, Update i Select upiti u sekundi za svaku razmatranu tehnologiju

MongoDB Insert primer sintakse	MariaDB/MySQL Insert primer sintakse

db.nonconformity.insertMany([
{
"_id" : 1001,
"mark" : "1657774A",
"part name" : "Branik",
"quantity" : 20,
"description" : "Neusklađenost dimenzija",
"placement" : "Mašina za montažu",
"selected disposition" : "Alternativna upotreba",
"disposition description" : "upotreba neusaglašenih proizvoda u svrhe za koje nisu prvobitno definisane",
"production date" : new Date("2019-05-10")
}
]);
	INSERT INTO nonconformity VALUES
	(1001, '1657774A', 'Branik', 20,
	' Neusklađenost dimenzija ', 'Mašina za monta',
	'Alternativna upotreba', 'upotreba neusaglašenih proizvoda u svrhe za koje nisu prvobitno definisane',
	'2019-05-10')

MongoDB Update primer sintakse	MariaDB/MySQL Update primer sintakse

db.neusaglašenosti.update(
{ _id: 1001 }, // određuje koji dokument treba ažurirati
{
$inc: { quantity: 25 }, // povećava vrednost polja
$set: { // zamenjuje vrednost polja
"selected disposition" : "Vratiti dobavljaču",
"disposition description" : "Proizvodi se moraju vratiti dobavljaču jer su oštećeni."
}
}
)
	UPDATE neusaglašenosti
	SET quantity = quantity + 5
	selected disposition = "Vratiti dobavljaču",
	disposition description = "Proizvodi se moraju vratiti dobavljaču jer su oštećeni."
	WHERE _id = 1001

MongoDB select primer sintakse	MariaDB/MySQL select primer sintakse
db.neusaglašenosti.find({})	SELECT * FROM neusaglašenosti

Nakon pripreme uslova ispitivanja i realizacije ispitivanja, utvrđena su sva tri razmatrana scenarija (Tabela 3).

Testovi uvedeni u ovom delu studije izvedeni su na jednom serveru, ali stvari mogu izgledati drugačije sa podacima koji se dele po grupama. Ovu činjenicu treba uzeti u obzir pri budućim ispitivanjima.

Tabela 3. Upiti u sekundi za svaku razmatranu tehnologiju

Insert upiti						
Tehnologija	500 upita	1000 upita	2500 upita	5000 upita	7500 upita	10000 upita
MySQL/Apache/PHP	0.0800	0.1638	0.4019	0.8014	1.2037	1.6027
MariaDB/Apache/PHP	0.0692	0.1439	0.3479	0.6931	1.0385	1.3846
MEAN	0.0224	0.0660	0.2323	0.3671	0.6284	0.9271
Update upiti						
Tehnologija	500 upita	1000 upita	2500 upita	5000 upita	7500 upita	10000 upita
MySQL/Apache/PHP	0.0697	0.1552	0.3873	0.8789	1.4402	2.0828
MariaDB/Apache/PHP	0.0783	0.1445	0.2722	0.3427	0.5177	0.6900
MEAN	0.0106	0.0525	0.2023	0.3254	0.3677	0.4368
Select upiti						
Tehnologija	500 upita	1000 upita	2500 upita	5000 upita	7500 upita	10000 upita
MySQL/Apache/PHP	0.0394	0.0732	0.1965	0.3943	0.6011	0.7999
MariaDB/Apache/PHP	0.0306	0.0655	0.1696	0.3385	0.5156	0.6826
MEAN	0.0037	0.0328	0.1116	0.1832	0.3110	0.4597

Tabela 3 pokazuje da rešenje zasnovano na MongoDB -u ima veću brzinu kada je reč o umetanju, izmeni i pronalaženju podataka u poređenju sa rešenjima zasnovanim na MySQL -u i MariaDB -u, uglavnom kada se radi o velikoj količini podataka. Čini se da je povećanje vremena za sve tri vrste rešenja DBMS linearno. U scenarijima i okolnostima obuhvaćenim ovom studijom, autori su otkrili da je prelaskom sa MySQL i MariaDB tehnologija na MongoDB tehnologiju moguće dobiti znatno bržu bazu podataka sa relativno sličnom strukturom.

4. DISKUSIJA

Ovaj rad je sastavljen na I4.0 istraživanju počevši od ciljeva kvaliteta za postizanje usaglašenosti u vezi sa specifikacijama, smanjenjem varijacija, smanjenjem otpada, sprečavanjem kvarova, usklađivanjem između strategije i poboljšanja rada, efikasnošću i efektivnošću opreme i poboljšanjem operacija.

Predstavljeni softver je uključivao neke zahteve i jedinstvene karakteristike koje ga razlikuju od sličnih rešenja, pre svega u modulu gde je: 1) Android Sensor okvir koristio senzore sa mobilnih platformi, koje su koristili i autori ovog rada; 2) novi model RNN -a mogao bi efikasno analizirati moguće neusaglašenosti, jer su sekvencijalni podaci odredili korektivnu akciju, na osnovu znanja o prethodno priznatim neusaglašenostima; i 3) autori su omogućili mobilnoj platformi prikupljanje podataka sa drugih senzora i IoT-a. Omogućava da ovo rešenje nadmaši slične proizvode, donoseći dodatnu vrednost organizacijama. Predstavljeno rešenje omogućilo je identifikovanje proizvoda ili resursa, pretvarajući mobilnu platformu u čitač bar koda, omogućavajući potpunu sledljivost izveštaja. Kada je došlo do stvaranja neusaglašenosti proizvoda ili situacije, uspostavljeni algoritam je prosledio zadatak namenskom menadžeru kvaliteta predlažući moguće radnje. Autori su implementirali modul za RNN za otkrivanje mogućih obrazaca za korektivne radnje. Ovaj modul će omogućiti odgovornoj osobi da koristi neke definisane obrasce ili da odluči koristeći predloge ili preduzimajući potpuno nove radnje. Osim toga, rešenje bi moglo pomoći u definisanju istih radnji, kao što su prerada, popravka, dozvole, ispravke i otpad.

Osnovna novina, koja je predstavljena u ovom radu, odnosi se na integrisanje istraživanja u okviru kontrole kvaliteta, menadžmenta i softverskog inženjeringa. Razvijeno softversko rešenje namerava se koristiti za pristupačnu identifikaciju i izveštavanje neusaglašenosti sa mogućnošću integracije drugih softverskih modula za analizu kvaliteta, rešavanje problema, korektivne/preventivne radnje i korišćenje visokog nivoa primenjenih metoda (mašinsko učenje i veštačko metode optimizacije inteligencije).

Osim toga, ovaj rad ukazuje na to da bi mala, pristupačna rešenja razvijena da budu prilagođena korisnicima mogla da uključe neke od glavnih principa upravljanja kvalitetom, poput angažovanja zaposlenih. Osim toga, upotreba MEAN okvira pruža poboljšanu mogućnost za prepoznavanje obrazaca i ispunjenje drugih principa upravljanja kvalitetom, poput poboljšanja i donošenja odluka zasnovanih na dokazima.

5. ZAKLJUČAK

Količina podataka u stvarnom vremenu prikupljenih iz više izvora u proizvodnim organizacijama stalno se povećava. Ako se ti podaci čuvaju, postoji ogromna prilika da se olakša protok informacija i poboljšaju proizvodni procesi pomoću analize velikih podataka i ispravnih odluka. Prema tome, osnovna premisa ove studije je da je jedan od mogućih fundamentalnih koraka ka I4.0, a zatim i uključivanju koncepata kvaliteta 4.0, implementacija mobilnih aplikacija za poboljšanje upravljanje kvalitetom i proizvodnje. Shodno tome, ova studija predlaže specijalizovanu mobilnu aplikaciju zasnovanu na ulogama sa više interfejsa podeljenih ulogama koje se mogu koristiti za izveštavanje NC-ova u realnom vremenu i sticanje uvida u podatke o naknadnom otkrivanju proizvodnih nedostataka i uzroka, mapiranju nedostataka, kvaru mašine i smanjenje zastoja.

Kako upravljanje neusaglašenostima predstavlja jedan od bitnih zadataka upravljanja kvalitetom, neophodno je nabaviti i koristiti informacioni sistem da bi se olakšao protok informacija i omogućila primena efikasnih proaktivnih i korektivnih mera upravljanja kvalitetom u realnom vremenu. Uporedo sa identifikacijom, dokumentacija o neusaglašenostima se pojavila kao problem. Rešenja na ovu temu iz široke literature uglavnom se zasnivaju na tradicionalnim merama i procedurama za rešavanje neusaglašenosti i obično ih uzimaju samo predstavnici upravljanja kvalitetom i zahtevaju značajno vreme. Neke od ovih dilema mogle bi biti razrešene konvergencijom između Kvaliteta, I4.0 i IoT -a. Inovativna softverska rešenja mogla bi doprineti naprednijem upravljanjau neusaglašenostima.

Softversko rešenje donosi koristi i zaposlenima, menadžerima i zainteresovanim stranama kroz (1) uključivanje svih zaposlenih; (2) digitalizacija i poboljšanje postojećih neusaglašenosti sistema izveštavanja; (3) poboljšanje kulture o prijavljivanju neusaglašenosti; (4) bolje razumevanje i merenje doprinosa poslodavaca kroz upavljanje neusaglašenostima; (5) olakšavanje upotrebe tehnologije pristupačnom i pogodnom za širu publiku u industriji (izvorni kod demo verzije je javno dostupan na skladištu GitHub: https://github.com/ckm-kualiti-center/nonconformiti.

Konačno, razvijeno rešenje je implementirano u 3 mala i srednja preduzeća. Prvi rezultati pokazuju nekoliko prednosti u povećanju otkrivanja neusaglašenosti, izveštavanju, vremenu i povećanju učešća zaposlenih u broju preventivnih i korektivnih radnji i poboljšanju sistema upravljanja kvalitetom u celini. Broj korektivnih i preventivnih radnji preduzet je na osnovu pomoći modula RNN. Sve NC su bile povezane sa posebnim odeljcima standarda ISO 9001: 2015, tako da su menadžeri kvaliteta i menadžeri u kompanijama mogli da imaju uvid u izvore problema i osnovu za definisanje različitih upravljačkih akcija.

Sistem se može nadograditi i proširiti u mnogo različitih pravaca, poput razvojnih modula za upravljanje dokumentacijom ili napredno prepoznavanje slike sistema (kao deo kontrole kvaliteta) radi podrške i međusobnog povezivanja sa drugim sistemima (bezbednost, upravljanje životnom sredinom).

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REAL-TIME SOFTWARE TOOL FOR NONCONFORMITY MANAGEMENT IN SMALL AND MEDIUM ENTERPRISES WITHIN THE INDUSTRY 4.0 AND QUALITY 4.0 CONCEPTS

Abstract: *This paper aims to propose a software solution for detecting nonconformities and defining preventive and corrective actions that expand the use of mobile devices in accordance with the paradigms of Industry 4.0 and Quality 4.0. The presented design of the software solution is based on the JavaScript programming language and its ability to be implemented at all levels of software solutions through interconnected frameworks (MongoDB, Express.js, Angular and Node.js) within MEAN. The developed solution was implemented in three small and medium enterprises. The first results show several advantages in increasing non-compliance and reporting. All non-compliances were related to special sections of the ISO 9001: 2015 standard, so that quality managers and managers in companies had an insight into the sources of problems and the basis for defining different management actions. The main contribution of the paper is reflected in the presentation of a software solution intended for accessible identification and reports on a large number of non-compliances, integrated with other software modules.*

Keywords: *Industry 4.0, Quality 4.0, nonconformity report, nonconformity management, open source solution.*

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TESTING OF THE CATERPILLAR TRACK PARTS E-650 FOR THE PRIMARY MINING INDUSTRY

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Apstract: *The casting of caterpillar tack parts used to form the caterpillar assembly, as components of the crawler excavator, are responsible components and from the aspect of their production, casting can be considered the most favorable technological process. In these metallurgically complex and geometrically demanding castings, in addition to the appropriate technology, it is necessary to correctly define the material. In addition to the selection of the appropriate material, the intensity of wear, dynamic strength, and other mechanical characteristics are greatly influenced by the microstructure of the material, and one of the main indicators of quality is the depth of hardenability on wearing surfaces. For these reasons, great attention should be paid to the examination of what is the subject of this paper.*

Keywords: *testing, control, caterpillar tack part, basic mining industry.*

1. INTRODUCTION

An excavator is a self-propelled machine of continuous action intended to excavate tailings and useful mineral raw materials in surface mines [1]. Track part castings are used to form the track joint assembly (tracks) as a component of the crawler excavator [2]. Metal tracks are resistant to wear and damage and are made by metal casting technology in sand molds. This technology applies to the characteristics of large metallurgical complexities and high geometric accuracy of measurements and shapes.

The caterpillar tack part are mainly made of GS-40 MnCrSi3V (chemical composition: C% (0.35–0.45); Si (% 0.50–0.75); Mn% (0.60–0.90); Cr% (0.5–0.8), Ni% (≤0.3), P% (<0.04), S% (<0.04) and Cu% (≤0.30), then from G30CrMoV6-4 + KT1 (chemical composition: C% (0.27–0.34); Si max% (0.60); Mn% (0.60-1.00); Cr% (1.30-1, 70); Mo% (0.30–0.50); P% (<0.025); S% (<0.02) and V% (0.05–0.15) or of GS 42CrMo4 whose chemical composition: C% (0.38–0.45), Si% (0.10–0.40), Cr% (0.90–1.20), Mo% (0.15–0.30), Cu% (0.40). It is usually required that the caterpillar track part be delivered in an improved condition (R_m≥750 MPa and R_e≥390 Mpa) in the case of GS-40 MnCrSi3V casting material. 2015, from the material G 30CrMoV6-4 + KT1 at 20 °C, require the following mechanical properties: $Rp_{0.2}$ is a minimum of 700 MPa, R_m ranges from 850 to 1000 MPa, elongation is: A=14%

and *KV* (energy impact) [J] = 45 [3]. One of the special requirements during delivery is that the caterpillar track part is induced on wearing surfaces with a depth of probability of 10 ± 2 mm and a hardness of 52 ± 5HRC on the surface, or 35 ± 5 HRC at a depth of 10 ± 2 mm. The test is performed by the "POLDI" method, at three places at three points along with the depth of the calcined layer, symmetrically to the condemnation of the article [4].

Upon delivery, a report on the metallographic inspection of the cross-section of the induction hardened surface of the casting is required. It is necessary for the induction-hardened layer to be symmetrical to the cross-sectional axis and to reach a width of 116 mm and a depth of 10 mm. Also, the condition is that the transition from the hardened zone to the unhardened area is gradual and that the primary material has a delicate and uniform structure. Regarding the thermal treatment of the casting of the caterpillar tack part, it is necessary to perform improvement and induction hardening. This paper will present the process of testing and controlling the caterpillar track parts for the primary mining industry.

2. TESTING AND CONTROL OF CATERPILLAR TRACK PARTS

Testing of the caterpillar track parts E -650 for SRs 1300 excavator consists, in addition to the general technical conditions of delivery of steel castings, of control of chemical composition, mechanical properties, and delivery conditions SRPS EN 10293: 2015: Castings - castings - castings for general industrial use and SRPS EN 1559-2: 2015 Foundry - Technical delivery conditions - Part 2: Additional requirements for cast steel castings [5,6].

2.1 Chemical composition testing

Depending on the quality of the steel, the chemical composition of the casting must correspond to the corresponding part of the standard SRPS EN 10293: 2015, section 7.2.1 and is determined for each batch separately [5]. The certificate of chemical composition is issued according to the type of certificate SRPS EN 10204: 2018-3.1 [7].

The the caterpillar track parts E-650 was cast from GS 42CrMo4 material with the following chemical composition: C% (0.41); Si% (0.35); Mn% (0.73); P% (0.01); S% (0.01); Cr% (1.10) and Mo% (0.27).

2.2 Testing of mechanical properties

Samples for testing were taken in the prescribed manner, as follows:

A) Tensile strength according to SRPS EN 10293: 2015, section 7.2.1, type of a certificate according to SRPS EN 10204: 2018-3.1.
B) Impact and bending resistance test (SRPS EN ISO 148-1: 2017 Metallic materials - Impact test with Charpi pendulum - Part 1: Test methods) and SRPS EN 10293: 2015; section 7.2.2 .; at room temperature [5,8].

With regard to testing units, the number of samples, sample location, sampling, and testing, it should be noted that each batch of heat treatment, after melting, is tested. The tensile test specimen and the test unit (three specimens) for the impact toughness and bending test were taken from the casting itself.

Table 1. Realized mechanical properties of casting

	$Rp_{0.2}$ [MPa]	R_m [MPa]	*A* [%]	*KV* [J]
Min.	390	750	11	45
Max.	/	1050	/	/
GS 42 Cr Mo4				

2.3 Examination of the internal condition of castings

Testing of the internal condition of castings was performed in accordance with SRPS EN 1559-2: 2015 Section 7.3.3. Ultrasonic testing of steel castings was performed according to the provisions of the standard SRPS EN 12680-2: 2012, and the procedure was performed in accordance with the DGS method. The test areas are divided into zones [9,10].

Zone 1: hardened (induction hardened) area (high-pressure area), openings, and transitions (Fig. 1). Zone 2: other areas of the casting. The required quality level for test zone

1 is level 3, and for the rest, it is level 4. The readings are without extension and at a distance of at least 30 mm in all three directions. Acceptance of feedback signals is according to SRPS EN 12680-2: 2012, section 5.5.5.1.

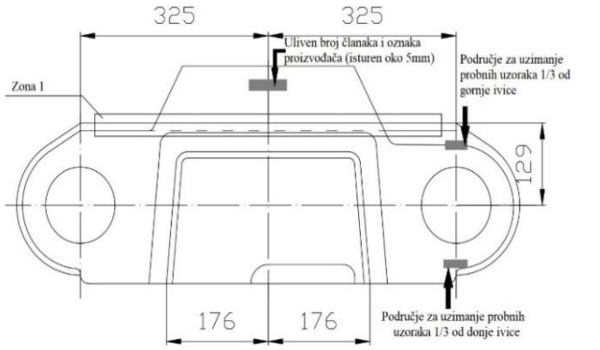

Figure 1. Drawing of a caterpillar track part with characteristic places for taking a test sample

Accumulation of readings with readings up to 6 dB below the registration limits is not permitted. The test was performed after the last thermal treatments and the test area consisted of the entire available area. In terms of surface condition, the boundary pattern 4, S1 is for the case of surface sandblasting (the case in this paper) and 4, S2 in the case of sanded surfaces. Permissible roughness R_a≤ 25 µm and must be documented by measurement and recording.

2.4 Examination of the external condition of castings

The condition of the external surfaces on the casting of the caterpillar track parts E-650 was determined according to SRPS EN 1559-2: 2015, section 7.3.3.2 and section 7.3.4.2. Surface testing was performed using magnetic particle testing methods (SRPS EN 1369: 2014), and the permitted limits are the data by zones in Figure 2. Zone 1: welding area (SRPS EN 1369: 2014: table 2: SM1; Table 3: LM1/AM1); Zone 2: Openings and passages (SRPS EN 1369: 2014: Table 2: SM2; Table 3: LM2/AM2; Zone 3: Other casting areas (SRPS EN 1369: 2014: Table 2: SM3; Table 3: LM3/AM3. No cracks were observed during the casting test [11]. The machined outer surfaces were tested with magnetic particles, and the machined opening surfaces were tested with penetrants.

Permitted limits are defined according to SRPS EN 1369: 2014; SM1; Foundry - Testing with liquid penetrants - Part 1: Castings live in sand molds, gravity cast, and live under low pressure; LP1/AP1. Cracks in the castings were not observed during the test [12].

2.5 Induction hardening of the caterpillar track part

The depth of the hardened layer is shown by the diagram in Figure 2, for each mm of depth in a minimum of three directions.

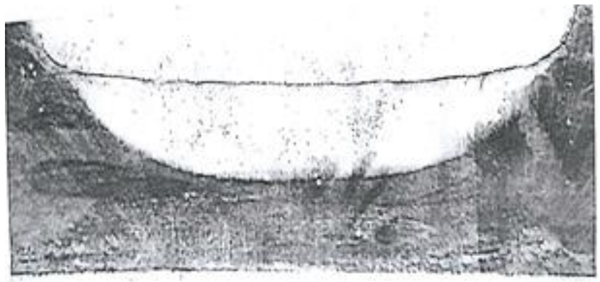

Figure 2. Induction hardened layer

Table 1. Measuring point I

mm	HV_{10}/HRC
0.8	514/49
1.6	572/52
2.4	642/55.,5
3.4	642/55.5
4.4	642/55.5
5.4	642/55.,5
6.4	572/52.8
7.4	572/52.8
8.4	514/49.1
9.4	464/45.6
10.4	385/38
11.0	340/35
11.4	274/27

The surface hardness of the induction hardened surface is 52HRC, and it was measured by drilling at a depth of 3 mm.

At measuring point I (tab.1), measured with Hv10 / HRC from the surface to the core, the depth of the induction-hardened layer is Nht 35RC, 11 mm.The measuring point I located in the middle of the tread. Measuring point II is located to the left of point I at a distance of 40 mm, and III measuring point is to the right and away from the point I, 40 mm. Figure 3 shows axes I, II, and III for testing the hardenability of depth.

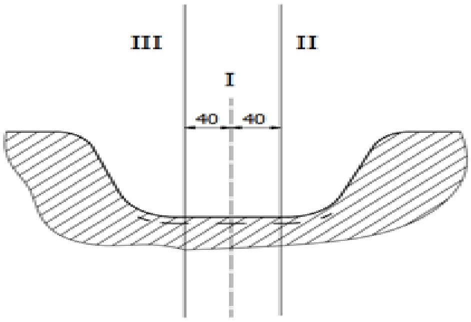

Figure 3. Sketch of the axes for testing the depth of hardenability

Table 2. Measuring point II

mm	HV_{10}/HRc
0.8	514/49.1
1.8	642/55.5
2.8	642/55.5
3.8	642/55.5
4.8	572/52.8
5.8	572/52.8
6.8	514/49.1
8.0	351/36
11.0	275/27

At measuring point II (Table 2), the depth of the induction hardened layer is Nht, 35RC 8.0 mm.

Table 3. Measuring point III

mm	HV_{10}/HRc
0.6	500/48.4
1.6	572/52.8
2.6	642/55.5
3.6	642/55.5
4.6	642/55.5
5.6	572/52.8
6.6	464/45.6
7.6	383/38
8.1	340/35
10.5	275/27

The depth of the induction hardened layer for measuring point III (Table 3) is 8.1 mm.

Figure 4 shows a diagram of hardness measurement by the depth of the measuring point.

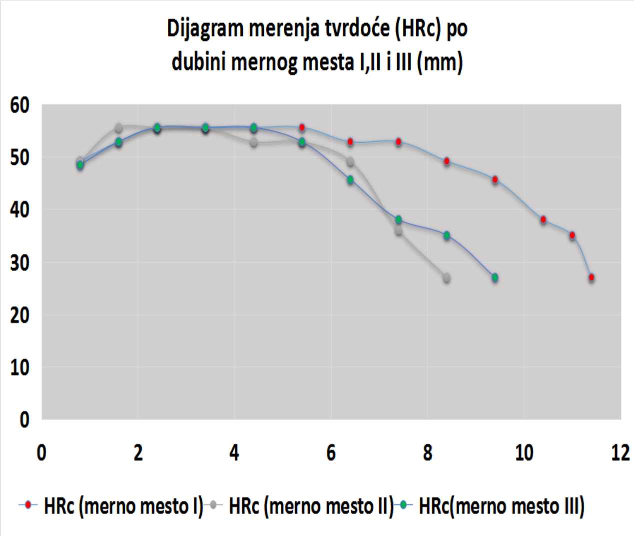

Figure 4. Diagram of hardness measurement by the depth of measuring point

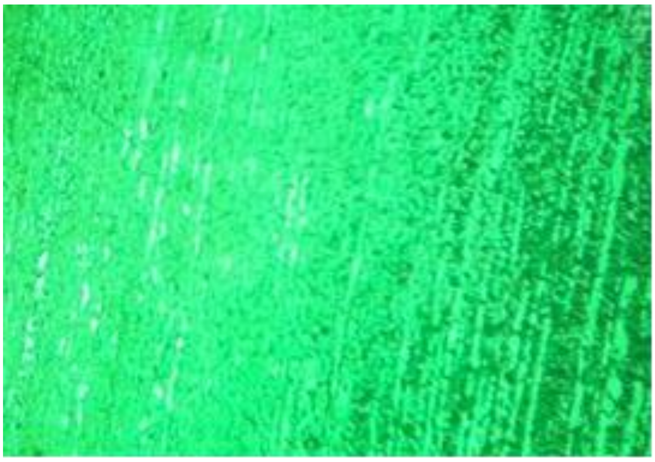

Figure 5. Microstructure of the casting

Figure 5 shows a clear transition from the basic structures (ferrite - perlite) to the martensite structure after improvement and induction hardening (hardened in oil at 830–860 °C). The fine and uniform structure of martensite is clearly observed.

3. CONCLUSION

The paper presents the control and testing procedure of the caterpillar tack part E-650 used on the SRs 1300 excavator.

Since the caterpillar tack part is from 42CrMo4, further research may consist of analysis and said casting of the cast and other materials, for example, 30CrMoV6-4 + QT1 or GS-40 MnCrSi3V, as well as monitoring and analyzing possible breakage during exploitation.

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UNAPREĐENJE KVALITETA KONFIGURACIJE MODULARNIH TREZORSKIH PROSTORIJA PRIMENOM REGRESIONE ANALIZE

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Apstrakt: *Modularne trezorske prostorije (MTP) se grade od industrijski proizvedenih elemenata, koji se sastavljaju na mestu korišćenja. Projektuju se po individualnom zahtevu kupca koji bira stepen sigurnosti po standardu EN 1143-1 i definiše raspoložive dimenzije prostora u koje je potrebno smestiti ovakav proizvod. Konfigurisanje modularne trezorske prostorije se ostvaruje kombinacijom standardnih modula koji se ponavljaju u svakom novom projektu i međusobno se razlikuju samo po broju i dimenzijama.*
Primenom statističke analize i alata kvaliteta broj grešaka u procesu izrade MTP je optimizovan i sveden na prihvatljiv minimum. Dopunska analiza je pokazala da postoji zavisnost ukupnog broja grešaka od dimenzija modula MTP. Implementacijom dobijenih matematičkih modela u procesu konfiguracije proizvoda je moguće dodatno uticati na smanjenje grešaka a time i na unapređenje kvaliteta konfiguracije MTP.

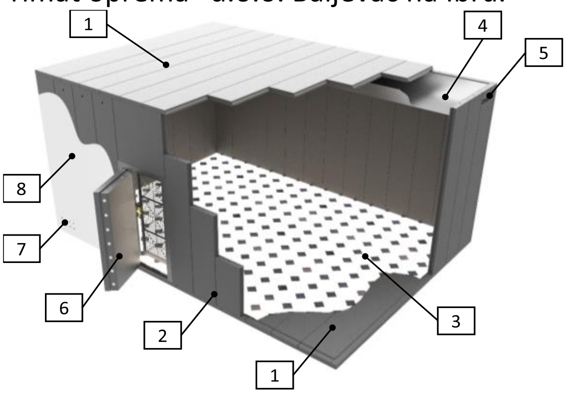
Ključne reči: *modularne trezorske prostorije, regresiona analiza, unapređenje kvaliteta.*

1. UVOD

Trezorska prostorija je prostorija sa posebnim sigurnosnim karakteristikama i namenjena je za čuvanje novca, dragocenosti, vrednosnih papira, poverljivih dokumenata i sl. Korisnici trezorskih prostorija su *bankarske institucije, pošte, Vlade i državne službe, vojne i policijske organizacije, farmaceutske kompanije, industrijska preduzeća* i dr. [1-5].

S obzirom da je klasičan način gradnje trezorskih prostorija skup i dugo traje danas se sve više koristi sistem gradnje koji je zasnovan na modularnoj strukturi.

Modularne trezorske prostorije (MTP) rade se po zahvetu kupca koji bira stepen sigurnosti po standardu EN 1143-1 [6] i daje raspoložive dimenzije prostora u koje je potrebno smestiti ovakav proizvod. Modularnim pristupom osiguravaju se prednosti serijske proizvodnje i istovremeno omogućuje konstruisanje proizvoda prilagođenih individualnim zahtevima kupca [1-5]. Na slici 1 je prikazan izgled MTP „MODULPRIM" iz proizvodnog programa kompanije „Primat" a.d. Maribor koja se proizvodi u privrednom društvu „Primat oprema" d.o.o. Baljevac na Ibru.



Slika 1. Modularna trezorska prostorija [1,3,4]

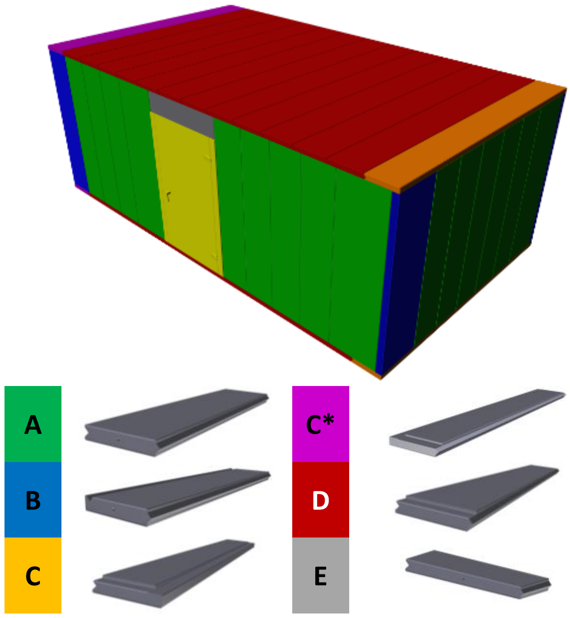
Osnovni elementi MTP prikazane na slici 1 su: 1. elementi krova i poda; 2. elementi sigurnosnih stanica; 3. unutrašnje obloge; 4. kablovski vodovi; 5. ventilacioni sistem; 6. trezorska vrata; 7. provetravanje; 8. spoljašnje obloge.

Proces konfigurisanja MTP započinje definisanjem liste zahteva koja se formira na osnovu zahteva kupca. Zadatak procesa konfigurisanja je da iz zadatog skupa modula i komponenti, koristeći poznata pravila i ograničenja među odabranim elementima, odredi varijantu proizvoda koja će zadovoljiti zadate zahteve. Najzahtevniji i najodgovorniji posao pri konfigurisanju MTP je proračun parametara pojedinačnih modula kao i broja i rasporeda istih [4]. Osnovni parametri modula koje je potrebno izračunati su širina (*b*) i dužina svakog modula (*l*). Dužina modula je određena konstrukcionim karakteristikama i raspoloživim prostorom za ugradnju, a širina modula se može birati u rasponu od 450 do 850 mm. Klasifikacija modula data je u tabeli 1., a njihov oblik i položaj ugradnje na slici 2.

Tabela 1. Klasifikacija modula [1, 11]

Kriterijum podele		Vrsta modula						
I	Funkcija	Osnovni modul			Modul za povezivanje			
II	Oblik (Tip)	**A**		**D**	**B**	**C**		**E**
Oznaka		A	A1, A2, A3, A4	D	B1, B2, B2	C	C*	E

U skladu sa menadžmentom sistema kvaliteta ISO 9001 u privrednom društvu „Primat oprema“ d.o.o. Baljevac se konstantno prati brojnost grešaka u procesu izrade i montaže MTP. Za selekciju najuticajnijih grešaka se koristi Pareto analiza a za kontrolu stabilnosti i sposobnosti procesa atributivne i numeričke kontrolne karte kvaliteta. Iako je primenom statističke analize i analize kvaliteta broj grešaka u procesu izrade MTP optimizovan i sveden na prihvatljiv minimum stalno se radi na unapređenju kvaliteta ovih proizvoda.



Slika 2. Oblik i položaj modula u MTP [1]

Primenom regresione analize je ustanovljeno da postoji zavisnost ukupnog broja grešaka od dimenzija modula MTP čime se ukazala mogućnost da se ugradnjom dobijenih matematičkih modela u proces konfiguracije proizvoda dodatno utiče na smanjenje grešaka a time i na unapređenje kvaliteta konfiguracije MTP.

2. STOHASTIČKI REGRESIONI MODEL

2.1 Klasifikacija grešaka

Za *MTP* tipa *MODULPRIM* stepena sigurnosti VS, V; VI; VII; VIII i IX kontrolnim planom su definisane 23 greške koje treba kontrolisati 100%. One obuhvataju faze sklapanja, betoniranja i farbanja modula (tabela 2).

2.2 Merenje i analiza podataka

U analiziranom periodu urađeno je 6 MTP tipa MODULPRIM 5. Svaka MTP je imala različiti broj sastavnih modula. Za analizu zavisnosti ukupnog broja grešaka od dužine i širine modula, moduli su grupisani u dve grupe. ***Grupa 1*** obuhvata zidne module tipa **A** i **B** a ***grupa 2*** podne i plafonske module tipa **C**, **Cz**, i **D**. Grupe su definisane na osnovu konstrukcione i tehnološke sličnosti modula. Modul **E** (modul iznad trezorskih vrata) nije analiziran jer njegove dimenzije direktno zavise od dimenzija trezorskih vrata i nije ih moguće optimizovati.

U nastavku će biti prikazana regresiona analiza za ***grupu 2*** koja obuhvata module **C**, **Cz**, i **D**. U posmatranom periodu je urađeno 52 modula iz ove grupe. Podaci o ukupnom broju grešaka i dimenzije modula dati su u tabeli 3.

Tabela 2. Klasifikacija grešaka u procesu izrade *MTP MODULPRIM*

R. br.	**Oznaka**	**Karakteristika**	**Zahtev/ tolerancija**	**Uzorkovanje**		**Merna tehnika/alat**
				vel.	**frekv.**	
1	G1	Kontrolna mera: -Širina -Dužina -Visina	±1 mm ±1 mm ±0,5 mm	1	100%	Trakasti metar i pomično kljunasto merilo
2	G2	Zavarenost krajeva armature	3 ◺ *n* × 10	1	100%	Vizuelno/trakasti metar
3	G3	Zavarenost ojačivača kroz tehnološke otvore i krajeve	3 ⊓ 1 × 15	1	100%	Vizuelno
4	G4	Zavarenost gnezda	Kontinualno	1	100%	Vizuelno
5	G5	Zavarenost cevi 3/4" × L mm	3 ◺ 2 × 15 (27)	1	100%	Vizuelno/ trakasti metar
6	G6	Zavarenost odstojnika	3 ◺ *n* × 10 (90)	1	100%	Vizuelno/ trakasti metar
7	G7	Položaj cevi prema crtežu	Постављене према цртежу	1	100%	Trakasti metar
8	G8	Zavarenost zaključnica (spolja i unutra)	3 ◺ *n* × 15 (90)	1	100%	Vizuelno/ trakasti metar
9	G9	Pravost i ugaonost omotača	±2 mm/±1°	1	100%	Lenjir/ugaonik/mašinski uglomer
10	G10	Fina obrušenost zavarenog spoja (spolja)	Vizuelno	1	100%	Vizuelno
11	G11	Zavarenost veznih traka	Prisutnost	1	100%	Vizuelno
12	G12	Oznaka modula (signo oznaka)	Prisutnost	1	100%	Vizuelno
13	G13	Položaj ventilacionog sklopa	Položaj	1	100%	Trakasti metar
14	G14	Poravnatost zaključnice sa omotačem	Poravnatost	1	100%	Vizuelno
15	G15	Betoniranje po recepturi	Broj recepture 028/035	1	100%	Dnevnik betoniranja
16	G16	Popunjenost betonom	+0/-1	1	100%	Lenjir i merni listići
17	G17	Očišćenost od betona	Bez betona	1	100%	Vizuelno
18	G18	Očišćenost ventilacionih otvora od betona	Bez betona	1	100%	Vizuelno
19	G19	Prohodnost navrtke M20	Prohodan navoj	1	100%	Kontrolni vijak
20	G20	Ofarbanost osnovnom bojom	Ravnomerno nanešena boja po celoj površini lamele	1	100%	Vizuelno
21	G21	Ravnost površina	±2 mm	1	100%	Lenjir i merni listići
22	G22	Ugaonost	±1°	1	100%	Mašinski uglomer
23	G23	Signo oznaka modula (flomasterom)	Signo oznaka	1	100%	Vizuelno

Tabela 3. Podaci o brojnosti grešaka u zavisnosti od *b* i *l* za module C, Cz, i D

R. br.	Tip modula	*b* (mm)	*l* (mm)	ΣG_i
1	**C**	470	1790	3
2	**C**	470	1790	2
3	**Cz**	470	1790	3
4	**Cz**	470	1790	3
5	**D**	550	1790	1
6	**D**	550	1790	1
7	**D**	550	1790	0
8	**D**	550	1790	1
9	**D**	650	1790	1
10	**D**	650	1790	0
11	**D**	650	1790	1
12	**D**	780	1790	0
13	**D**	780	1790	0
14	**D**	780	1790	0
15	**C**	550	2350	1
16	**C**	550	2350	1
17	**Cz**	550	2350	1
18	**Cz**	550	2350	1
19	**D**	550	2350	1
20	**D**	550	2350	0
21	**D**	550	2350	1
22	**D**	550	2350	1
23	**D**	550	2350	2
24	**D**	550	2350	1
25	**D**	550	2350	1
26	**D**	550	2350	1

R. br.	Tip modula	*b* (mm)	*l* (mm)	ΣGi
27	**D**	550	2350	0
28	**D**	550	2350	1
29	**C**	750	2940	1
30	**C**	750	2940	1
31	**Cz**	750	2940	0
32	**Cz**	650	2940	0
33	**D**	650	2940	1
34	**D**	550	2940	2
35	**D**	550	2940	2
36	**D**	550	2940	0
37	**D**	550	2940	1
38	**D**	550	2940	2
39	**D**	550	2940	0
40	**D**	550	2940	2
41	**D**	550	2940	1
42	**D**	550	2940	1
43	**D**	550	2940	1
44	**D**	550	2940	0
45	**D**	550	2940	1
46	**D**	550	2940	2
47	**D**	550	2940	2
48	**D**	550	2940	1
49	**D**	550	2940	1
50	**D**	450	2940	3
51	**D**	450	2940	2
52	**D**	450	2940	2

2.3 Regresiona analiza

Problem se svodi na iznalaženje funkcionalne zavisnosti između ukupnog broja grešaka $\boldsymbol{\Sigma G_i}$ kao izlazne performanse procesa i ulaznih parametara: širine modula *b* i dužine modula *l.* Za kvantifikaciju odnosa između nezavisnih ulaznih parametara i zavisne promenljive procesa (odziva) je korišćena ***metodologija odzivne površine*** RSM (*Response Surface Methodology)* [7-10]. Dobijeni matematički model u vidu polinoma *n*-tog reda predstavlja ***funkciju odziva*** koja se grafički može prikazati kao ***odzivna površina.***

Obrada podataka je urađena u softverskom paketu *Design Expert v.9.0.6.2.* Od matematičkih modela koji su na raspolaganju predložen je ***kvadratni model*** (tabela 4).

Tabela 4. Tabela zbirnih statističkih podataka

Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0,69935	0,35763	0,33141	0,27045	27,21783	
2FI	0,69831	0,37261	0,33340	0,25441	27,81631	
Quadratic	0,60936	0,54217	0,49241	0,43604	21,03994	Suggested
Cubic	0,61003	0,56110	0,49128	0,39970	22,39572	Aliased

Primenjena je *ANOVA* analiza i izvršena je redukcija nesignifikantnih (beznačajnih) članova metodom unazad (*Backward Elimination Regression with Alpha to Exit* = 0,100). Iz dalje anallize su isključeni članovi čija je *p*-vrednost veća od 0,10. U ovom slučaju to su članovi B, AB i B^2 (gde je: **A** je parametar ***b***, **B** je parametar ***l***). Analiza varijansi za preostale članove je prikazana u tabeli 5.

Tabela 5. *ANOVA* analiza za redukovani kvadratni model

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value; Prob > F**	
Model	18,3180	2	9,1590	23,6335	6,52533E-08	significant
A-*b*	17,9609	1	17,9609	46,3454	1,31716E-08	
A^2	4,9813	1	4,9813	12,8535	0,00077	
Residual	18,9896	49	0,3875			
Lack of Fit	3,6236	6	0,6039	1,6900	0,14666	not significant
Pure Error	15,3661	43	0,3574			
Cor Total	37,3077	51				

F vrednost modela (F=23,63) ukazuje da je model signifikantan (značajan) i da postoji šansa manja od 0,01% da je vrednost F posledica šuma. Niska vrednost verovatnoće (p<0,05) potvrđuje da su parametri modela takođe signifikantni. Nedostatak sposobnosti prilagođavanja (*eng. Lack of Fit)* ima F-vrednost 1,69 što ukazuje da varijacija vrednosti merene veličine kod istovetnih ponavljanja nije signifikantna u odnosu na čistu grešku. Koeficijent determinacije (R-squared) i ostale statistike (tabela 6) imaju dobre vrednosti što potvrđuje opravdanost izbora matematičkog modela.

Tabela 6. Računske vrednosti statistika za ocenu matematičkog modela

Std. Dev.	0,6225	R-Squared	0,4910
Mean	1,1154	Adj R-Squared	0,4702
C.V. %	55,8130	Pred R-Squared	0,4296
PRESS	21,2791	Adeq Precision	15,4855

Međutim, dijagnoza statističkih svojstava predloženog modela je pokazala da raspodela ostataka (reziduala) nije normalna. Matematički model je transformisan pomoću *Square Root* funkcije ($y'=\sqrt{y+k}$) pri čemu je *λ*=0,5 a *k*=2,5. Ponovna *ANOVA* analiza (tabela 7) je potvrdila adekvatnost transformisanog modela.

Statistike modela su poboljšane i njihove vrednosti su prikazane u tabeli 8.

Tabela 8. Računske vrednosti statistika za ocenu matematičkog modela

Std. Dev.	0,16543	R-Squared	0,46749
Mean	1,88864	Adj R-Squared	0,44576
C.V. %	8,75903	Pred R-Squared	0,40658
PRESS	1,49431	Adeq Precision	14,84931

Tabela 7. *ANOVA* analiza za transformisani linearni model

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value; Prob > F**	
Model	1,17722	2	0,58861	21,50883	1,97224E-07	significant
A-*b*	1,16621	1	1,16621	42,61537	3,57351E-08	
A^2	0,27589	1	0,27589	10,08136	0,00259	
Residual	1,34093	49	0,02737			
Lack of Fit	0,22714	6	0,03786	1,46154	0,21420	not significant
Pure Error	1,11379	43	0,02590			
Cor Total	2,51815	51				

Ponovna dijagnoza statističkih svojstava transformisanog modela je pokazala da je raspodela ostataka (reziduala) normalna. Nakon primene *Box-Cox* procedure vrednost λ je 0,5, optimalna vrednost λ je 0,66 a interval pouzdanosti od 95% za λ (donji C.I. = -0,46, gornji C.I = 1,73) sadrži vrednost λ=0,46 čime je dokazana opravdanost transformacije modela (slika 3).

2.4 Stohastički regresioni model

Kako je parametar *l* (dužina modula) nesignifikantan to znači da ukupan broj grešaka zavisi od parametra *b* (širina modula).

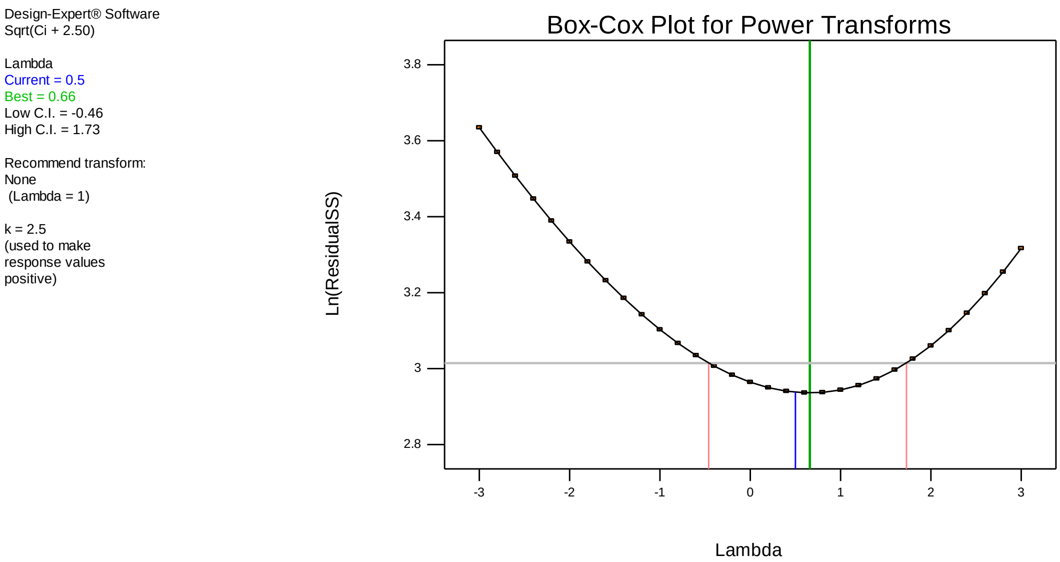
Konačna jednačina transformisanog matematičkog modela, sa realnim koeficijentima, koji adekvatno opisuje zavisnost ukupnog broja grešaka modula od širine (*b*) modula glasi:

$$\sqrt{G_i+2,5}=6,00847-1,21627\cdot 10^{-2}\cdot b_i+ +8,4966\cdot 10^{-6}\cdot b_i^2. \quad (1)$$

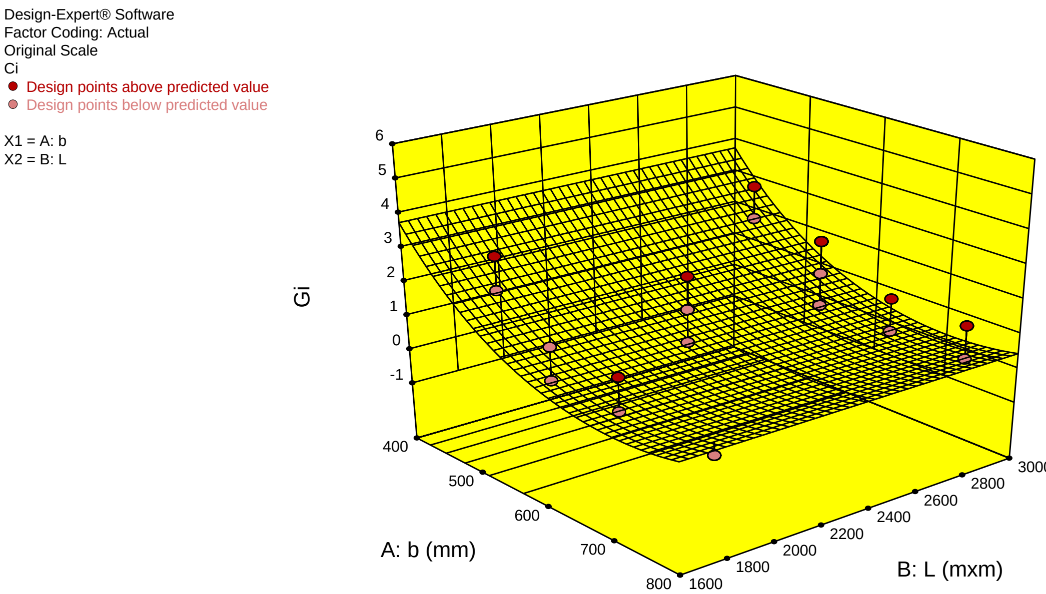
odnosno:

$$G_i=(6,00847-1,21627\cdot 10^{-2}\cdot b_i+ +8,4966\cdot 10^{-6}\cdot b_i^2)^2-2,5. \quad (2)$$

Grafički prikaz matematičkog modela opisanog jednačinom (2) i raspored eksperimentalnih tačaka dat je na slici 4.



Slika 3. *Box-Cox* dijagram transformisanog kvadratnog modela



Slika 4. 3*D* dijagram odzivne površine broja grešaka $G_i = f(b,l)$ za module **C**, **Cz**, i **D**

3. ZAKLJUČAK

U okviru doktorske disertacije *Razvoj modela za integraciju sistema odlučivanja u proces konfiguracije složenih proizvoda* [11] razvijen je integrisani model za automatsko konfigurisanje optimalne varijante složenih proizvoda u industriji prerade metala sa aspekta troškova, kvaliteta i vremena izrade proizvoda. Model se sastoji od 9 modula od kojih većina može predstavljati poseban konfigurator za određenu oblast a zajedno integrisani u jednu celinu predstavljaju *konfiguracioni sistem* na osnovu kojeg je moguće dobiti optimalnu konfiguracionu varijantu proizvoda koja zadovoljava individualne zahteve kupca i koja je ekonomski najpovoljnija za proizvođača.

Praktična primena predloženog modela i testiranje razvijenog programskog sistema „IAKS MODULPRIM“ u realnim uslovima je realizovana na primeru konfigurisanja MTP. Za verifikaciju i validaciju predloženog modela je odabrano 8 primera MTP tipa MODULPRIM stepena sigurnosti 5. Primeri su odabrani tako da reprezentuju MTP koje se najčešće realizuju.

Efekat integracije stohastičkog modela zavisnosti ukupnog broja grešaka od dimenzija modula u konfigurator proizvoda je smanjenje ukupnog broka grešaka na svim modulima MTP u proseku za 28,7%. Time je pokazano da je primenom alata kvaliteta i adekvatnih planova eksperimenata i implementacijom njihovih rezultata moguće ostvariti unapređenje kvaliteta proizvoda još u procesu njegove konfiguracije.

ZAHVALNOST

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IMPROVEMENT OF THE MODULAR STRONGROOMS CONFIGURATION QUALITY USING REGRESSION ANALYSIS

Abstract: *Modular strongrooms (MTP) are made of industrially prefabricated elements which are assembled on site. Their design is based on the customer's request related to the safety level, in accordance with the standard EN 1143-1. Also, a customer sets room dimensions where MTP will be placed. The modular strongroom configuration is made by combining standard modules. These modules, which differ from each other only in their number and dimensions are used in each new project.*
The optimization through the application of statistical analysis and quality tools has led to the reduction of the number of errors in the MTP development process to an acceptable minimum. Additional analysis has revealed a dependence between the total number of errors and dimensions of the MTP module. Additional reduction of errors, and thus improvement of the MTP configuration quality is possible using the mathematical models obtained in the configuration process.

Keywords: *modular strongrooms, regression analysis, quality improvement.*

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EFEKTI UNAPREĐENJA KVALITETA ORMANA ZA ORUŽJE S1 100/10

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Apstrakst: *Privredno društvo „Primat oprema" d.o.o. Baljevac proizvodi sigurnosnu opremu koja se koristi za čuvanje dragocenosti. Deo ovog programa su ormani za oružje namenjeni za čuvanje dugocevnog oružja. U skladu sa zahtevima standarda QMS konstantno se radi na unapređenju kvaliteta proizvoda. U radu su prikazani efekti primene alata kvaliteta na unapređenje kvaliteta ormana za oružje S1 100/10.*

Ključne reči: *unapređenje kvaliteta, ormani za oružje, alati kvaliteta*

1. UVOD

Kvalitet nekog proizvoda određuju njegove proizvodne i upotrebne karakteristike, koje se stvaraju u pojedinim fazama njegovog nastanka. Unapređenje kvaliteta je jedan od osnovnih zahteva standarda ISO 9001:2015. Standard zahteva kontinualna unapređenja, neprekidna merenja performansi i stalna unapređenja usaglašenosti i sposobnosti procesa na bazi rezultata i podataka merenja.

U procesu unapređenja kvaliteta značajno mesto zauzimaju statističke metode jer pomažu da se kontrola u tehnološkim i poslovnim procesima usmeri na faktore koji najviše utiču na te procese. Na osnovu toga se zaključuje koje i kakve korektivne mere treba preduzeti da bi se osigurao stabilan i zadovoljavajući kvalitet.

U ovom radu je na primeru ormana za oružje S1 100/10 iz proizvodnog programa Privrednog društva „Primat Oprema" d.o.o.-Baljevac prikazan efekat primene statističkih metoda za unapređenje kvaliteta proizvoda i procesa.

2. ORMANI ZA ORUŽJE

Privredno društvo „Primat Oprema" d.o.o.-Baljevac proizvodi sigurnosnu opremu koja se koristi za čuvanje dragocenosti kao što su: novac, nakit, važna dokumenta i sl. Proizvodni program obuhvata: blagajne, trezore, trezorske prostorije, trezorska vrata i različite vrste sigurnosnih ormana. Sva sigurnosna oprema je sertifikovana od strane nemačkog instituta VdS prema Evropskom standardu EN 1143-1 [1, 2, 3].

U okviru sigurnosnih ormana ova kompanija proizvodi ormane za oružje namenjene za čuvanje dugocevnog oružja tipa TS-1 i TS-2 [2]. U toku 2017/2018. godine je uveden novi tip ormana S1 100/10 (slika 1).

Kućište i vrata ormana su izrađena od kvalitetnog čeličnog lima debljine 4mm. Ormani imaju pripremljena dva otvora na leđnoj strani i četiri otvora u dnu za pričvršćivanje na zid i u pod. Za zaključavanje se koriste brave sigurnosnog stepena A po EN 1300 [2]. Opremljeni su sa držačima za 10 pušaka, imaju 4 mesta za odlaganje na unutrašnjim bočnim stranama ormana i imaju jednu odvojivu policu. Osnovne karakteristike su prikazane u tabeli 1.

Slika 1. Ormani za oružje S1 100/10

Tabela 1. Osnovne karakteristike modela ormana S1 100/10 [2]

Model	Spoljne dimenzije V x Š x D [mm]	Unutrašnje dimenzije V x Š x D [mm]	Odlaganje za maks. br. pušaka	Težina [kg]
TS - 2	1450 x 430 x 350	1407 x 422 x 286	10	84

3. STATISTIČKA KONTROLA PROCESA

Privredno društvo „Primat Oprema“ d.o.o. primenjije QMS usaglašen sa zahtevima standarada ISO 9001:2015. Kontrola proizvoda i način evidentiranja rezultata sprovodi se po proceduri za kontrolu koja podrazumeva upotrebu atributivnih kontrolnih karti kvaliteta i Pareto analizu. Kontrolnim planom je definisano 16 defekata koje treba kontrolisati 100% (tabela 2).

3.1. Klasifikacija defekata

Početno kontrolisanje je izvršeno na prvoj seriji koja je proizvedena u novembru 2017. godine. Urađeno je 120 komada proizvoda. Podaci su grupisani u 20 uzoraka od po 6 komada. Podaci o broju ustanovljenih defekata (neusaglašenosti) su prikazani u tabeli 3. U istoj tabeli je izvršeno sabiranje ukupnog broja defekata a dobijene vrednosti su prikazane u poslednjoj koloni tabele.

Za analizu stabilnosti proteklog procesa je korišćena *u*-kontrolna karta. Da bi se ocenila stabilnost proteklog procesa, pored vrednosti centralne linije i kontrolnih granica računaju se i granice zona upozorenja $\bar{u} \pm 1\sigma$ i $\bar{u} \pm 2\sigma$, tj. granice zona A, B i C [4].

Tabela 2. Klasifikacija defekata na ormanu S1 100/10

Naziv defekta	Oznaka
Zaštita šarke na poklopcu	G1
Poravnatost krova sa omotačem	G2
Zavarivanje krova	G3
Zavarivanje dna	G4
Zazor između kućišta i vrata	G5
Poravnatost vrata sa kućištem	G6
Ravnost stranica	G7
Brušenje zavara na vratima i kućištu	G8
Pravilno okrenut nosač brave	G9
Zavarivanje uglova u vratima	G10
Zavarivanje nosača naslona puške	G11
Otvaranje vrata	G12
Pozicioniranje naslona puške	G13
Zavarenost i ugaonost police	G14
Zavijen vijak na donjoj šarki	G15
Zavarivanje manganske ploče za vrata	G16

Tabela 3. Prikaz dobijenih podataka za model ormana S1 100/10 za prvu seriju

	ОПИС ГРЕШКЕ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Σ
G1	Заштита шарке на поклопцу	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G2	Поравнатост крова са омотачем	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G3	Заваривање крова	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G4	Заваривање дна	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G5	Зазор између кућишта и врата	2	1	3	3	1	2	3	2	1	2	3	1	1	2	2	4	3	4	2	1	**43**
G6	Поравнатост врата са кућиштем	1	2	1	0	1	2	1	0	0	0	2	0	2	1	0	0	0	0	0	0	**13**
G7	Равност страница	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
G8	Брушење завара на вратима и кућишту	0	0	0	0	0	0	0	0	1	1	1	2	0	0	0	0	0	0	0	0	**5**
G9	Правилно окренут носач браве	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G10	Заваривање углова у вратима	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
G11	Заваривање носача наслона пушке	1	0	0	0	1	0	1	1	1	0	0	0	1	1	0	0	1	1	0	0	**9**
G12	Отварање врата	1	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	**5**
G13	Позиционирање наслона пушке	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	**2**
G14	Завареност и угаоност полице	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	**2**
G15	Завијен вијак на доњој шарки	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
G16	Заваривање манганске плоче за врата	1	3	1	2	3	2	1	0	0	0	1	1	2	0	0	0	0	0	0	0	**17**
	∑Ui	**7**	**7**	**7**	**5**	**6**	**6**	**8**	**3**	**4**	**3**	**7**	**4**	**6**	**4**	**4**	**5**	**5**	**5**	**2**	**1**	**99**

Vrednost centralne linije se izračunava na osnovu jednačine:

$$CLu = \bar{u} = \frac{1}{s}\sum_{i=1}^{s} u_i \ . \qquad (1)$$

Vrednosti kontrolnih granica se računa na osnovu sledećih jednačina:

$$GKGu = \bar{u} + 3 \cdot \frac{\sqrt{\bar{u}}}{\sqrt{n_i}} \ , \qquad (2)$$

$$DKGu = \bar{u} - 3 \cdot \frac{\sqrt{\bar{u}}}{\sqrt{n_i}} \ , \qquad (3)$$

pri čemu se u slučaju negativne vrednosti za donju kontrolnu granicu dobijena vrednost zamenjuje sa nulom.

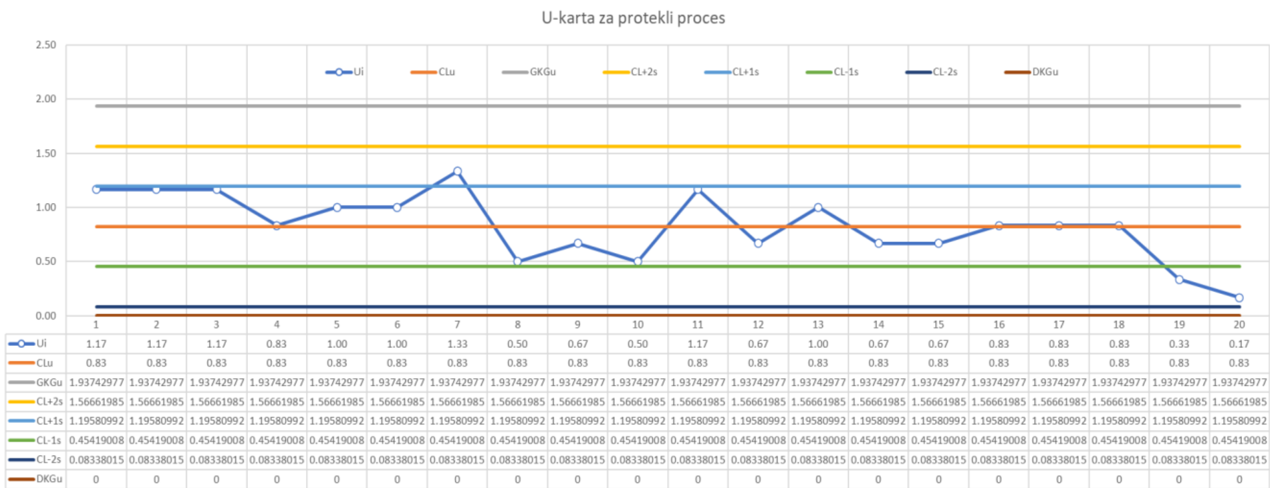
Vrednosti centralne linije i kontrolnih granica za analizirani period su:

$$CLu = 0{,}83$$
$$GKGu = 1{,}94$$
$$DKGu = 0{,}00$$

Granice zona „**B**“ i „**C**“ su:

$$\bar{u} + 1\sigma = 1{,}20$$
$$\bar{u} - 1\sigma = 0{,}45$$
$$\bar{u} + 2\sigma = 1{,}57$$
$$\bar{u} - 2\sigma = 0{,}08$$

Izgled *u*- karte sa ucrtanom centralnom linijom i kontrolnim granicama pokazuje da su sve tačke unutar kontrolnih granica (slika 2) i da su zadovoljena sva 4 uslova stabilnosti proteklog procesa [4], pa se može smatrati da je protekli proces bio stabilan.



Slika 2. *U*-kontrolna karta za prvu seriju ormana za oružje S1 100/10

Pošto je protekli proces bio stabilan, usvojena je reprezentativna vrednosti za prosečan broj defekata i centralna linija i kontrolne granice za tekući proces (tabela 4).

Tabela 4. Centralna linija i kontrolnne granice za tekući proces

CENTRALNA LINIJA I KONTROLNE GRANICE ZA TEKUĆI PROCES	
$CL_{u'} = u' = 0{,}83$	$GKG_{u'} = u' + 3 \cdot \sqrt{u'} = 1{,}94$ $DKG_{u'} = u' - 3 \cdot \sqrt{u'} = 0{,}00$

3.2. Analiza brojnosti grešaka i selekcija uticajnih grešaka

Dalji postupak analize podataka podržan je primenom Pareto dijagrama kojim se selektuju kritični defekti čije uzroke nastanka treba utvrditi kako bi se sprovele korektivne aktivnosti za njihovo otklanjanje. Primenom Pareto dijagrama prikazuje se, u opadajućem redosledu, relativni značaj (učešće, uticaj) posmatrane veličine ili grupe veličina u skupu veličina čija se analiza izvodi.

Defekti su razvrstani po brojnosti pojavljivanja i formirana je tabela 5 u kojoj su defekti klasifikovani u tri grupe:

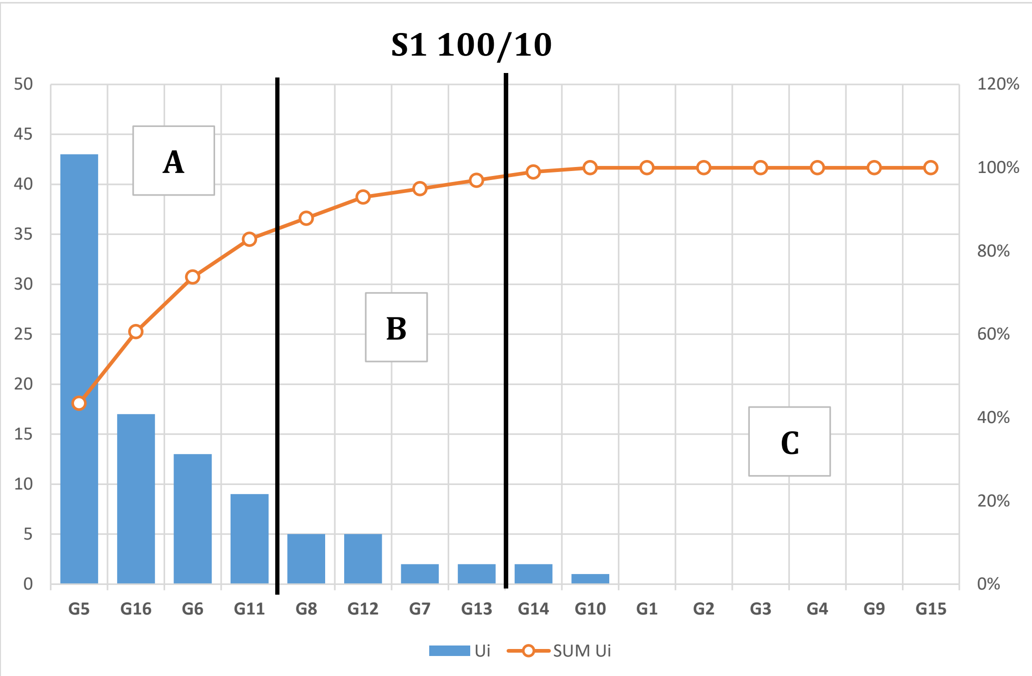
- grupa A koja obuhvata 82,8 % svih defekata,
- grupa B koja obuhvata 14,2 % svih defekata,
- grupa C koja obuhvata 3,0 % svih defekata.

Pareto dijagram dobijen na osnovu tabele 5 je prikazan na slici 3.

Tabela 5. Klasifikacija defekata prema brojnosti za za prvu seriju

Gi	Ui	SUM	Ui (%)	SUM (%)	GRUPA
G5	43	43	43.4%	43.4%	A
G16	17	60	17.2%	60.6%	
G6	13	73	13.1%	73.7%	
G11	9	82	9.1%	82.8%	
G8	5	87	5.1%	87.9%	B
G12	5	92	5.1%	92.9%	
G7	2	94	2.0%	94.9%	
G13	2	96	2.0%	97.0%	
G14	2	98	2.0%	99.0%	C
G10	1	99	1.0%	100.0%	
G1	0	99	0.0%	100.0%	
G2	0	99	0.0%	100.0%	
G3	0	99	0.0%	100.0%	
G4	0	99	0.0%	100.0%	
G9	0	99	0.0%	100.0%	
G15	0	99	0.0%	100.0%	
Σ	99				

Nakon analize sprovedene su korektivne mere za eliminisanje defekata iz grupe A.



Slika 3. Pareto dijagram za prvu seriju ormana S1 100/10

4. EFEKTI UNAPREĐENJE KVALITETA PROIZVODA I PROCESA

Počev od prve serije, unapređenje procesa izrade i sklapanja ormana za oružje tipa S1 100/10 se sprovodilo u skladu sa Metodom sedam koraka za rešenje problema [5]:

- Selekcija problema.
- Prikupljanje i analiza podataka.
- Analiza uzroka.
- Planiranje i uvođenje rešenja.
- Ocena efekata.
- Standardizacija.
- Refleksija ili odziv.

Za svaku sledeću seriju ormana je primenjena ista procedura. Na osnovu proteklog procesa su utvrđene centralne linije i kontrolne granice za tekući proces, pomoću Pareto analize su selektovani kritični defekti, analizirani su uzroci njihovog nastanka i sprovedene korektivne aktivnosti za njihovo otklanjanje.

U posmatranom periodu (decembar 2017. - decembar 2018.) ukupno je proizvedeno 1998 komada ormana S1 100/10 lansiranih u 7 serija. Pregled broja proizvedenih komada po serijama i klasifikacija veličine i broja uzoraka za U-kontrolnu kartu je prikazana u tabeli 6.

Iz tabele 7 je vidljivo da je iz serije u seriju vrednost cenralne linije (prosečni broj defekata po komadu) sve manja a kontrolne granice sve uže.

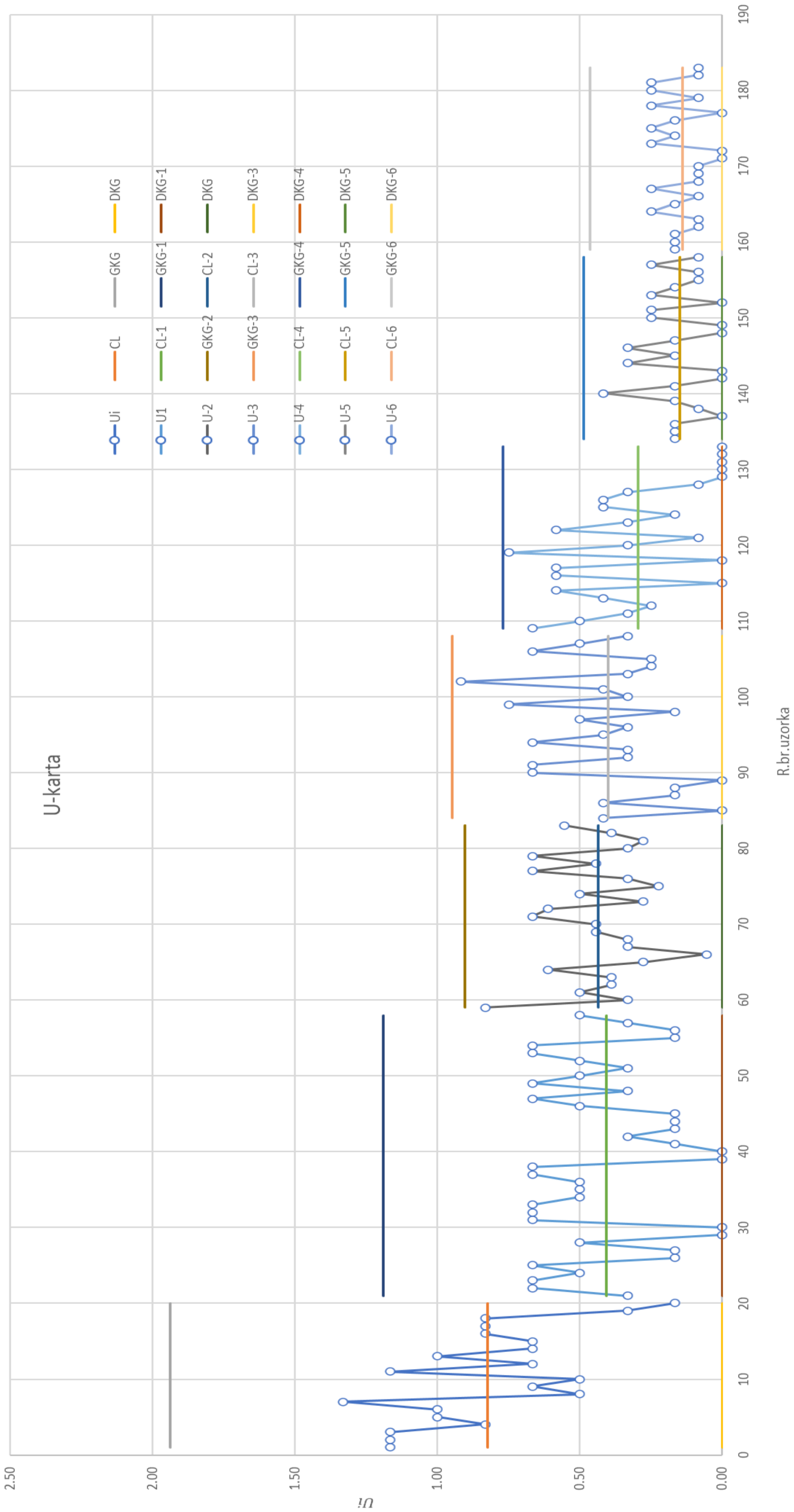
Tabela 6. Klasifikacija podataka za U-kontrolnu kartu po serijama

Serija br.	1	2	3	4	5	6	7
Mesec	Decembar	Januar	Maj	Jun	Jul	Avgust	Decembar
n - vel. uzorka	6	6	18	12	12	12	12
s - br. uzoraka	20	38	25	25	25	25	25
N=ns	120	228	450	300	300	300	300

Tabela 7. Centralna linija i kontrolne granice za tekući proces za sve serije

Jednačine	**Mesec**						
	Decembar	Januar	Maj	Jun	Jul	Avgust	Decembar
$CL_{u'} = u'$	0,83	0,41	0,44	0,40	0,30	0,15	0,14
$GKG_{u'} = u' + 3 \cdot \sqrt{u'}$	1,94	1,19	0,90	0,95	0,77	0,49	0,46
$DKG_{u'} = u' - 3 \cdot \sqrt{u'}$	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Opisana poboljšanja se bolje mogu uočiti ukoliko se kontrolne karte koje su analizirane po serijama u posmatranoj godini prikažu uzastopno jedna za drugom. Na slici 4 se uočava kako su se kretale centralna linija i kontrolne granice i da je kvalitet proizvoda iz meseca u mesec bio sve bolji uz konstantno održavanje stabilnosti procesa.



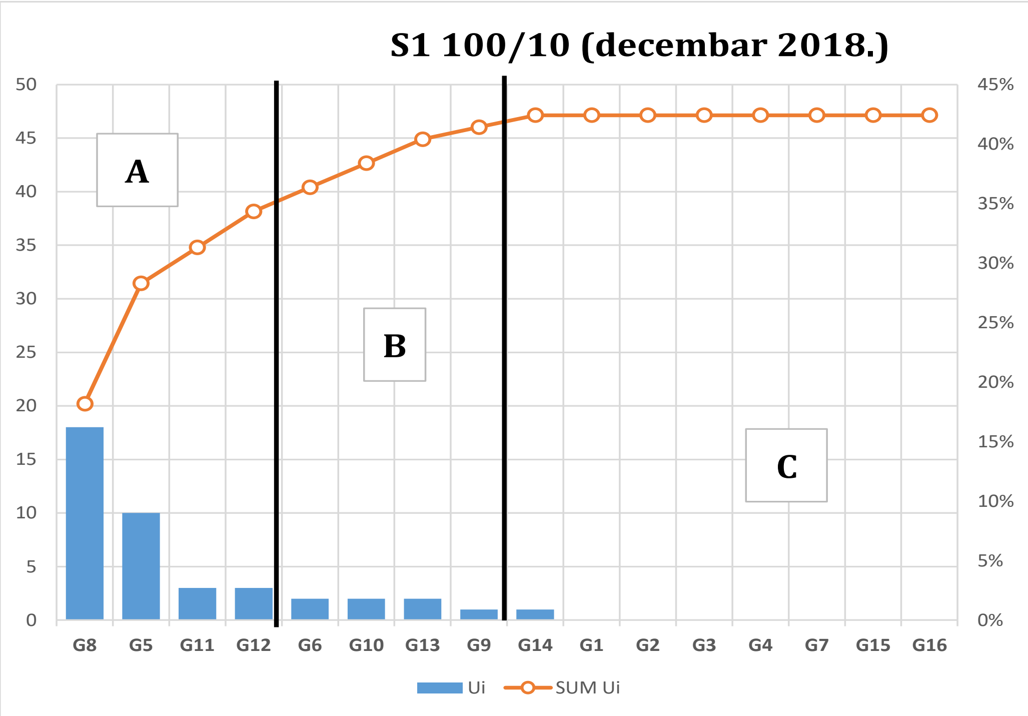
Slika 4. Izgled kontrolnih karti u posmatranom periodu

Pareto analiza za poslednju seriju (tabela 8 i slika 5) pokazuje sledeće:

- U decembru 2017. je na 120 komada ormana ukupno detektovano 99 defekata tj. 0,825 defekata po komadu a u decembru sledeće godine je na 300 komada detektovano samo 42 defekta tj. 0,14 defekata po komadu. Broj defekata po komadu je smanjen oko 6 puta.
- Najbrojniji defekt u prvoj seriji je G5 koji je detektovan 43 puta na 120 komada proizvoda tj. 0,35 defekata po komadu a na poslednjoj seriji samo 10 puta na 300 komada proizvoda tj. 0,033 defekata/komadu.
- Defekt G16 je kompletno elimisan tj. sa 0,14 defekata/komadu je sveden na 0 defekata/komadu.
- Defekt G6 je smanjen sa 0,108 na 0,007 defekata/komadu.
- Defekt G11 je smanjen sa 0,075 na 0,010 defekata/komadu itd.

Tabela 8. Klasifikacija defekata po brojnosti na poslednjoj seriji

Gi	Ui	SUM	Ui (%)	SUM (%)	GRUPA
G8	18	18	18.2%	18.2%	A
G5	10	28	10.1%	28.3%	
G11	3	31	3.0%	31.3%	
G12	3	34	3.0%	34.3%	
G6	2	36	2.0%	36.4%	B
G10	2	38	2.0%	38.4%	
G13	2	40	2.0%	40.4%	
G9	1	41	1.0%	41.4%	
G14	1	42	1.0%	42.4%	C
G1	0	42	0.0%	42.4%	
G2	0	42	0.0%	42.4%	
G3	0	42	0.0%	42.4%	
G4	0	42	0.0%	42.4%	
G7	0	42	0.0%	42.4%	
G15	0	42	0.0%	42.4%	
G16	0	42	0.0%	42.4%	
Σ	**42**				



Slika 5. Pareto dijagram za poslednju seriju ormana S1 100/10

5. ZAKLJUČAK

Sprovedena analiza je pokazala da kontinualan rad na unapređenju procesa uvek daje pozitivne efekte. Ostvareni efekti u procesu izrade i sklapanja ormana za oružje S1 100/10 su rezultat sledećih preduzetih korektivnih mera:

- Konstantno praćenje i upravljanje procesom primenom kontrolnih karti;
- Kontinualna obuka radnika;
- Stalna kontrola, popravka i unapređenje šablona tj. pribora za zavarivanje kao bi se ostvarila dimenziona tačnost proizvoda;
- Izrada i unapređenje uputstva za izradu sa vizuelnim prikazima za sve operacije sklapanja ormana.

Osim navedenog, treba istaći i da je i vreme učinilo svoje i da su iz meseca u mesec radnici imali sve više iskustva i rutine u obavljanju operacija.

Napred izloženo potvrđuje ispravnost primene statističkih metoda i alata kvaliteta za unapređenje sistema kvaliteta proizvoda i procesa, smanjenje troškova kvaliteta i obezbeđenje veće konkurentnost na tržištu.

ZAHVALNOST

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THE EFFECTS OF A QUALITY IMPROVEMENT IN THE CASE OF THE GUN CABINET S1 100/10

Abstract : *Company "Primat oprema" d.o.o. Baljevac produces safety equipment used for storing valuables securely. One part of the company's product portfolio is a gun cabinet used for the safe storage of long-barreled guns. Continuous improvement of the product quality is made under the requirements of the QMS standard. This article presents the effects of the application of quality tools for quality improvement in the case of the gun cabinet S1 100/10.*

Keywords : *quality improvement, gun cabinets, quality tools*

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University of Kragujevac

Čačak, Serbia, 14 – 15. October 2021

ISPITIVANJE PROMENE ČVRSTOĆE U ZAVISNOSTI OD KOLIČINE UGLJENIKA I VANADIJUMA KOD VISOKO LEGIRANIH Cr-Mo-V ČELIKA

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Absdtrakt: *Cilj ovih istraživanja je bio da se ispita uticaj ugljenika i vanadijuma na čvrstoću samokaljivih čelika. Ispitivanja su izvršena na visoko legiranom Cr-Mo-V čeliku. Očigledno da vanadijum utiče na proces ošvršćavanja ovih legura na taj način što sužava temperaturni interval kristalizacije pri čemu se iz rastopa obrazuju V_6C_5 karbidi koji blokiraju dalji rast austenitnih dentrita i na taj način pomažu dobijanje sitnozrnaste strukture. Vanadijum kao legirajući element pomera likvidus i solidus ka višim temperaturama, obrazuje V_6C_5 karbide, jednim delom raspoređuje se između faza prisutnih u čeliku; karbida $(Cr,Fe)_7C_3$ i austenita. Postojanje vanadijuma omogućuje formiranje $(Cr,Fe)_{23}C_6$ karbida i njegovo taloženje u austenitu u toku procesa hlađenja, u lokalnim područjima oko finih karbidnih čestica transformiše u martenzit. To znači da vanadijum smanjuje količinu zaostalog austenita i time poboljšava prokaljivost čelika.*

Ključne reči: *Samokaljivi čelik, ugljenik, vanadijum, čvrstoća, mikrostruktura.*

1. UVOD

Samokaljivi čelici spadaju u grupu čelika otpornih na habanje što ih čini upotrebljivim u širokom području primene. Osnovne karakteristike ovih čelika je visoka tvrdoća, čvrstoća, zbog visokog sadržaja ugljenika, a relativno mala udarna žilavost. Istraživanja koja su izvršena nad ovim čelicima imala su za cilj da se ispita uticaj nekih legirajućih elementa na mehaničke karakteristike materijala (tvrdoća, čvrstoća i žilavost). Kao legirajući elementi uključeni su hrom, molibden i vanadijum. Istraživanja su imala za cilj poboljšanje karakteristika ovih čelika, kroz povećanu otpornost na abrazivno i udarno-zamorno habanje. Osnovni cilj istraživanja je da se kod ovih čelika zadrži ili sasvim malo snizi tvrdoća i čvrstoća, a poveća udarna žilavost. Ovakav jedan kompromis može da se potraži u termičkom režimu tako što bi se dobila martenzitna struktura sa manjim sadržajem zaostalog austenita [1].

2. UTICAJ Cr i Mo NA STRUKTURU I SVOJSTVA ČELIKA

Hrom je osnovni legirajući element kod čelika sa povišenom tvrdoćom i otpornošću na habanje. Hrom reaguje sa ugljenikom i formira tvrde karbide otporne na habanje, zatim sprečava transformaciju austenita u perlit u toku hlađenja i utiče na strukturu metalne osnove čelika zatvarajući γ područje u faznom dijagramu. Najbolju žilavost i tvrdoću imaju strukture sa karbidima $(Cr,Fe)_7C_3$ koji se obrazuju u čeliku koji sadrži preko 6% hroma. Veći procenat hroma ne daje bolje rezultate jer on ograničava procenat ugljenika, a sa povećanjem ugljenika smanjuje se eutektička koncentracija. Hrom ne povećava prokaljivost ali u kombinaciji sa većim sadržajem ugljenika povoljno deluje na dubinu zakaljanog sloja.

Molibnden onemogućuje nastajanje perlita i trasformaciju austenita premešta u beinitnu i martenzitnu oblast. Iz tog razloga molibden i pri malim sadržajima povećava prokaljivost. Na taj način on obezbeđuje dobijanje tvrde i čvrste martenzitne metalne osnove u kojoj su sadržani legirani karbidi. Molibden gradi intersticijsku fazu Mo_2C, i pri povećanom sadržaju molibdena formira se određena količina ove faze u strukturi čelika.

3. UTICAJ VANADIJUMA

Dodavanjem vanadijuma visokolegiranim hromnim čelicima struktura postaje finija. Usitnjavanje strukture dodavanjem vanadijuma objašnjava se uticajem vanadijuma na proces kristalizacije. Pored toga, vanadijum menja morfologiju eutektičkog $(Cr,Fe)_7C_3$ karbida. Sa porastom sadržaja vanadijuma radialni raspored karbida postaje dominantniji, a udeo dugačkih usmerenih lamela i ploča se ne smanjuje [2].

Prisustvo vanadijuma i u malim procentima ima pozitivno dejstvo na visokolegirane Cr-Mo čelike jer se u toku izdvajanja primarnog austenita iz rastopine formiraju kristali karbida V_6C_5 koji blokiraju dalji rast austenitnih dendrita i na taj način pomažu dobijanje sitnozrnaste strukture. Kod visokohromnih čelika sa sadržajem oko 12%Cr i 1,4-1,8%C i pri sadržaju iznad 2,5% vanadijuma formira se karbid vanadijuma sa kubnom kristalnom rešetkom. Karbid tipa VC je globularnog oblika i često sa eutektičkim karbidom $(Cr,Fe)_7C_3$, koji se kristališe u obliku šipki, koje radijalno rastu iz nukleusa formirajući sferične ćelije zajedno sa austenitom [3-7].

Kada je sadržaj vanadijuma mali u procesu izdvajanja primarnog austenita obrazuje se V_6C_5 karbidi koji blokiraju dalji rast austenitnih dendrita i na taj način pomažu dobijanje sitnozrne strukture. Pored toga što vanadijum obrazuje pomenute karbide on se jednim delom raspoređuje između faza karbida $(Cr,Fe)_7C_3$ i austenita. U lokalnim područjima oko finih karbidnih čestica austenit se transformiše u martenzit pa time vanadijum smanjuje količinu zaostalog austenita, a time i poboljšava prokaljivost čelika.

4. OPIS EKSPERIMENTA

Istraživanja **s**u bazirana na samokaljivom čeliku hemijskog sastava sa 12,5%Cr, 1,2%Mo dok se procenat ugljenika menja u rasponu od 1,4 do 1,8 % i vanadijuma u rasponu od 0,5 do 3% . Probni uzorci su izliveni u obliku epruveta standardnog oblika za ispitivanje zatezne čvrstoće. Za izlivanje uzoraka korišćena je indukciona frekfrentna peć ABB tip ITMK-500. Kalupi za izlivanje su izrađeni pomoću modela standarnim metodama. Odlivci su potom termički obrađeni kaljenjem i niskotemperaturnim otpuštanjem na temperaturi od 250°C. Ovaj vid termičke obrade je karakerističan za visokolegirane Cr-Mo čelike. Za svaki sadržaj ugljenika menjan je sadržaj vanadijuma u rasponu od 0,5 do 3%, na taj način je pripremljeno više serija uzoraka. Kako bi rezultati bili merodavni načinjeno je po tri istovetna uzorka. Na slici 1. prikazan je izgled pripremljenih probnih uzoraka za ispitivanje zatezne čvrstoće.

Slika 1. Izgled probnih uzoraka

Tabela 1. Hemijski sastav svih uzoraka

Redni broj	Hemijski sastav				
	C (%)	Cr (%)	Mo (%)	S (%)	V (%)
1	1,542	11,831	1,115	0,03	0,554
2	1,536	11,562	1,111	0,03	1,053
3	1,521	11,311	1,094	0,032	1,976
4	1,624	10,076	1,062	0,026	2,992
5	1,753	10,839	1,125	0,035	0,502
6	1,711	10,524	1,130	0,035	1,006
7	1,632	11,466	1,268	0,022	1,908
8	1,626	11,236	1,248	0,020	2,801
9	1,972	9,990	1,138	0,034	0,549
10	1,890	9,995	1,127	0,035	0,981
11	1,836	9,712	1,090	0,033	2,038
12	1,767	9,742	1,129	0,038	2,983

Hemijski sastav izlivenih uzoraka za ispitivanje čvrstoće prikazan je u tabeli 1.

Dimenzije uzoraka za ispitivanje zatezne čvstoće urađeni su prema standardu JUS EN 10 002-1 (EU 18:1979). Ispitivanje je vršeno na kidalici SCHENCK-TREBEL tipa TYP-PM 400 Rn maksimalne sile 400 KN.

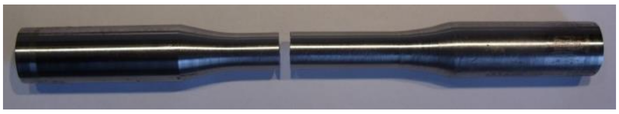
5. REZULTATI ISPITIVANJA

Rezultati ispitivanja termički obrađenih uzoraka i otpuštenih na temperaturi 250°C sa različitim sastavom ugljenika i vanadijuma prikazani su u tabeli 2.

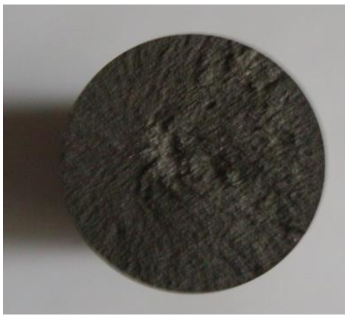
Tabela 2. Rezultati ispitivanja čvrstoće

r.br.	Hemijski sastav		Zatezna čvrstoća, MPa
	C, %	V, %	
1	1,4	0,5	673,67
2		1	655,10
3		2	642,32
4		3	569,41
5	1,6	0,5	658,52
6		1	631,19
7		2	621,57
8		3	558,63
9	1,8	0,5	629,29
10		1	622,18
11		2	615,99
12		3	547,21

Na slici 2. dat je izgled probnog uzoraka nakon ispitivanja, a na slici 3. Izgled prelomne površine.



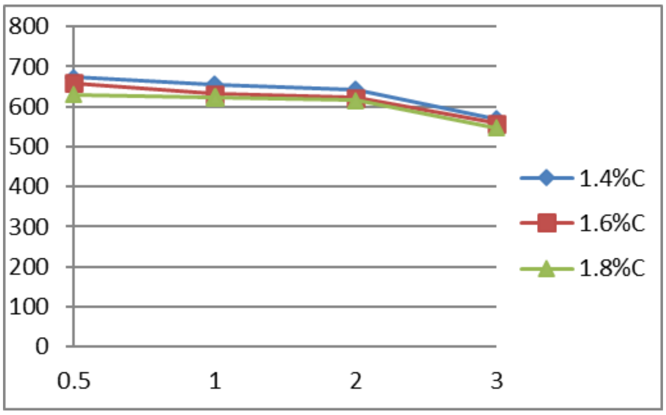
Slika 2. Probni uzorak nakon ispitivanja



Slika 3. Izgled prelomne površine

Na osnovu izgleda polomljenog probnog uzorka i prelomne površine može se zaključiti da je u pitanju izrazito krti lom, što dalje ukazuje da probni uzorci imaju izarazito veliku tvrdoću.

Na slici 4. prikazan je dijagram promene čvrstoće u zavisnosti od količine vanadijuma i ugljenika.



Slika 4. Dijagram promene čvrstoće

4.1 Uticaj vanadijuma na zateznu čvrstoću

Ispitivanje zatezne čvrstoće izvršeno je na po tri uzorka iz svake serije tako da je uzeta srednja vrednost kao merodavna. U tabeli 2. prikazani su rezultati ispitivanja zatezne čvrstoće, a na slici 4. dat je dijagram promene čvrstoće u funkciji promene vanadijuma. Deformacije istezanja su veoma male uz nagli porast sile zatezanja. Analizom dobijenih podataka može se uočiti da vanadijuma ne utiče značajno na zateznu čvrstoću i ona ostaje pribižno konstantna. U celini moglo bi se konstantovati da vanadijum u pomenutim odnosima sa ugljenikom nema značajan uticaj na promenu zatezne čvrstoće. Takođe, tvrdoća je uglavnom ostala nepromenjena dok je žilavost značajno porasla [8].

6. MOGUĆNOSTI PRIMENE

Dodatak 3% vanadijuma čelicima, formira leguru koja ima veoma dobru kombinaciju zatezne čvrstoće i tvrdoće pa samim tim mogu da imaju široku oblast primene.

Stoga čelik uz dodatak 3% V i 1,8%C (ovaj sastav ima najbolji odnos čvrstoće, tvrdoće i žilavosti) može sa uspehom da se koristi za izradu delova i sklopova koji su u eksploataciji izloženi abrazionom, koroziono-abrazionom, udarno-zamornom ili kombinovanom tipu habanja. Asortiman ovih delova čine: delovi građevinskih i rudarskih mašina (zubi bagera i navlake zuba), delovi drobilica i mlinova za kamen, rudu, ugalj i minerale (kugle, čekići, udarne ploče, obloge mlina i separacione rešetke), habajući delovi u procesnim postrojenjima (šipke bunkera za abrazivne materijale, lopatice uređaja za peskarenje, tela muljnih pumpi, kalupi za briketiranje uglja i čeličnih strugotina, gusenice tenkova i transportera itd.).

7. ZAKLJUČAK

U ovom radu ispitan je uticaj vanadijuma na čvrstoću čelika sa količinom ugljenika: 1,4%, 1,6% i 1,8% i sa sadržajem hroma od 12%, i molibdena 1,3%. Sa povećanjem sadržaja vanadijuma struktura postaje finija što utiče na mehaničke osobine čelika, tj. na čvrstoću i tvrdoću pa i na udarnu žilavost. U ispitivanoj leguri gde je količina ugljenika bila 1,4%, 1,6% i 1,8%; povećavana je kolikčina vanadijuma (0,5%, 1%, 2% i 3%). Evidentno je da veći sadržaj vanadijuma od 3% ne vodi poboljšanju svojstva ovog čelika, pa iz tog razloga istraživanja sa većim procentom vanadijuma nisu obuhvaćena ovim radom.

Diskusija rezultata u tački 4.1 ukazuje da povećanje količine vanadijuma pozitivno utiče na karakteristike čelika (tvrdoću i žilavost) dok je čvrstoća ostala na prihvatljivom visokom nivou. U odnosu na oblast primene i potrebna mehanička svojstva (nekada se želi povećanje čvrstoće i smanjenje žilavosti i obrnuto) može se izabrati sastav ispitivanih čelika.

Prisustvo tvrdih karbida tipa $(Cr,Fe)_7C_3$, V_6C_5 i VC, njihov sadržaj, povoljan raspored i morfologija obezbeđuju dobru otpornost na abrazivno habanje čak i u slučajevima kada su u kontaktu sa ekstremno abrazivnim materijalima kao što su kvarc, feldspat i drugi.

Istraživanja se mogu naknadno proširiti ispitivanjem čelika sa povećanom količinom ugljenika (od 1,8% do 2,2%) dok će se količina vanadijuma menjati u istim granicama. Takođe, u budućim ispitivanjima bilo bi poželjno sve ove varijacije čelika podvrgnuti ispitivanju otpornosti na habanje.

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INFULENCE OF CARBON AND VANADIUM CONTENT ON THE TENSILE STRENGTH OF Cr-Mo-V STEELS

Abstract: *The aim of this research was to investigate the influence of carbon and vanadium content on strength of high alloyed air-hardening Cr-Mo-V steel. The vanadium has a strong effect on a solidification of these alloys by narrowing temperature inteval of austenite formation. During that process from molten metal the* V_6C_5 *carbides are formed so they block further growth of autenite dendrites what leads to obtaining the smallgrained structure. Vanadium as an alloying element moves liquidus and solidus temperatures to higher temperatures, forms carbides and is partly distributed between the steel phases; carbide* $(Cr, Fe)_7C_3$ *and austenite. The presence of vanadium enables the formation of* $(Cr, Fe)_{23}C_6$ *carbide and its deposition in austenite during the cooling process, in local areas around fine carbide particles it transforms into martensite. This means that vanadium reduces the amount of residual austenite and thus improves the hardenability of steel.*

Key words: *Air-hardening steel, carbon, vanadium, strength, microstructure.*

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EFFECT OF SEVERE PLASTIC DEFORMATION ON MATERIAL STRENGTH AND HARDNESS

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Abstract: *Conventional metal forming creates a part of the desired shape and function, and this is usually accompanied by the change of material properties. Contrary to conventional metal forming technologies, severe plastic deformation (SPD) is being exclusively used to improve the properties of the processed material for bulk and sheet metal workpieces. This paper presents the most well-known SPD methods, alongside the method developed by the author - Upsetting by V-shape dies, and Upsetting by plane strain dies. Typical features of SPD processing and material improvement are also covered. During the processing, the increase of hardness, strength, and microstructure change is present, while the workability is kept sufficiently high compared to conventional forming. An essential feature of the SPD processes is typically the presence of rotation of the principal axes of the stress tensor with the processed material. Another significant feature is the presence of a predominantly compressive stress state which increases material workability. This helps to impose high values of strain into the workpiece, hence the name "severe" in the name of this method. An equivalent strain of 1800 can be achieved using the SPD method. Material properties or other parameters are usually related to the equivalent strain. In the upsetting by V-shape dies, the processed material is heat-treated low-carbon steel (C15E), the average grain size of a starting material was 19.1 µm, and the billets were machined to prismatic shape (70 × 14 × 14 mm). The processing was carried out in a total of eighteen upsetting stages at room temperature, and the accumulated strain was 3.38. A plane strain compression SPD die was used to improve the properties of 316L medical-grade stainless steel in six upsetting stages.*

Keywords: *severe plastic deformation, methods, hardness, strength, V-shape dies, low carbon steel.*

1. INTRODUCTION

Modern products face stricter specifications, performance demands, and environmental regulations compared to their predecessors [1]. That leads to change or the improvement of the current products, services, and manufacturing technologies. It is a well-known fact that material processing during, for example, part manufacturing causes specific changes in "original" material. These changes can be desirable or undesirable, depending on the part requirements. Processing by conventional metal forming technologies usually causes an increase in hardness and strength and a decrease in ductility. These changes of properties may be related to the microstructure of the workpiece. For example, the Hall-Petch equation establishes the relationship between the yield stress (material strength) and average crystal grain size [2], [3]. That implies that if the grain size is reduced, the strength of the material will increase. It is worth noting that there is a limit for this strengthening behavior – for pure copper, the limit is approximately 20 nm [4]. Further grain reduction reverses the strengthening effect, i.e., the material becomes softer. Similar behavior is also found in other materials. As an example, refining the grain size in pure copper increased the yield strength from 200 to 800-900 MPa. The same trend is present in the increase in hardness, where increased imposed strain caused grain refinement [5].

Processing by conventional metal forming methods does cause grain refinement, but usually in a certain region or area. To spread the refinement effect across the whole volume or in a controlled manner, unique metal forming methods were developed for this purpose, that is, severe plastic deformation methods. The word "severe" also stands for high strains usually imposed into the workpiece – there are reports of equivalent strains up to 1800 obtained with some SPD methods [6].

As with conventional methods, SPD methods can be classified as bulk or sheet metal forming methods, or for processing at room, warm or hot temperatures. The most well-known methods are ECAP (Equal Channel Angular Pressing) [7], [8] and HPT (High-Pressure Torsion) [6], [9]. It is important to mention that SPD methods do not require special equipment; SPD dies can be fitted to existing presses and metal forming machines.

This paper gives a brief introduction to the subject of strength and hardness behavior under severe plastic deformation and presents some of the experimental results obtained by the authors. The issue of processing by severe plastic deformation is relatively unknown, even among those that deal with conventional metal plastic deformation. Recent review papers on this topic can be found in [10]–[13].

2. SPD METHODS

The most common SPD method is the ECAP, developed by Vladimir Segal in the nineteen-seventies. The method consists of pressing the billet through two identical channels that intersect each other at angle 2φ (Figure 1).

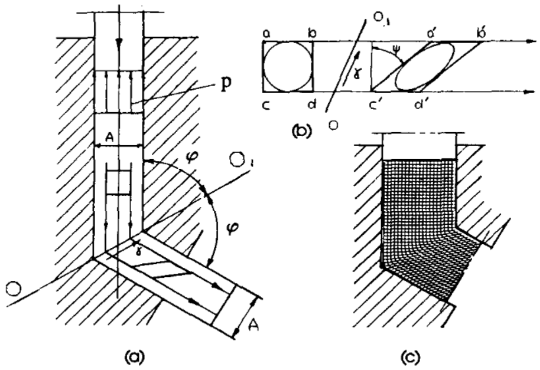

Figure 1. Processing by ECAP: (a) process schematics, (b) element shearing [14]

Once the workpiece passes through the channels intersection plane (OO_1), shearing of the material and grain refinement occurs. Pressing of the workpiece can be repeated many times until the desired strain or microstructure is obtained. Strain per pass can be calculated by Equation 1.

$$\varepsilon_i = \left(2/3\text{^}\left(1/2\right)\right)\cdot\cot\varphi \,. \qquad (1)$$

An interesting feature of the ECAP processing is the rotation of the workpiece between the pressing passes – routes A and C. The influence of routes and the number of passes on the limit of elasticity, ultimate tensile strength, and hardness are shown in Figure 2. The figure shows that increasing the number of passes (and total strain) increases all mechanical properties considered. Also, different routes have a slight effect on the properties. However, the increase is present up to a certain number of passes when the saturation of the properties takes place, despite imposed strain increase. This effect is also present with other SPD methods. Compared to other methods, the significant advantage of ECAP processing is the equal distribution of microstructure and mechanical properties through the workpiece cross-section.

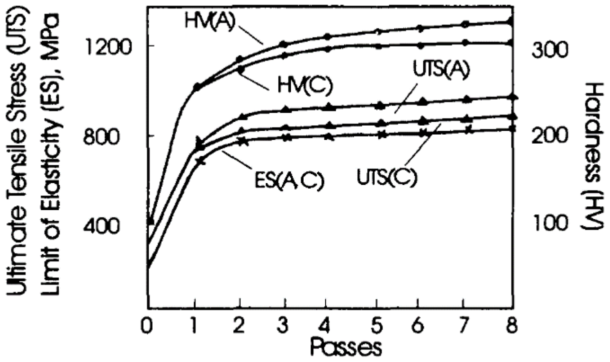

Figure 2. The effect of the number of passes (N) and routes (A and C) of Armco Iron on hardness (HV), ultimate tensile stress (UTS) and limit of elasticity [14]

The second most used SPD method is the processing by HPT. The foundations of this method were initially established by P. W. Bridgman when he studied the effects of high pressures on materials, particularly on materials with relatively low workability. The method consists of inserting the thin disc (thickness is usually about 0.8 mm) in between two anvils which compress the disc and rotate relative to each other (Figure 3).

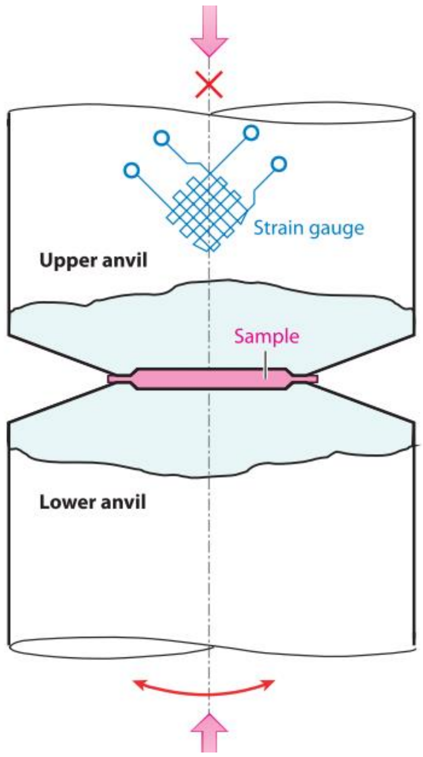

Figure 3. Schematic representation of the High-pressure torsion of a sample [6]

The grain refinement effect is related to imposed shear strain and is dependent on the number of anvil rotations (*N*), sample thickness (*t*), distance from the center (*r*), and anvil pressure. The strain can be calculated according to the following Equation (2):

$$\gamma = 2\pi \cdot N \cdot r / t \,. \tag{2}$$

The disadvantage of this process is uneven strain distribution through disc diameter since the strain depends on the center's distance (*r*). That causes the unevenness of average grain size and mechanical properties – higher values of imposed strain, smaller grains, and improved properties are found at the edge of the disc. The effect of *N* and *r* on microhardness is presented in Figure 4 [5]. The number of turns increases microhardness; however, the differences are not pronounced with a higher number of turns. Also, microhardness is higher with a higher distance from the center. The saturation effect is also present in this processing.

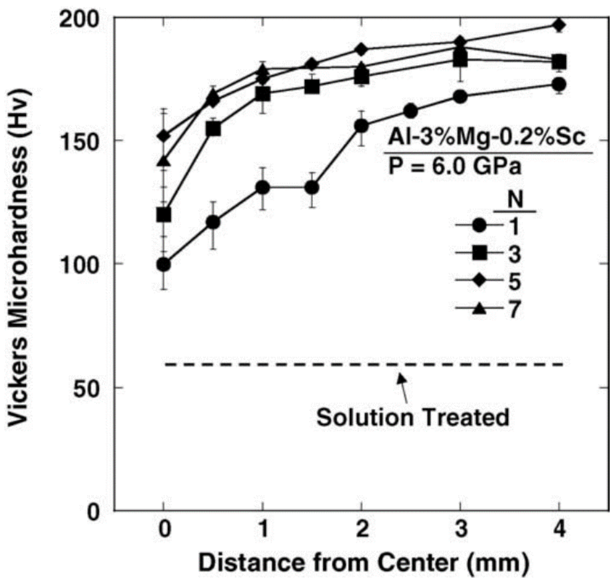

Figure 4. Vickers microhardness depending on *r* and *N* under 6.0 GPa applied pressure (Al–3% Mg–0.2% Sc alloy) [5]

The effect of HPT processing and the number of revolutions (N) on engineering stress and strain are presented in Figure 5. It can be observed that the HPT processing causes an increase in material strength. Interestingly, an increase in the number of turns (*N*) causes an increase in elongation. In contrast, there is almost no difference in engineering stress whether one or five revolutions are used for processing (curves 2 and 3).

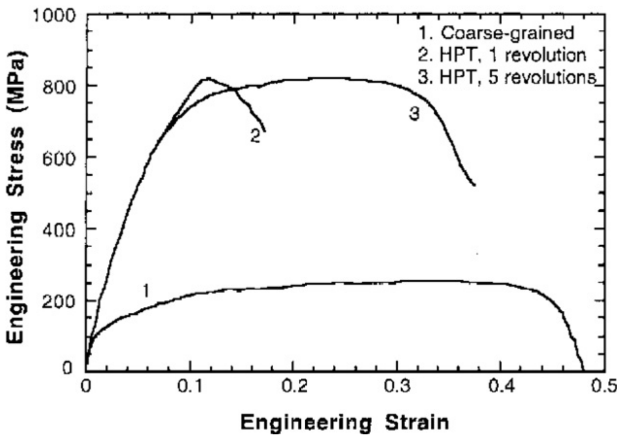

Figure 5. Engineering stress–engineering strain curves for commercial purity titanium tested at 523 K [15]

3. UPSETTING BY V-SHAPE DIES

For the past ten years, the Laboratory for the technology of plasticity at the Faculty of technical sciences has been studying the effect of SPD on different metallic materials. This paper presents two SPD dies invented at the Laboratory that are based on compression – Upsetting by V-shape dies (Figure 6) and Plane strain compression dies (Figure 11).

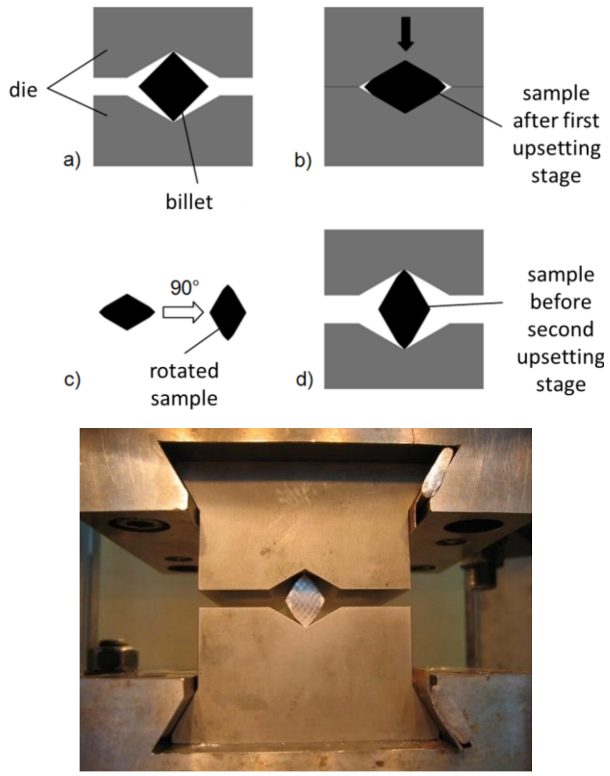

Figure 6. Upsetting by V-shape dies [16]

In upsetting by V-shape dies, prismatic billet (70 × 14 × 14 mm) made of low carbon steel C15E is inserted in-between two identical dies with V-shaped grooves and upset until the dies are closed (Figure 6b). After the upsetting stage, the sample is removed, rotated for 90° (Figure 6c), and reinserted between the dies (Figure 6d). In the study carried out in the Ph.D. thesis [16], eighteen stages and a 3.38 strain at the sample forehead were achieved. During the upsetting, a slight workpiece elongation is present because of the die openings. It is rational to presume that the state of strain is close to that of plane strain. During the processing, the average size of ferritic grains was reduced from 19.1 µm to 252 nm (Figure 7).

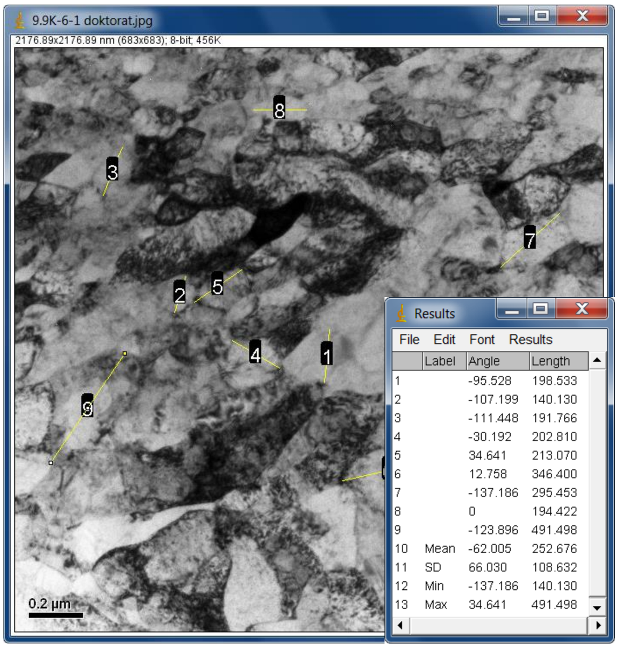

Figure 7. Average grain size after twelve stages

Material behavior after tensile testing for different upsetting stages (including initial material) is presented in Figure 8. The highest tensile stress is present in the sample upset in four stages. Further increase of upsetting stages causes a slight drop in stress. Similar observations are found for maximal elongation. One of the disadvantages of this processing is the unevenness of strain distribution and grain refinement. Consequently, material properties improvement is pronounced at the sample center, while peripheral regions suffer from diminished improvement. The unevenness can be illustrated by strain distribution obtained by numerical simulation (Figure 9).

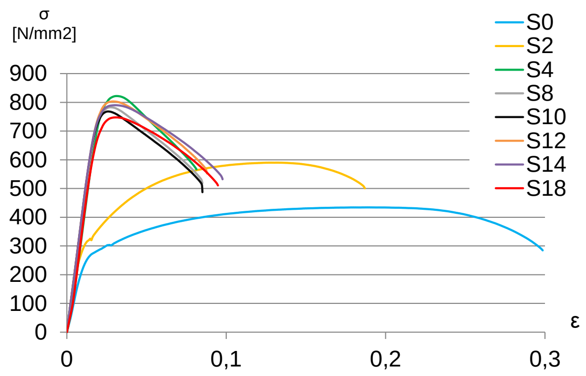

Figure 8. Tensile testing of the samples upset in various number of stages (S0 – initial material, S18 – material upset in eighteen stages)

The highest values of imposed strain are found at the sample center (red color). The unevenness can be explained by the design of the V-shaped grooves and the presence of the die openings.

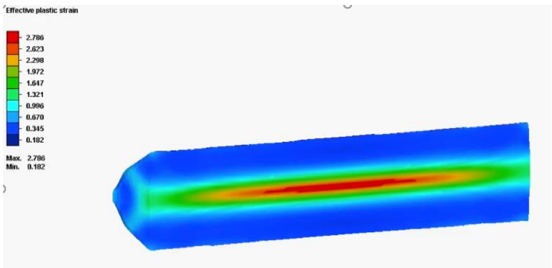

Figure 9. Effective strain distribution at seventeen upsetting stages obtained by numerical simulation (one half of the model)

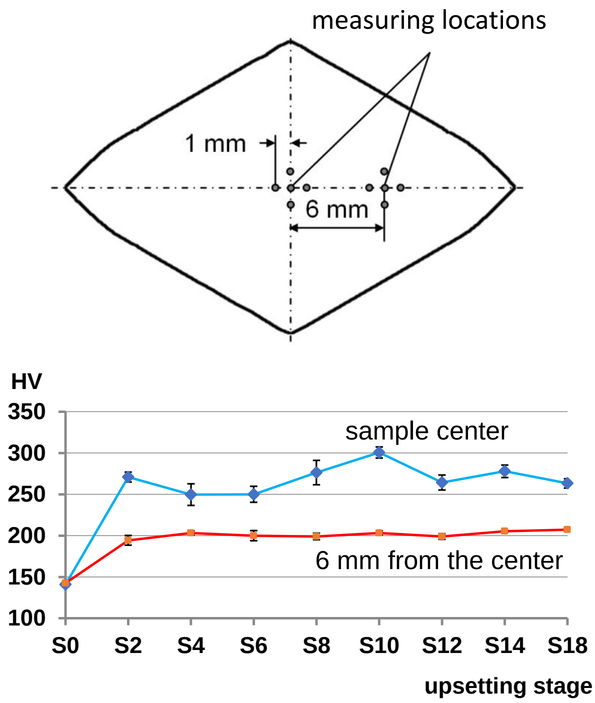

Figure 10. Hardness distribution in two regions (central and peripheral) vs. number of stages

The unevenness of material properties can be confirmed experimentally by measuring hardness. It was found that the central region is present a few millimeters from the center, and the peripheral region ranges from 6 mm to the edge of the sample. Thus, the hardness measurements are carried out according to Figure 10. The increase of number stages increased initial hardness from 141 HV to 300 HV at the sample center for ten upsetting stages and to about 200 HV for the peripheral region (6 mm from the center). Again, the hardness saturation effect can be observed.

4. UPSETTING BY PLANE STRAIN COMPRESSION DIES

A plane strain compression dies are used to process the 316L medical grade stainless steel by SPD (Figure 11). The research on this subject is still being performed. So far, six upsetting stages have increased average hardness from 170 HB to 438 HB.

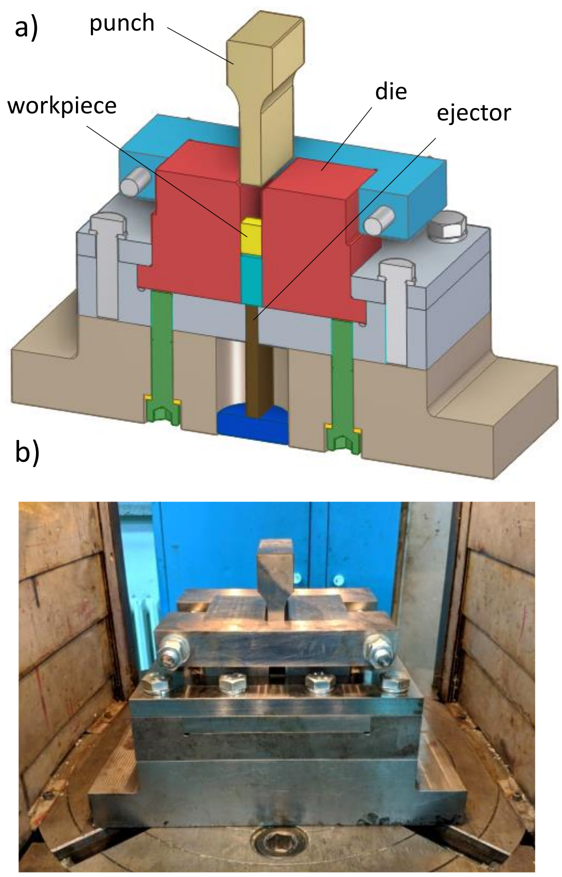

Figure 11. Plane strain die: (a) cross-section of the CAD model, (b) a photo of the die attached on the hydraulic press [17]

5. CONCLUSION

Severe plastic deformation is one of the alternatives and promising technology for improving material properties. The success of SPD methods is based on imposing high values of strain into the metallic material subjected to predominantly compressive stresses. Two SPD methods developed by the Laboratory for the technology of plasticity demonstrated the possibility of material improvement through hardness and strength enhancement. Although the number of publications related to the SPD is increasing year by year, these methods have not gained popularity. The main reason why SPD methods are not widely used in industrial practice is the lack of awareness. Hopefully, this paper can attract interest in this useful metalworking technology.

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CHEMICAL ENHANCTAMENT OF SURFACE QUALITY USING ACETONE IN ABS 3D PRINTED PRODUCTS

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Abstract: *Additive technologies or 3D printing are increasingly used in all branches of industry, especially in prototyping and re-engineering. In recent times, they are also used for the manufacturing of final products. Therefore, the surface quality of the final product as well as its mechanical properties is very important. The quality of the surface can be affected to some extent by reducing the layer thickness, which in FDM around 0.1 mm. One way to improve surfaces is to chemically enhancing of surfaces by treating them with certain liquids (solvents). This paper present the process of improving the quality of surfaces by exposing samples of ABS thermoplastic, manufactured at FDM 3D printer, to acetone vapor and immersion in acetone. The exposure time as well as the temperature was varied, and then their influence on the surface roughness and swelling of the samples was measured. The surfaces were also imaged with a microscope. It was found that the optimal enhancing is achieved by the process of exposure to acetone vapor, although better results are achieved by immersion, because increased swelling was observed in these samples, ie. the appearance of bubbles at the micro level.*

Keywords: *ABS, 3D printing, surface quality, acetone, microscopy.*

1. INTRODUCTION

Additive manufacturing (AM) or 3D printing is a rapidly expanding advanced manufacturing technology that enables high accuracy and low-cost manufacturing of physical models and complex geometric structures. The application of these technologies significantly accelerates the development and shortens the production time of new products. Additive technologies make it possible to make parts from just a few millimetres to entire residential buildings. [1-5].

The term additive technology can be explained by the following definition "adding material in the form of layers, which is in contrast to conventional technologies to subtractive manufacturing in order to obtain the desired product" [1-5].

The goal of additive technologies is to quickly and accurately create a three-dimensional object, based on CAD models, with the goal of significant cost reduction compared to traditional technologies [4-6]. These technologies can be divided into several groups based on the principle of operation:

• Binder jetting
• Sheet lamination
• Material extrusion
• Direct energy deposition
• Material jetting
• Powder bed fusion
• Vat photo polymerisation [5, 6]

The processes also differ according to the type of material from which the part is made:

• Polymers,
• Ceramics,
• Metal.

Process of 3D printing consists of several steps. The first step is to create a 3D model and adjust the print parameters; this process is called pre-printing preparation. The next step is the production of the part, i.e. 3D printing. The last step is to remove the excess material and, if necessary, to correct the product and this process is called post processing. [6,7].

Fuse deposition Modelling (FDM) is a typical representative of additive technologies and consists in the fact that the product is manufactured by building layer by layer of thermoplastic materials. The material is used in the form of a wire and is wound on a spool; the wire can be of different diameters, as follows: 1.75 mm; 2.85mm and 3mm. The group of materials most commonly used includes for 3D printing:

• Acrylonitrile butadiene styrene - ABS
• Prolactic acid - PLA
• Polyethylene terephthalate glycol - PET-G
• Polyvinyl Alcohol - PVA

Typical FDM printer is shown in figure 1. The printing process consists in drawing a wire filament (fig. 1 position 1) through the hot extruder (fig. 1 position 2) set to melting temperature of the filament. In the extruder, the solid material turns into a liquid state and is applied layer by layer to the hot working bed (fig.1 position3), until the finished product is obtained.[8]

Figure 1. Tipical FDM printer [8]

Pre-printing preparation is one of the most important processes in FDM printing. During this process, a CAD model with the appropriate extension STL, OBJ, etc. needs to be processed by a piece of software called a "slicer," which converts the model into a series of thin layers and produces a G-code file. In this step it is necessary to set the following parameter:

• Working parameters
• Printing speed
• Layer thickness
• Infill pattern
• Infill density

Working parameters mainly depend on the type of material, so the manufacturer's recommendations for extruder and work bed temperatures are mainly used.

Printing speed represents the speed of movement of the nozzle and the following speeds are distinguished: printing speed, infill speed and travel speed.

Layer thickness denotes the height of layer which is stacked over other 3d printing is carried out by the addition of filament over layer. [6-9]

Infill pattern presents outer coated part of plastic which is inside the print. In 3D printing, different infill patterns can be used lines, concentric, zigzag, etc. [6-9]

Infill density is an amount of plastic whichever is incorporated inside the printing, usually ranging from 20 to 80 percent, rarely 100 percent is used.

All the above mentioned parameters affect the properties of the product. The influence of parameters can be divided into two basic categories:

- Impact on surface quality and dimensional stability
- Influence on mechanical properties.

This paper will present a process of enhancing of surface quality of 3D printing parts from ABS by chemical enhancing by vaporising and immersion in organic dissolve-acetone and its influence at tensile properties.

2. EXPERIMENTAL

2.1 Material and samples

For the purposes of this research, ABS thermoplastic filament was used, where the following 3D printing parameters were used:

- Density 1.04g / cm3;
- Filament diameter 3 mm;
- Extruder temperature: 220-240 ° C;
- Bed temperature: 100-110 ° C.
- Layer thinness: 0.2mm

The samples were made on a Pangu I3 printer with a nozzle diameter of 0.3 mm, with a print space size of 150x150x150mm, and printing temperature at 225° C.

For the purposes of this research, test tubes were made according to the ISO 178 standard - Determination of flexural properties, of the following dimensions: width 10 mm; length 80mm and height 4mm, which is shown in Figure 2.

Figure 2. Test sample

2.2 Methods

ABS or Acrylonitrile butadiene styrene is a common thermoplastic polymer typically used for injection moulding applications. ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids and animal, vegetable and mineral oils, but they are dissolved by esters, ketones, chloroform, and ethylene dichloride. Therefore, acetone was used to chemically enhancing of the sample surface in this research.

Chemically enhancing of the sample surface was performed in two ways:

- by vaporising
- by immersion

Vaporising was conducted in desiccator, as shown in Figure 3.

Figure 3. Dessicator with samples

The vaporising parameters are shown in Table 1.

Table 1. Vaporising parameters

	Time of exposure [min.]	Temperature [°C]
1.	20	25
2.	20	55
3.	20	85

The desiccator with samples and acetone was placed in oven type Memmert Uf55 and adjusted according to the parameters from Table 1. After that, the samples were left to condition for 24 hours at air, after which the measurement of surface roughness was performed.

The procedure for immersing of the samples in acetone is shown in Figure 4.

Figure 4. Test sample

Acetone immersion parameters are shown in Table 2. It must be noted that a new chemical was used for each immersion.

Table 2. Immersion parameters

	Time of exposure [sec.]	Temperature [°C]
1.	60	25
2.	90	25
3.	120	25

After that, the samples were left to condition for 24 hours at air, after which the measurement of surface roughness was performed. Namely, materials that are susceptible to dissolution have the property of swelling. The mass of the samples was measured before and after chemical treating on a scale RADWAG PS2100R2, accuracy 0.01g. to determine the swelling of the samples

After conditioning of the samples, the surface roughness of the samples before and after the chemically enhancing was measured. Roughness measurement was performed on the device Surftest "Mitutoyo" type SJ410. The appearance of the measuring point with the samples is shown in Figure 5.

Figure 5. Surface roughness measuring point

The surface of the samples was imaged with a metallurgical microscope type Micros-Austria MCXI700.

3. RESULT AND DISCUSSION

All presented results represent the mean value of three measurements of all three samples. Figure 6 shows the results of measuring of the surface roughness of samples treated with acetone vapour. Based on the diagram, it can be concluded that with increasing temperature, the surface roughness decreases. This can be explained by the fact that with increasing of temperature, the aggressiveness of vapour acetone increases, i.e. decomposition of layers of ABS plastic in contact with acetone vapour.

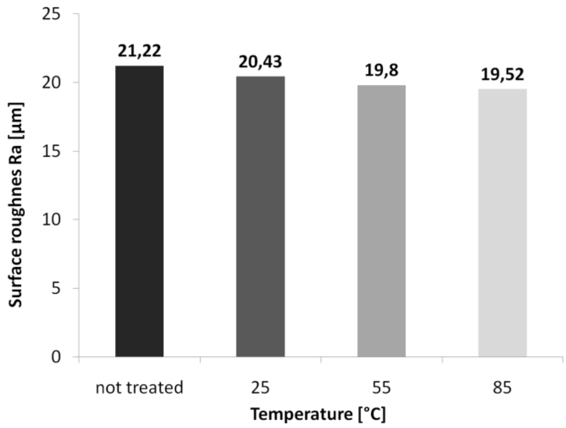
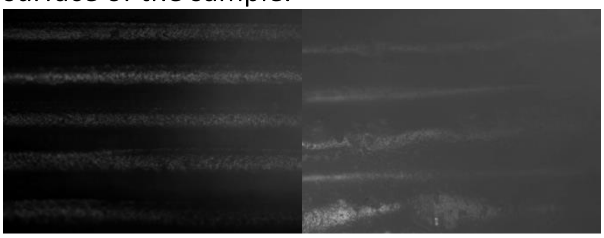


Figure 6. Influence of vapour treating on surface quality

Figure 7 shows the surface of the sample with a magnification of x50 before (a) and after (b) treatment. From the pictures it can be seen that there has been a change in the surface of the sample.



a **b**

Figure 7. Image of the sample surface under a microscope-vapourig

Figure 8 shows the results of measuring of the surface roughness of samples with were immersion in acetone liquid. The temperatures are not marked in the figure because they are identical in all examined cases.

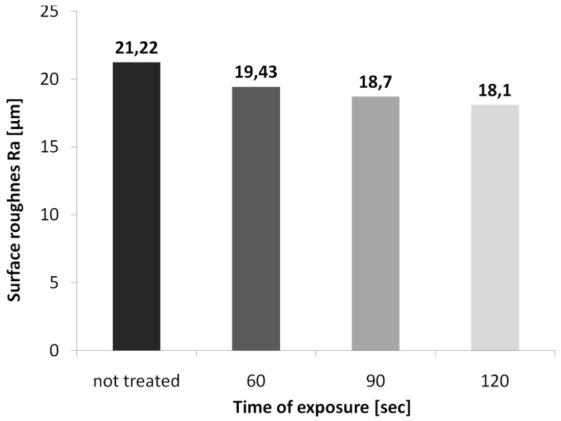
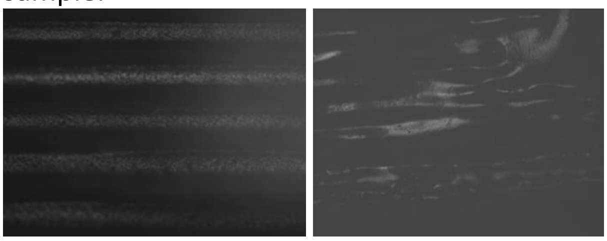


Figure 8. Influence of immersion time and temperature on surface quality

Based on the diagram, it also can be concluded that with increasing of time of exposure, the surface roughness decreases. Figure 9 shows the surface of the sample with a magnification of x50 before (a) and after (b) treatment. From the figures it can be seen that there has been a change in the surface of the sample.



a **b**

Figure 9. Image of the sample surface under a microscope - immersion

Also, if compared Figures 7b and 9b it can be clearly seen that there has been a change in the shape of the surface, ie. that the print lines are barely visible in the sample shown in Figure 9b. While printing contours can be recognized in Figure 7b.

This conclusion is confirmed by the diagram shown in the figure 10 so it can be clearly concluded that with increasing of temperature and the concentration of liquid, there is a faster decomposition of the sample surface, regardless of the exposure time.

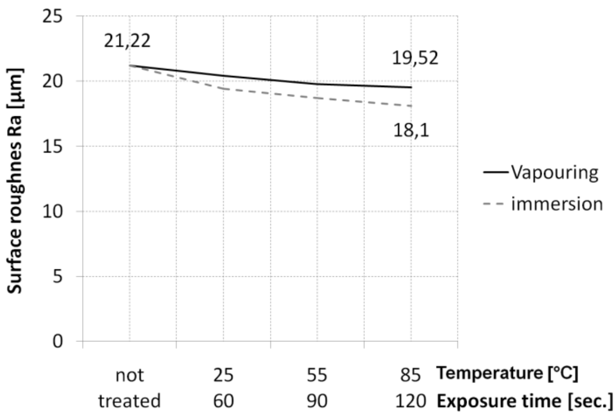


Figure 10. Comparative display of results

However, the negative consequence of prolonged exposure to higher concentrations of acetone leads to swelling of the samples, which is shown in Table 3.

This change also applies to the dimensions and shape of the samples. The increase in sample weight in the last case of treatment (expouse 120 sec. in acetone liquide) was 4,1%.

Table 3. Swelling of the samples

Vaporising		Sweeling ratio
1.	20min.-25 **°C**	1%
2.	20min.-55 **°C**	1%
3.	20min.-85 **°C**	2,5%
Immersion		**Sweeling ratio**
1.	60sec.- 25 **°C**	1,3%
2.	90sec.- 25 **°C**	2,4%
3.	120sec.- 25 **°C**	4,1%

Due to the swelling of the samples, changes occur both on the surface and inside the material, which disrupts the structure. The appearance of the surface of the samples on which bubbles (red arrows) can be observed is shown in Figure 11. the magnification on the microscope was x100.

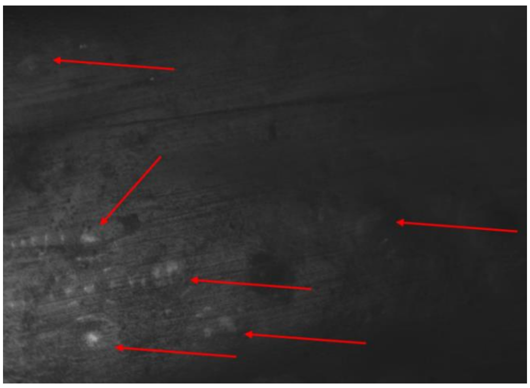


Figure 11. Image of the sweeling surface under a microscope x100

By increasing the magnification to x200, a large number of bubbles per print line can be clearly seen in Figure 12.

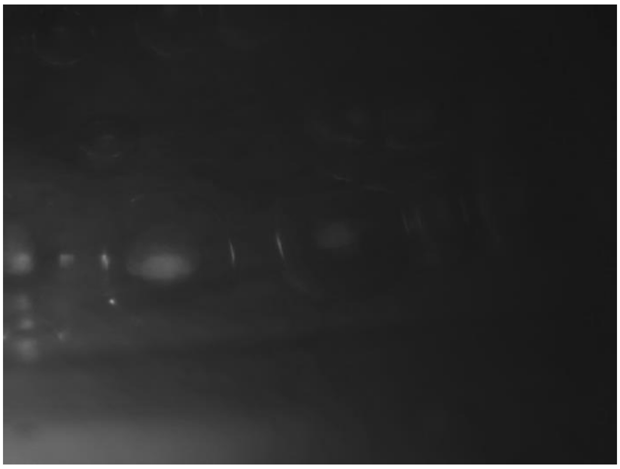


Figure 12. Image of bubbles at the sweeling surface under a microscope x200

4. CONCLUSION

In recent times, 3D printing is increasingly used to make final products. The question that arises is how to achieve the best quality of surface of final product. The quality of the product surface depends mainly on the printing parameters and the performance of the printer. However, in recent times, various techniques have been used to improve the surface quality of the surface such as sanding, cold welding, gap filling, polishing, painting, dipping, epoxy coating one of these technologies is chemical enhancing.

This paper presents the procedure of chemical surface enhancing using acetone (by vaporising and immersion). Parameters such as temperature and exposure time were varied. Only solvents can be used for the chemical enhancing process, so the swelling of the samples is also considered. After the performed experiments and measurements, it was concluded that the best result is achieved by vaporising at medium temperatures, because the immersion procedure results in the appearance of bubbles and disturbances to the overall structure of the material at the micro level. Therefore, the influence of chemical enhancing on mechanical properties should be taken for further consideration.

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APPLICATION OF THE CES EDUPACK SOFTWARE IN THE SELECTION OF THE ALUMINIUM TRUSS JOINING

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Abstract: *The task of each industrial manufacturing is to create a quality product with better characteristics, attractive appearance and a lower price. These goals are achieved by daily improvements of the manufacturing processes and construction solutions, as well as adequate selection of materials. Therefore, the choice of materials and manufacturing processes with optimal parameters are the important integral part of the design process of a particular product. Ranking of possible materials and processes is based on one or more goals, and the most obvious is the reduction of costs or the increase of quality regardless of cost, although it is usually a compromise between the two. Since there is a large number of materials and processes that can meet the requirements needed for the manufacturing of some part, designers now have at their disposal various types of software that could make this choice easier and faster. Selection of the welding process of aluminum truss using the CES EduPack software will be shown in this paper.*

Keywords: *Materials selection, process selection, aluminum, welding, software CES EduPack.*

1. INTRODUCTION

The task of each product is to have a good quality, as good as possible usability attributes, a better appearance and a lower price, and to provide as much profit as possible. This can be achieved only by good design solution, appropriate manufacturing process and proper material selection.

Material is primarily selected in the design and construction phase of the product, and rarely at the manufacturing phase, due to the possible problems in the materials procurement or eventual wrong decisions made in the construction. Given that the price of the product and its competitiveness will largely depend on the decisions made during the design of the product, it can be concluded that all the activities carried out in developing the idea of the product have great importance and responsibility.

At the very beginning of the product design it is necessary to clearly define its role in exploitation, with special attention to be given to performance characteristics (mass, dimensions, durability, reliability, energy consumption, maintenance, transport, etc.), then the various external influences and the environment (stress type - static, dynamic, impact, working temperature, vibration, humidity, aggressiveness of the environment, friction and wear, etc.), the interaction of contact surfaces (mechanical condition and roughness of the surface, tolerance, deviation of shape and fabrication errors, etc.), as well as influence on the people (tactility, noise, appearance, stability, convenience of cleaning and maintenance, ecology, etc.), (Table 1).

During the design phase, it is necessary to take the manufacturing process into account which will provide a quality product and a reduction in total costs.

The starting point of design process is a market need or a new idea, and the end point is specification of the product that meets certain needs. Between the need and the product specification are the phases shown in Figure 1: conceptual design, embodiment design and detailed design [1].

Table 1. Factors influencing material selection [2]

Manufacturing process	Functional requirements	Costs	Working conditions
Plasticity	Strength	Raw materials	Pressure
Deformability	Hardness	Processing	Temperature
Ductility	Brittleness	Storage	Flow
Formability	Thermal conductivity	Workforce	Type of material
Weldability	Fatigue	Control	Corrosion
Thermal formability	Creep	Packing	Environment
Final treatment	Aesthetic appearance	Taxes	Fire protection

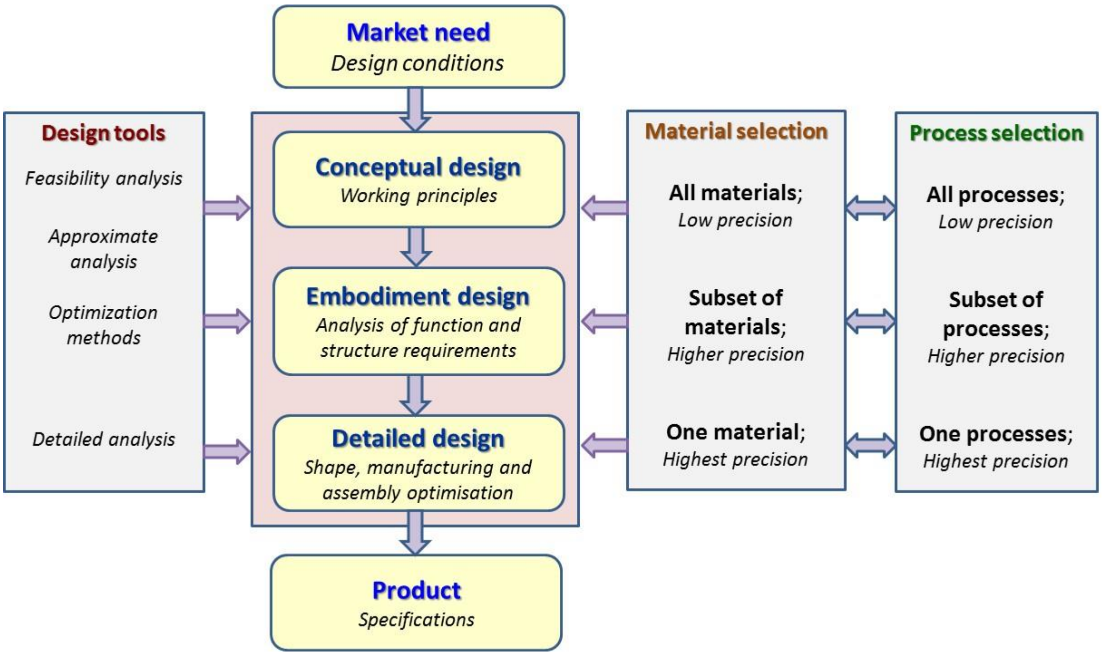

Figure 1. Schematic diagram of the design process [3]

All options are open during the conceptual design: the constructor considers alternative concepts and the ways in which they can be implemented. In the next phase of embodiment design the constructor chooses one or several concepts and tries to analyze them from as many aspects as possible. This includes the dimensioning of components and the material selection that will correctly perform functions in terms of loads, temperatures, and environment, taking into account both performance and price. This phase ends with the choice of feasible solution, which is transferred to a detailed design phase. Specifications for each component are made in this phase. Critical components can be subjected to precise mechanical or thermal analysis. Optimization methods are applied to components and groups of components in order to choose the best variants. In the end, the final choice of geometry and materials, as well as the way of manufacturing and economic aspects, is made. The phase ends with a detailed manufacturer's specification.

In case of product development it is not always necessary to start from scratch. The original design implies a new idea or working principle. New materials can offer new, unique combinations of features that enable genuine design. Sometimes new material proposes a new product, and sometimes, the new product requires the development of new material. Nuclear technology led to the development of a series of new alloys of zirconium and low-carbon stainless steel; space technology stimulates the development of a low-density composite; the technology of gas turbines today led to the development of alloys for high temperatures and ceramic coatings. The original design sounds exciting, but most designs are not like that [4].

Almost all designs are adaptive or developmental. The starting point is usually the existing product. The motive for redesigning may be to improve performance, reduce costs or adapt to market conditions that are changing. Adaptive design takes the existing concept and looks for new possibilities in performance through refinement. This is also often facilitated by material changes: polymers replace metals in home appliances; carbon fiber replaces wood in sports equipment, etc. [5].

2. MATERIAL AND PROCESS SELECTION METHODOLOGY

Systematic material selection is necessary as more and more new materials are being made every day that should meet numerous complex demands. Proper material selection means taking into account the market requirements and the products application, the conditions and possibilities of manufacturing, as well as the corresponding requirements of the product function.

Three new activities are equally represented in the new product development: structural design, material selection and selection of manufacturing process.

By combining different types of materials, shapes and dimensions of products and manufacturing processes, various product solutions are obtained. An increasing number of materials and manufacturing processes make the construction process more complex and responsible, and it is very often expected from them to decisively influence the properties and behavior of the product.

Therefore, designers are increasingly turning to the methodical process of material selection, and less to experience, although it is still necessary in some phases of decision making.

When developing possible solutions - in the conceptual, development and design phase, for each variant, those materials that meet the requirements regarding this solution - functional, manufacturing, exploitation and economic, are determined [6].

For each possible solution, a specific manufacturing process is determined and the choice of materials is often determined by the criteria of technology and costs.

At any stage of the product development, the intermediate of the material selection can be several groups or types of suitable materials, so it is necessary to perform optimization based on the defined criteria.

3. COST EFFECTIVE DESIGN OF MATERIAL

During the design process, all elements of the product life cycle are first considered, starting with the concept all the way to disposal and destruction, taking into account different user requirements, appropriate quality, cost and price.

Product development methods simultaneously analyze different design-manufacturing variants, varying the design forms, materials and methods of manufacturing. Structural design, material selection and the selection of manufacturing processes are inseparably linked activities. The choice of the manufacturing process is a difficult task because the same part can be formed in several ways, with different quality, manufacturing time and costs.

There are two possible approaches in material selection based on the type of manufacturing process [7]:

- Manufacturing processes are determined for a known group or type of material - approach is typical for classical constructors and
- Materials are chosen for a pre-defined manufacturing process - the approach is characteristic for technologists.

The manufacturing process must achieve the desired quality for the selected material, shape, dimensions, tolerances and workpiece surface conditions with minimal costs and manufacturing time. In doing so, the constructor should be provided with information about the possibilities of the available manufacturing processes in order to select the most favorable process in the given circumstances.

4.1 Manufacturing material properties and manufacturing process selection

The selected material, in addition to having the properties that enable function during use, should also be suitable for forming by manufacturing processes with the lowest possible cost. The manufacturing properties of materials that include technical and economic criteria for the evaluation of materials and their corresponding manufacturing methods depend on: the composition, structure, shape and dimensions of the starting material - semi-finished products, the equipment on which the material is processed, the parameters of the manufacturing process, the applied tools and the human factor.

During manufacturing process, the initial composition, microstructure and material properties change accidentally or intentionally during manufacturing and this change depends on the specific manufacturing process.

The material selection will be better if the manufacturing conditions are better known. The suitability of the materials for manufacturing can be determined in different ways [7]:

- By examining the physical and mechanical properties of the starting material,
- Technological testing of semi-products - pipes, sheets, wire,
- Supervising and monitoring the behavior of materials during manufacturing,
- Determining errors after the performed process
- Testing of material properties after the forming process and
- Empirical estimates

The aforementioned data and indicators can determine the manufacturing properties by numerical or descriptive estimates, which only give a rough picture of the suitability of a material for a particular manufacturing process and can only be used as an orientation in the selection of the appropriate combination of material and method.

The manufacturing process is influenced by the following properties and characteristics of the material: composition, condition, structure, impurities, inclusions, processing history (casting, forging, drawing, cold or hot processing, etc.), shape (bar, tube, wire, sheet) of the initial semifinished product, physical and mechanical properties, part size, batch size, as well as the manufacturing characteristics (deformability, weldability, etc.) and material costs.

The initial shape and dimensions should be as close as possible to the final geometry of the product in order to make the best use of the material. Determining the starting shape in geometrically basic parts is simple, but in complex shapes this can be a problem because different starting forms and methods can then be possible. The dimensions of the semi-finished products should be greater than the final part just as much as it is necessary for removing the surface errors. In some cases, excess material should be provided for handling or positioning of the workpiece.

In the literature it is possible to find, for metals, the dependence between the processing type and the achieved surface roughness, as well as the types of processing and tolerances that can be maintained [1]. Almost all polymer adaptation processes give an excellent surface condition, but stability of dimensions and tolerance depends on the type of polymer and the processing conditions.

It should be kept in mind that, for any material, reducing the tolerances and reducing of surface roughness leads to a significant increase in manufacturing costs. The price of the material can significantly affect the total cost of making the product. For example, the use of more expensive materials can make a cheaper product, due to the application of a cheaper manufacturing process, or cheaper material can lead to higher costs due to increased damage or wear of the tool.

The choice of manufacturing methods is related to product characteristics and depends on: the shape of the semi-finished products and the finished part, the minimum and maximum permissible dimensions of the part (volume, mass), the complexity of the shape, the required tolerance and roughness of the surface, the details on the surface (radii, curves, notches) etc.

The manufacturing process depends on the size of batches for which manufacturing is paid off due to the fixed costs of equipment and tools. Large batches justify investing in equipment, tools and automation. The use of quick-exchange tools and flexible automation leads to a significant reduction in costs.

The equipment available significantly affects the choice of the manufacturing process and is very often stated and limited. In specific cases, if it is considered to be profitable, equipment can be purchased, which requires certain investments. It is also possible to count on the possibility of cooperating or producing some positions in the appropriate service centers.

The most important characteristics for comparison of manufacturing processes are: manufacturing cycle time, product quality (required roughness of the surface and tolerance, product of corresponding mechanical properties and without errors), flexibility, material usability and operating costs.

4. COMPUTER SYSTEMS FOR MATERIAL SELECTION IN THE MANUFACTURING PROCESS

Selection of material or manufacturing process is not an easy task in engineering practice and it is one of the few in the process of constructing a product that is subjected to constant changes. On the other hand, the wrong materials selection in the very beginning of construction could have irretrievable damage to the manufacturing and exploitation process. Knowing the quality of the available materials and their characteristics, as well as tracking trends in the development of new materials, are essential parts of good engineering practice [8].

Data and information about materials must always be available to constructors and designers of new products, as well as to technologists. They can be found in classic literature (manuals, catalogs, standards, recommendations, ...) or in electronically prepared databases on the computer (intranet, internet).

Since the number of materials rises each day more and more, and bearing in mind that the large number of properties can be attributed to any material that users potentially need, then the data from classical literature, because of their inertia, lose their importance more and more, and data and information about materials that are systematically collected, evaluated and stored in computer databases for the last several decades, are increasingly gaining importance [9].

Intensive development of software and hardware in previous years has enabled a step further, i.e. creation of special software packages – expert systems that not only include the aforementioned databases, but also offer opportunity for interactive materials or process selection for various engineering applications. The abovementioned expert systems allow to not expect an expert knowledge of materials from constructor and provide faster informing and decision making in product development and materials selection or manufacturing process.

Computer databases exist in a number of companies, enterprises and public services, and many of them are commercially available, while the knowledge bases are less developed.

Therefore, at the present time, there is a growing practice that the results of research and testing of materials are rapidly transferred into engineering activities using information and communication technologies.

4.1 CES EDUPACK (Cambridge Engineering Selector EduPack)

CES EduPack is one of the most commonly used EC for material selection. It is a PC application that enables both constructors and material experts, and other engineers, to find proper materials that will constitute the optimum solution for their product. This product is of great help in decision making about materials in the early stage of product design, redesign or replacement of existing material with a new one.

CES offers tools that support a rational selection methodology developed by Professor Mike Ashby with colleagues at Cambridge University and Granta Design Ltd company (http://www.grantadesign.com/products/ces/). The method represents the industry standard of systematic approach to the materials selection [10]. CES software and database modules are functionally connected in packages. Each package is designed to allow the complete solution for the specific CAD needs.

CES system is composed of a series of connected modules. The material selection is guided by the design of construction, which means that the input data are exactly the design requirements. These requirements are further transferred into orders for material selection and properties of machining process.

CES EduPack is the central module of the CES system, and allows engineers to select smaller groups of materials that optimally meet the design requirements from the existing material databases.

Program then offers the creation of selection charts that give a visual representation of important properties, or a combination of properties of material or process (Figure 2). CES EduPack enables numerous tools with sophisticated strategy and automatically maintains the direction of selection results.

Preview of this way ranked material properties is the first step in the materials selection. These charts give a ranking list of potential material or manufacturing process candidates. Combining multiple charts can significantly narrow the range of possible candidates. At the point when the group of satisfactory materials or manufacturing process is found, CES EduPack program enables direct access to a huge source of additional information related to these materials (diagrams, figures, texts, tabular data, etc.) that are enabled by Granta Design, but also to other sources (for example Campus, Prospector, ASME, Internet, etc.).

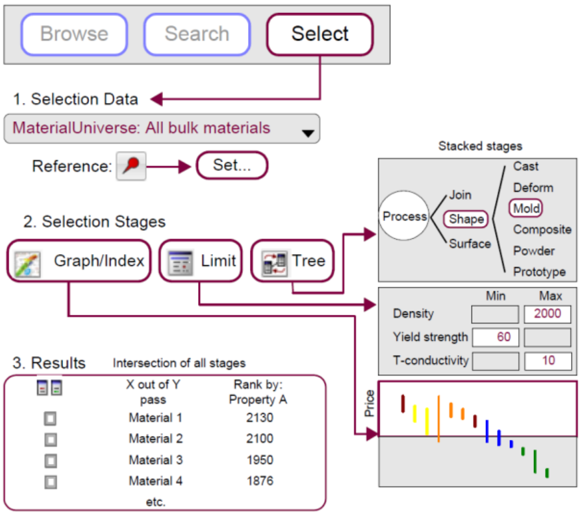

Figure 2. Principal scheme of setting limitations in the material and process selection

Even such a complex system for material selection cannot give one particular material as an answer to the required application, but offers a small group of different materials or manufacturing process as a solution, so the final selection is left to the user (constructors, engineers) with help of additional information (reference for some materials, or through additional requirements).

5. JOINING PROCESS SELECTION FOR CHARACTERISTIC REQUIREMENTS BY USING CES SELECTOR

The joining process selection will be shown in the case of a roof truss structure (Figure 3). The material selected for this construction is aluminum. The structure should be composed of tube profiles of different lengths. The construction must be strong, without the occurence of damage during use.

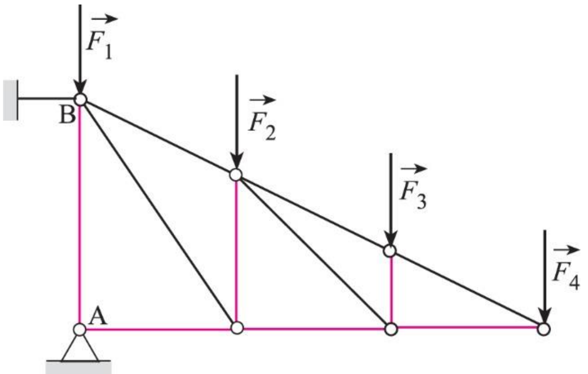

Figure 3. Geometry of roof truss

The joining can be performed using inseparable (welding, soldering, gluing) or separable (rivets, screws) connections. Separate connections are less suitable than inseparable due to lower endurance, and also because of the higher execution costs. Welding is certainly the most appropriate inseparable bonding, but due to the number of welding methods it is necessary to choose the most suitable one.

There are several factors that can affect the result and the quality of the welded joint itself. When choosing a welding process, one should bear in mind:

- type of material to be welded,
- thickness of material,
- welding position,
- available electric power supply (eg. single-phase or three-phase),
- strength of available power,
- weather conditions.

Table 2 shows the compatibility of the welding processes and the types of material.

Table 2. Compatibility of welding processes and types of material

Welding process	MMA	MIG	Pulsed MIG	MAG CO2	Pulsed MAG	MIG soldering	Wire feed	TIG DC	Pulsed TIG DC	Pulsed TIG AC	Pulsed TIG AC	Tig AC-DC
Material	*	*		*	*		*	*	*			
Structural steel				*	*				*			
Structural steel (thin)					*							
Galvanized sheet						*						
Stainless steel	*	*	*				*	*	*			
Aluminium	*	*	*							*	*	*
Copper	*		*					*	*			
Titanium			*					*	*			
Magnesium			*							*	*	*

There are a total of 53 joining processes in the CES EduPack database. At this point for the welding of the aluminium truss, it is necessary to choose the optimal welding procedure. Table 3 shows the technical and economic constraints that the welding process must meet.

Due to the large number of various welding processes, only the number of welding processes will be indicated in following text during selection. The processes that satisfy all the requirements will be listed in the Table 4.

To satisfy the first criterion, ie. the type of materials to be welded, the list of 53 joining processes is reduced to 44 (Figure 4).

Table 3. Welding process requirements

Function	Welding of the truss rods	Constraints
Constants	- *Material*: aluminium - *Type of welded joint*: butt and corner joint. - *Type of welded joint loading*: compression, tension and bending. - *Shape*: circular - *Mass*: 0,5 – 100 kg - *Radius*: R = 15 mm - *Pipe wall thickness*: d = 4 mm - *Process type*: discrete	Technical constraints
Goal	Cost reduction	Economic constraints
Free variables	Process selection Process work conditions	

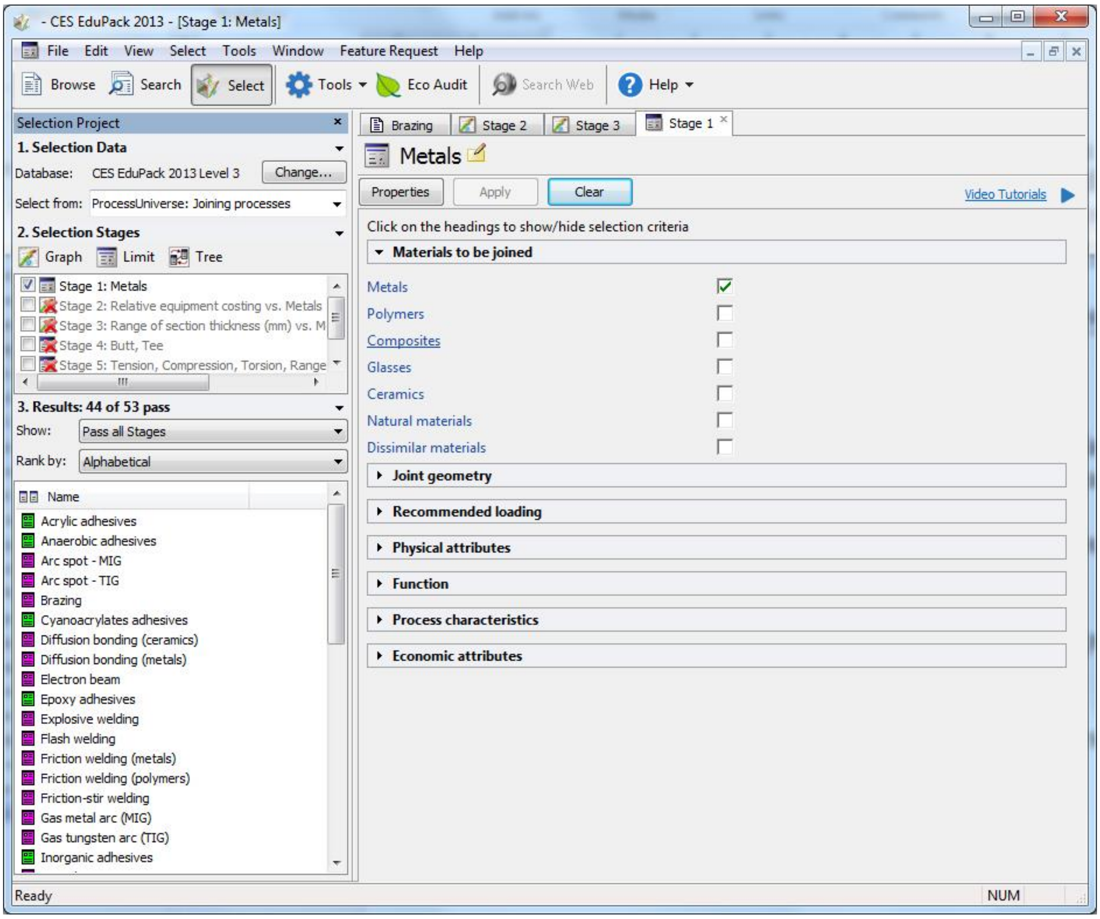

Figure 4. Material limitation according to CES EduPack

To satisfy the second criterion, ie. the joint geometry, the list of 44 joining processes is reduced to 25.

To satisfy the third criterion, ie. the type of loading of the welded joint, the list of 25 joining processes is reduced to 17. To satisfy the fourth criterion, ie. physical attributes of the welded joint, the list of 17 joining processes is reduced to 16. To satisfy the fifth criterion, ie. the requirement of the process to be discrete, the list of 16 joining processes is reduced to 14 (Figure 5).

Of the remaining 14 joining processes, it is necessary to remove 3 processes that do not fall into the welding process, but in the joining processes that allow disassembly without destruction, so the list is reduced to 11 processes. Figure 6 shows the difference in prices of the remaining welding processes.

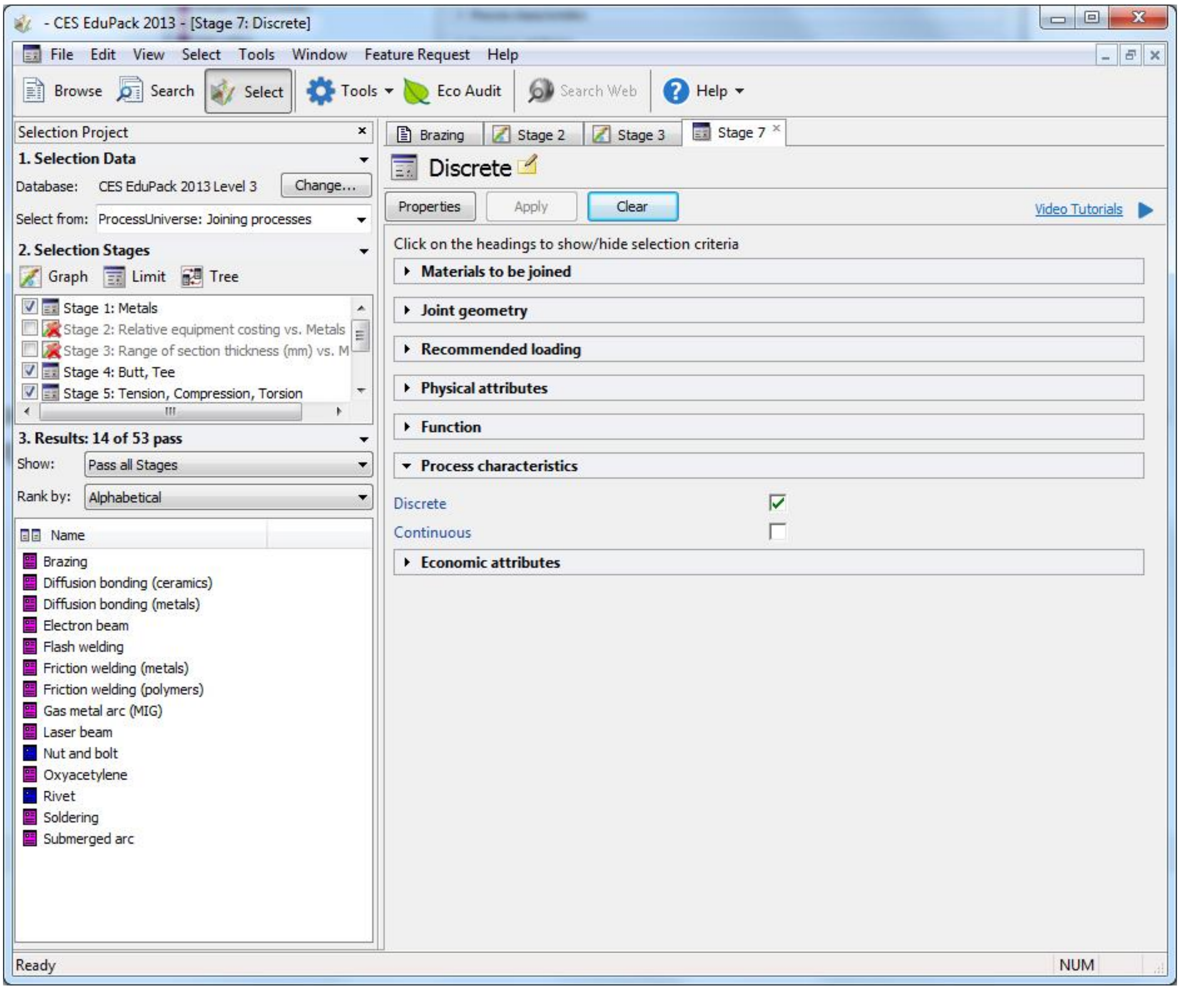

Figure 5. Process characteristics limitation according to CES EduPack

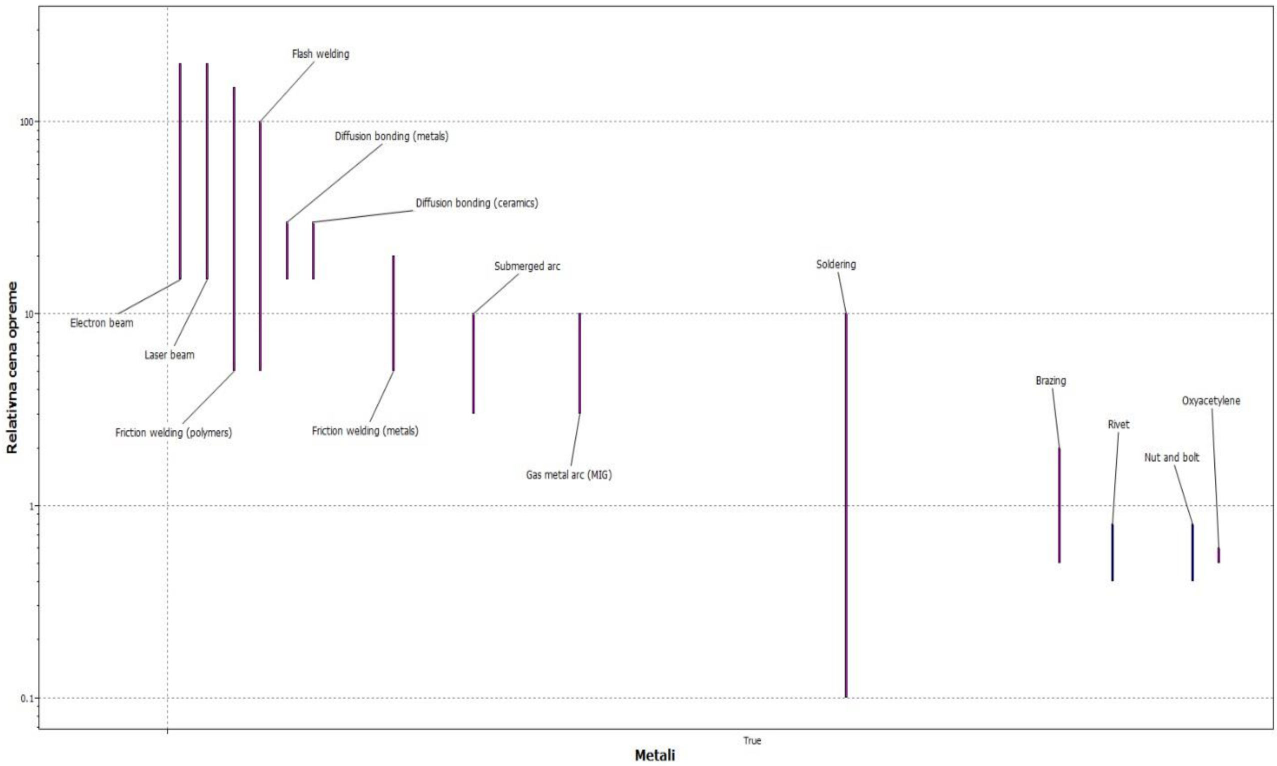

Figure 6. Prices of welded joint equipment according to CES EduPack

According to Figure 6, the first six processes are expensive, while the last five are soldering and processes where disassembly without destruction is possible. Table 4 lists the processes that meet the beforementioned requirements.

Table 4. Processes that meet the requirements

Welding process	Comment
Friction welding	Friction welding is not applicable in more complex shapes of truss. In the case of truss structures there is an approach problem.
Submerged arc welding	It was not found that this method can be used for welding of aluminum. This procedure is used in large batches. Welding is carried out in a horizontal position.
MIG welding	The possibility of a better approach, and according to Table 2 it is suitable for welding of aluminum.

According to Table 4, it can be concluded that the MIG welding procedure is the optimal solution, both in technical and economic terms.

6. CONCLUSION

An increasing number of materials and their characteristics, tendency for faster and more reliable information, the pursuit of more objective and more comprehensive comparisons, the increasingly present need for modeling and simulations, point to the use of computer systems that store and process information about materials.

Computer databases exist in a number of companies, and many are commercially available through public information services, while knowledge bases and associated expert systems are less developed.

The development of software and hardware allows the creators of the materials database to go a step further, i.e. to create special software packages, which will not only contain the mentioned databases, but will also offer the possibility of interactive selection of materials and manufacturing processes, which implies mutual communication between the user (the engineer) and the special software package (expert system).

The illustrated example of selecting the welding process of the roof truss construction using the CES EduPack indicates that the mentioned software can be used effectively, among other things, for the selection of the welding process.

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ON POLYMER- LAYERED SYLICATE NANOCOMPOSITES

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Abstract: *In the paper, unmixed, intercalated and exfoliated structures of polymer-layered silicate nanocomposites (PLSN) are described and « tortuous path model» relating to barrier properties of PLSN structures is explained. Then, the mechanism of clay nanoparticles exfoliation is depicted by mean-field, lattice-based model and step-wise skewing model. Next, solution induced intercalation, melt intercalation, in situ polymerization and electrostatic layer-by-layer self-assembly are presented as methods of PLSNs preparation. Subsequently, mechanical, thermal, barrier and flame retardancy properties of PLSN s are considered. Finally, fields of PLSNs applications are depicted, with special attention to the fields of commercial applications in auto industry. It is concluded that enhanced properties of PLSNs are related to the degree of dispersion and the degree of exfoliation (dispersion of platelets) of the tactoids (clay platelet stacks) in the polymer matrix.*

Keywords: *nano, composites, clay, exfoliation, dispersion.*

1. INTRODUCTION

Nanocomposites are a class of composites in which one or more separate phases have one dimension in the nanoscale. The field of nanocomposites involves the study of multiphase materials in which at least one of the constituent phases' dimension is less than 100 nm, [1].

Nanocomposites improve the good properties of the matrix with the enhanced performance of the nanostructures. The reason for applying nanoscale fillers into polymer matrices is the attainment of potentially unique properties, as a result of nanometric dimensions. In particular, it is possible to achieve high results using a low volume or weight fraction of nanomaterials, comparing to microfillers, [2].

The properties of nanocomposites rely on a range of variables, particularly the matrix material, which can exhibit nanoscale dimensions, loading, degree of dispersion, size, shape, and orientation of the nanoscale second phase and interactions between the matrix and the second phase, [1].

Polymer–clay nanocomposite (PCN) materials fall into the category of organic–inorganic hybrids consisting of organic polymers as the matrix and inorganic clay minerals as the reinforcing filler. Polymer–clay nanocomposite materials are also usually referred to as polymer-layered silicate nanocomposites (PLSN) because the inorganic fillers used are mostly natural or synthetic silicate materials such as montmorillonite, hectorite, laponite, fluorohectorite, etc., [3].

Because of the low price, availability, high aspect ratio as well as desirable nanostructure and interfacial interactions, clays can provide dramatic and adjustable improved properties at very low loadings, [4].

Polymer- clay nanocomposites are pioneered by researchers at Toyota, [5,6,7]. In 1990, they first used clay- nylon 6 composites for timing belt covers, [8].

Although first demonstrated for nylon, polymer-clay nanocompoites have since been prepared for a range of thermoplastic and thermoset polymers, [9].

This work aims to explore structures, mechanism of exfoliation, synthesis, properties and applications of polymer-clay nanocomposites.

2. STRUCTURES OF POLYMER - LAYERED SYLICATE NANOCOMPOSITES

There are many variants of clays, including montmorillonite, illite, vermiculite, hectorite, with some difference in their composition, structure, and basal spacing. Those members who are able to be exfoliated by polymer chains or monomers and distributed as individual clay layers within polymer matrix are suitable for the preparation of polymer nanocomposites,[4].

Montmorillonite is the most common clay mineral used in polymer/clay hybrids and is composed of an octahedral alumina sheet sandwiched between two tetrahedral silica sheets, making structure called platelet, [10].

The platelets have a net negative charge and are weakly bound via electrostatic forces with an interlayer of hydrated Na^{+}, Li^{+}, Ca^{2+}, Fe^{2+}, or Mg^{2+}cations. The thickness of each plate is 1 nm but laterally can achieve dimensions of 1 mm ,[11].

Stacks of platelets are called tactoids. The space between layers is called the gallery, [12].

Typical polymer–clay hybrids composed of layered nanoparticles (silicates, talc and mica) are aggregated to some degree, as the immiscibility of clay in the polymer leads to a very close proximity of sheets to one another, [13].

The hierarchy of mentioned clay structures is depicted in Fig. 1.

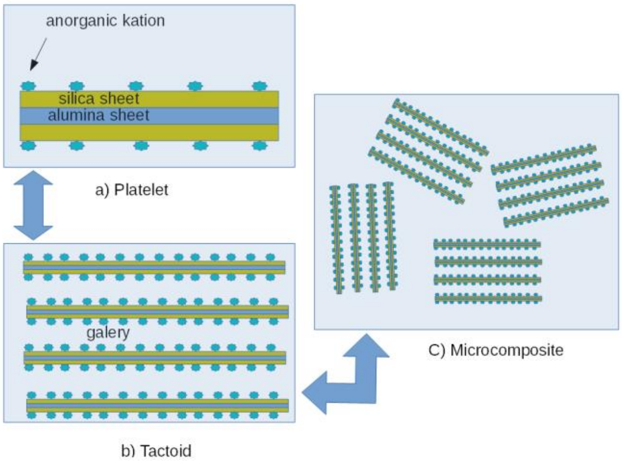

Figure 1. Hierarchy of clay structures: a)- primary clay structure; b)- secondary clay structure ; c)- tertiary clay structure

The degrees of dispersion in these composites are generally referred to as unmixed (highly aggregated), intercalated (minimally aggregated), and exfoliated (well dispersed). In the intercalated case, polymer chains interpenetrate stacked silicate layers with small separation distances (few nanometers) between the layers. In the exfoliated or delaminated morphology, the silicate layers are well dispersed within the polymer matrix (Fig. 2), [14].

Clay structure in polymer nanocomposites can be characterized as a combination of exfoliated platelets and intercalated tactoids, [15].

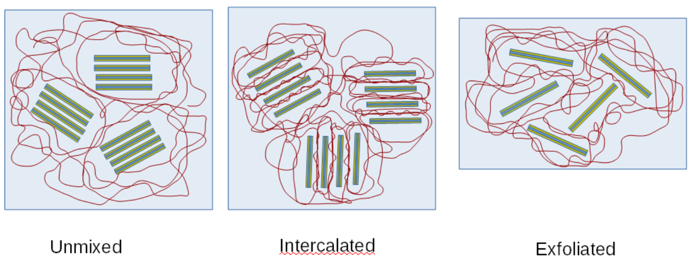

Figure 2. Structures of polymer- clay nanocomposites

3. BARIER THEORY OF POLIMER-CLAY NANOCOMPOSITES

Polymer-layered aluminosilicate nanocomposites can provide significant improvements in barrier properties of polymers, [16,17].

The enhanced barrier properties of PLSNs can be explained by the so-called ''tortuous path model'', given schematically in Fig. 3, [18].

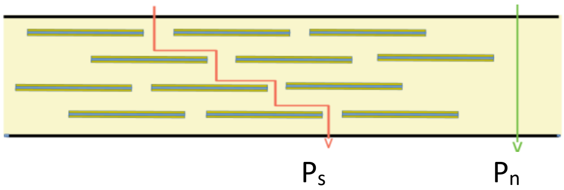

Figure 3. *The* tortuous path model

In this, model the ''tortuosity'' of the molecular trajectory of the permeant is determined by several parameters such as the length L of the lamellae and its state of aggregation expressed by the transversal dimension of the particle W, concentration of the delaminated clay Φ , and the mutual orientation of the lamellar planes expressed by the order parameter S defined below, [19]:

$$\frac{P_s}{P_p} = \frac{1-\Phi_s}{1+\frac{L}{W}\Phi_s\frac{2}{3}\left(S+\frac{1}{2}\right)} \quad (1)$$

$$S = \frac{1}{2}\left(3\cos^2\overline{\theta}-1\right) \quad (2)$$

where Ps and Pp represent the permeabilities of the polymer–silicate nanocomposite and pure polymer, respectively; L and W are the average length and width of a delaminated clay particle, respectively; and $\overline{\theta}$ is the average angle between the normal direction n to the barrier membrane and the normal direction to the surface of the lamellar plane p, as shown in Fig. 4.

It follows from this model that for a given concentration Φ_s of the aluminosilicate, barrier properties are maximized for a composite with highly delaminated aggregates (high L/W ratio) and a high degree of lamellar orientation (S→1), [9].

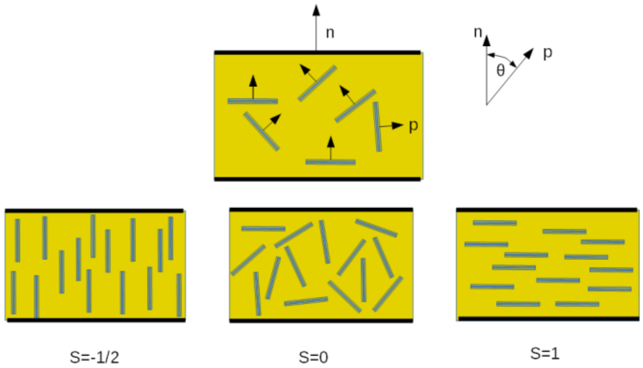

Figure 4 Effect of sheet orientation on the relative permeability in exfoliated nanocomposites

4. MECHANISMS OF EXFOLIATION

In the mean-field, lattice-based model of polymer intercalation in organically modified silicates the thermodynamic factors which control polymer intercalation into the clay galleries were outlined in terms of an interplay between entropic and energetic factors. The entropic penalty for confining the polymer inside the clay gallery may be partially compensated for by an increase in entropy of the surfactant chains (alkyl chains on organic modifier) as the clay layers separate. Although the tethered alkyl chains cannot increase their entropy by an increase in translational freedom, the expanded gallery spacing permits increased conformational entropy. Intercalation will be thermodynamically possible when favorable polymer–organically modified silicate energetic interactions overcome any unfavorable entropic factors. Further separation, i.e., driving exfoliation, depends on maximization of favorable polymer–surface interactions with the organically modified silicate, as well as minimization of unfavorable interactions with the tethered alkyl chains of the organic modifier. This explains the use of polymer functionalization with polar moieties. The polar functionalities on polypropylene participate in polar–polar interactions with the silicate surface, decreasing the free energy of the system. If the total free energy of the system is decreased by the combined entropic and energetic factors, then in-tercalation and exfoliation may occur, [10,20,21].

Fornes et al. proposed a model explaining exfoliation of intercalated silicate stacks by the stepwise skewing of the silicate sheets in the tactoids, followed by peeling, one-by-one, of the silicate layers off the silicate stacks by combined diffusion/shearing. The tactoids were shown to first skew apart forming shorter stacks of fewer and fewer numbers of silicate layers, followed by peeling of the individual layers off the tactoids forming exfoliated and dispersed layers, without short-range order with other silicate layers. The matrix polymer needs to have sufficient affinity for the silicate surface to cause spontaneous wetting of the surface to drive exfoliation. This is the required thermodynamic driving force. However, shear forces play a kinetic role by driving the peeling of silicate layers off the tactoids during the residence time of the system in the shear process. It was found that the higher the melt viscosity of the matrix polymer, the greater the stress exerted on the tactoids, driving this skewing and peeling process. Therefore higher molecular weight matrix polymer was associated with higher stresses and a higher degree of exfoliation, [10,22]. This model was supported by a further experimental study in which the clay tactoid was observed to be in the process of peeling apart in TEM images, [10,23].

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

5. PREPARATION OF POLYMER–CLAY NANOCOMPOSITE MATERIALS

The key to polymer-clay composites is polymer-clay compatibility at the interface. This requires that, in most cases, one must impart an organophilic character to the clay. In the case of hydrophilic polymers and silicate layers, pretreatment is not necessary. Most polymers, however, are hydrophobic and are not compatible with hydrophilic clays, [8].

Organic modification of clay can be achieved through the exchange of sodium ions with organic alkyl ammonium ions (Fig. 5). This modificatio makes the normally hydrophilic clay hydrophobic and potentially more compatible with the polymer being used in preparation of the polymer–clay nanocomposites, [4].

When polar polymers are used, exfoliation can be achieved by the addition of a surfactant to the material, typically a long-chain alkylammonium salt, [14].

However, for nonpolar polymers such as poly(ethylene) and poly(propylene), the addition of a surfactant is not sufficient to overcome the entropic penalty; thus a functional comonomer such as methyl methacrylate must be incorporated into the nonpolar polymer to allow nanoparticle dispersion within the matrix, [24].

Advances in processing have also led to decreased aggregation in clay–polyethylene materials, such as the use of supercritical CO_2 during polyethylene extrusion, [25, 26] .

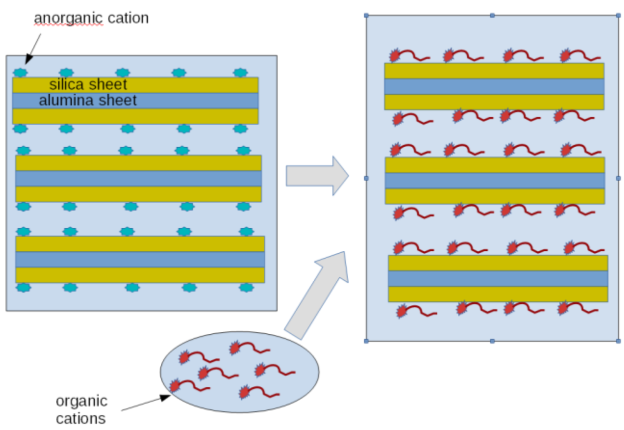

Figure 5. Ion substitution

Following methods can be used in preparation of polimer-clay nanocomposite materials:

5.1 Solution induced intercalation (exfoliation–adsorption method)

In this method, one solubilizes polymer in an organic solvent and the clay is dispersed in the solution, following which either the solvent is evaporated or the polymer precipitated, [8].

Polymer–clay nanocomposite materials, especially those based on polymers with high hydrophilicity, such as poly(vinyl alcohol), poly(ethylene oxide), and poly(acrylic acid), can be produced, [27, 28].

The clay dispersion is not very good; the process is expensive because of the high cost of the solvents required, and health and safety issues, [8].

5.2 Melt intercalation

This is a simple mix-and-heat process, in which the layered silicate, usually organically modified, is mixed with the polymer matrix in the molten state. As compared with exfoliation–adsorption method, it is a versatile and green approach as a wide variety of polymers can be applied and no solvents are needed, [21, 29, 30,31].

The silicates need to be surface treated through the organo-modification prior to introducing in the polymer melt, [8].

The effectiveness of blending will depend on parameters such as the melt viscosity, molecular mass, segmental structure of the polymer, and its softening temperature. The advantages of this approach are its simplicity, effectiveness, and the possibility of using a variety of large-scale formulations. The disadvantage resides in the possibility of thermal degradation of the polymer in the blend [9] .

5.3 In situ polymerization

Monomers/comonomers are polymerized with the presence of original/modified clay via different polymerization mechanisms. This is also often referred to as intercalative or interlamellar polymerization, in which the chain growth is expected to be inside the galleries of the layered silicate. The advantage of this method is that as the polymerization inside the galleries progresses, the clay particles will be gradually swollen and ultimately exfoliated into discrete layers. As a result, this approach can more likely lead to PCN materials with a delaminated structure, [3].

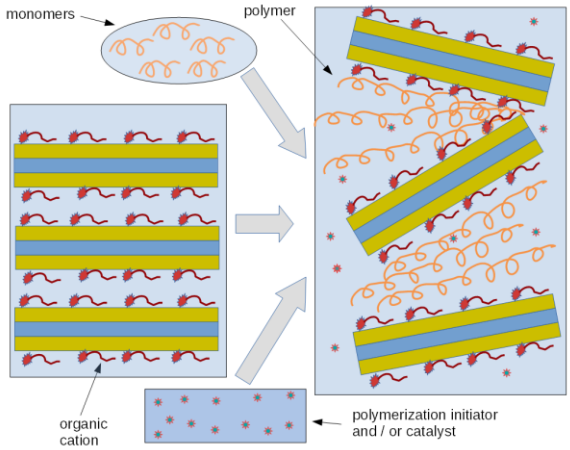

Figure 6. In situ polymerization

The silicate layers are mixed with the monomer together with the polymerization initiator and/or the catalyst, [8].

This is a convenient method for thermoset–clay nanocomposites, (Kumar and Kumbhat, 2016).

This method does not lead to completely exfoliated nanocomposites. It produces aggregated particles with a high silicate content and an intergallery polymer in which the stereostructure may keep a ‘‘memory’’ of its polymerization matrix, [9].

5.4 Electrostatic layer-by-layer self-assembly

In this technique, a clay mineral (‘‘organic’’ or pristine) is deposited from a solution (or suspension) on a smooth substrate (glass, mica, polymer, etc.) by dipping the substrate into a solution of a positively charged polyelectrolyte. Thus a positively charged surface is developed on the substrate on which negatively charged, ordered lamellae of aluminosilicate can be easily deposited by dipping the now positively charged substrate into a suspension of a finely dispersed aluminosilicate preferentially in a highly exfoliated state. An ordered, negatively charged lamellar layer is formed on top of the positively charged polymer. If necessary, the underlying substrate can be disposed off, generating free-standing nanocomposite films. The process of dipping can be repeated and varied to build ordered multilayered systems with several components. This approach to forming organic/inorganic nanocomposites has many advantages—it is simple, economical, and flexible. A variety of high-performance materials can be produced because of the synergistic effects of individual organic and inorganic components, [9].

6. PROPERTIES

Polymer clay nanocomposites can provide significant improvements in various properties of polymers, [9], such as:

- mechanical, [5]
- thermal, [32,33]
- barrier, [16,17]
- and flame retardancy, [34].

The bottom-up assembly of clay/polymer nanocomposite allowed the preparation of a homogeneous, transparent material, where the clay nanosheets have planar orientation. It was found that the stiffness and tensile strength of these multilayer nanocomposites are one order of magnitude greater than those of analogous nanocomposites. Nanoclays are also used as filler in polymers to increase the thermal stability (i.e., raising the degradation temperature) of polymers. This property was first demonstrated in the late 1960s for montmorillonite/PMMA composites. Combining traditional flame retardants with intercalated or, better, exfoliated clays can result in further improvements in flame retardance. Bottom-up assembly of clay/polymer nanocomposite allowed the preparation of a homogeneous, transparent material, where the clay nanosheets have planar orientation. It was found that the stiffness and tensile strength of these multilayer nanocomposites are one order of magnitude greater than those of analogous nanocomposites,[4].

Nanocomposites offer significant barrier properties, as observed by many researchers to date. Corrosion protection requirements of modern aircraft coating systems become increasingly demanding, and environmental as well as performance enhancements are sought. The incorporation of nanoclays into epoxy primers offers opportunities to develop environmentally benign, improved anticorrosion protection, which may provide new applications for nanocomposites. Nanocomposite made of 2.5% SC18 synthetic organoclay and system of Epon 828 airspace epoxy and D400 curring agent has very high barrier resistance for anticorrosion protection and can be cured at room temperature within a week, similar to the Epon 828/curing agent 8290-Y-60 system,[35].

7. APPLICATIONS

Polymer - clay nanocomposites have great potential for applications, ranging from automotive and aerospace to food packaging and tissue engineering, [35].

Airspace epoxy - clay nanocomposite can be used as primer layer for aircraft coating. Both commercially available organoclay (I.30E) and synthetic organoclays (SC6, SC8, SC12, and SC18) are compatible with aerospace epoxy resins such as Shell Epon 862 diglycidylbisphenol-F) with Epi-Cure curing agent W (diethyltoluenediamine),[35].

By Electrostatic layer-by-layer self-assembly variety of film-forming and membrane-forming nanocomposite materials can be obtained, which can be used for the separation of gases and vapors and other barrier applications. It can be used directly in industries for coating various substrates such as cellulose acetate, PET, Nafion™ , etc.,[9].

Some prominent applications include Polypropylene –clays for bodywork with anti-scratch properties; acetal–clays for ceiling lights; Polypropylene –clays for panes of doors; consoles and interior decoration due to esthetics and recyclable and lightness properties; nylon–clays for bumpers with enhanced mechanical and lightness properties; nylon–clays for fuel reservoirs with airtightness properties, [36].

8. CONCLUSION

Mixtures of clay platelets and polymer chains compose a colloidal system. Thus in the melt state, the propensity for the clay to be stably dispersed at the level of individual disks (an exfoliated clay dispersion) is dictated by clay, polymer, stabilizer, and compatibilizer potential interactions and the entropic effects of orientational disorder and confinement. Anisometric dimensions of clay platelets also have implications for stability because liquid crystalline phases may form. The anisometric shape and approximately 1 nm width of the clay platelets dramatically increase the amount of interfacial contact between the clay and the polymer matrix. Thus the clay surface can mediate changes in matrix polymer conformation, crystal structure, and crystal morphology through interfacial mechanisms that are absent in classical polymer composite materials. For these reasons, it is believed that nanocomposite materials with the clay platelets dispersed as isolated, exfoliated platelets are optimal for end-use properties. For example, the high aspect ratio of the exfoliated disk and their nanoscale width provide the greatest potential for solid-state mechanical property enhancement. Furthermore, the probability of defects and inclusions that can compromise the impact strength of composite materials is reduced by homogeneous dispersion at the nanoscale, [15].

The enhanced properties are related to the degree of dispersion and the degree of exfoliation (dispersion of platelets) of the tactoids (clay platelet stacks) in the polymer matrix, [11].

The weight advantage could present a significant impact on environmental concerns. It is estimated that the widespread use of Polymer - clay nanocomposites could save millions of liters of gasoline in one year of vehicle production and reduce related carbon dioxide emissions in huge proportions, [36].

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ODREĐIVANJE EKSPONENTA DEFORMACIONOG OJAČAVANJA ZA LIMOVE OD RAZLIČITIH MATERIJALA

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Apstrakt: *U ovom radu su izloženi rezultati eksperimentalnih istraživanja iz oblasti deformabilnosti, i to iz oblasti deformabilnosti tankih limova. Jedan od ciljeva istraživanja i publikovanja rada je reafirmacija eksponenta deformacionog ojačavanja ("n" faktora) kao vrlo važnog parametra deformabilnosti.*
Obiman eksperiment je zamišljen sa primenom tri metode za određivanje eksponenta deformacionog ojačavanja ("n" faktora) uz korišćenje 8 različitih materijala, čeličnih i materijala od obojenih metala i legura. Metode su bazirane na korišćenju savremene kompjuterizovane eksperimentalne opreme. U eksperimentu su korišćeni sledeći limovi: mesing CuZn37 (debljina 0.8 mm), austenitni nerđajući čelik X5CrNi18-10 (1.5 mm), niskougljenični čelik DC04 (0.8 mm), austenitni nerđajući čelik X5CrNiMo17-12-2 (2.0 mm), opružni čelik 51CrV4 (0.6 mm), Al legura AlMg3 (1.5 mm), Al legura AlCu4Mg1Mn (1.0 mm) i čist bakar Cu-DHP (0.8 mm). Izvršena je procena primenjenih metoda ispitivanja, kao i analiza i procena dobijenih rezultata za ispitivane materijale. Može se zaključiti da su primenjene metode veoma uspešne, i da su vrednosti "n" faktora ispitivanih materijala visoke tačnosti i vrlo upotrebljive u praksi.

Ključne reči: *deformabilnost, limovi, eksponent deformacionog ojačavanja.*

1. UVOD

U tehnološkim procesima plastičnog oblikovanja metala veliki značaj ima procena sposobnosti materijala za takvo oblikovanje, koju je potrebno doneti unapred, tokom projektovanja tehnologije. To važi u opštem slučaju, a naročito za plastično oblikovanje tankih limova kao specifičnih materijala. Upravo pomenuta sposobnost za plastično oblikovanje, kao skup osobina materijala, najčešće se obuhvata opštim terminom deformabilnost. Paralelno egzistiraju i termini: obradivost, plastičnost, duktilnost, istegljivost itd. Bez ulaska u detalje tumačenja značenja termina, što je u sferi jezika, t.j. semantike, može se reći da je u višedecenijskoj praksi preovladao termin deformabilnost (eng. formability) i da se odnosi na oblast plastičnog oblikovanja metala. Elastične defromacije, iako prisutne na početku procesa plastičnog oblikovanja, svojim višestruko manjim intenzitetom nisu ključne i predstavljaju tek smetnju, koju treba imati u vidu.

Procena deformabilnosti uvek iznova dobija na značaju pojavom novih materijala koji uglavnom imaju naglašene visoke vrednosti karakteristika čvrstoće i značajno manju plastičnost.

Na Fakultetu inženjerskih nauka Univerziteta u Kragujevcu (do 2011.g. Mašinskom fakultetu u Kragujevcu) nekoliko decenija se izvode istraživanja vezana za deformabilnost tankih limova. Neke od referenci koje odnose se na konkretnu temu ovoga rada date su u spisku literature ([1], [2], [3], [4], [5], [6]).

Određivanje defomabilnosti obavezno podrazumeva eksperimentalna ispitivanja, iako je moguće koristiti i virtuelnu (numeričku, kompjutersku) procenu preko različitih softvera.

Ispitivanje deformabilnosti može se podeliti na nekoliko oblasti [6]:

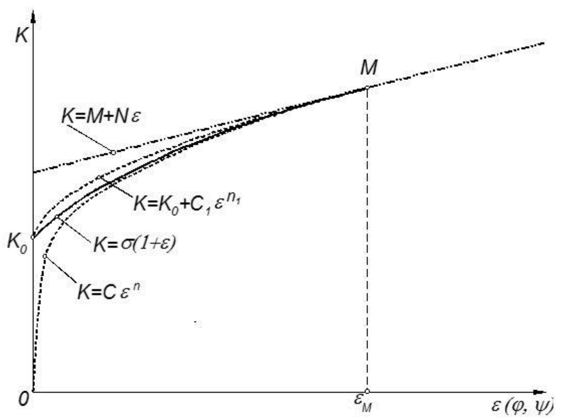
1) osnovni parametri,
2) deformaciono ojačavanje i krive tečenja,
2a) eksponent deformacionog ojačavanja ili "n" - faktor,
3) anizotropija,
3a) koeficijent normalne anizotropije ili "r" - faktor,
4) defleksione pojave,
6) granična deformabilnost,
9) kontaktni problemi, odnosno tribološke pojave.

Izučavanje fenomena deformacionog ojačavanja i procene njegovog uticaja na deformabilnost savremenih materijala je tema različitih istraživanja u svetu od kojih su ovde radi ilustracije navedena samo tri ([7], [8], [9]). Najjednostavniji i najpraktičniji način određivanja intenziteta deformacionog ojačavanja je preko eksponenta deformacionog ojačavanja ili "n" faktora. U ovom radu je izvedeno opsežno ispitivanje 8 različitih limova uz primenu 3 metode određivanja "n" faktora. Cilj je, s jedne strane, proceniti pouzdanost metoda ispitivanja na savremenim materijalima, a s druge, odrediti ovaj značajan parametar i analizirati njegove vrednosti iz aspekta uticaja na defomabilnost.

2. EKSPONENT DEFORMACIONOG OJAČAVANJA

Deformaciono ojačavanje je fenomen koji se javlja kod metala i legura pri ostvarivanju plastičnih (trajnih) deformacija i podrazumeva porast karakteristika čvrstoće sa porastom vrednosti plastične deformacije, uz pad karakteristika plastičnosti. Naročito je izraženo u hladnom stanju i zavisi prvenstveno od vrste i stanja materijala, dok ne zavisi od vrste naponskog stanja. U toplom stanju značajan uticaj ima brzina deformacije. Iz prethodnog bi se dalo zaključiti da je u slučajevima izraženog deformacionog ojačavanja deformabilnost nepovoljnija i obrnuto. Međutim, to nije uvek sasvim tako. Iz ovog razmatranja treba isključiti materijale veoma niske polazne plastičnosti, odnosno veoma krte materijale gde plastično oblikovanje i nije moguće izvesti u nekom značajnijem obimu. Dakle, postoje materijali odlične plastičnosti, međutim ako je kod njih ojačavanje minimalno, javlja se problem neprihvatljivo niske čvrstoće i krutosti gotovih otpresaka. Najbolje je da materijal ima odličnu polaznu plastičnost uz vrlo niske parametre čvrstoće, a da se efektom ojačavanja konačno dobije otpresak sa visokim vrednostima čvrstoće. Nažalost, to je uglavnom teško ostvariti, pa se danas često pribegava oblikovanju specijalnih limova vrlo visoke čvrstoće u toplom stanju.

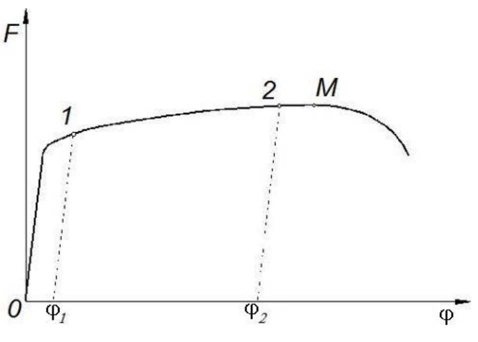
Najbolje praćenje efekta deformacionog ojačavanja ostvaruje se preko krivih tečenja ili krivih ojačanja ([1], [2], [3], [4], [5], [6]). One se određuju eksperimentalno i za limove se uglavnom koristi test jednoosnog zatezanja.



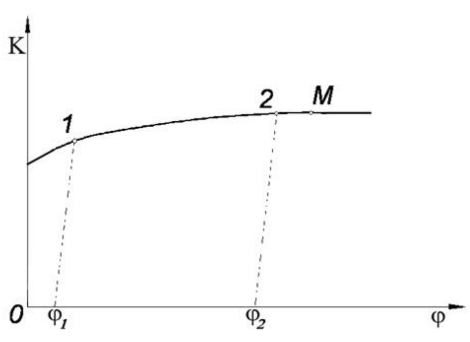
Slika 1. Kriva ojačanja i aproksimacije

Kriva tečenja je uglavnom glatka monotono rastuća kriva linija eksponencijalnog tipa. Na slici 1 eksperimentalna kriva predstavljena je punom linijom, a tri analitičke aproksimacije isprekidanim linijama. Naročito je korisna aproksimacija tipa **K=C·(deformacija)^n**, koja se u zapadnoj literaturi naziva Holomonovim izrazom [7]. Jasno je da eksponent "n" određuje nagib krive i odmah je ustanovljeno da može da posluži kao značajan parametar koji direktno pokazuje intenzitet ojačavanja, a posredno utiče na deformabilnost. Uvidela se dobra korelacija sa parametrom Eriksenovog testa za limove, kao i sa intenzitetom maksimalne homogene plastične deformacije pri jednoosnom zatezanju. U početku se mislilo da "n" faktor može da bude univerzalni parametar deformabilnosti, ali je ubrzo postalo jasno da je njegova direktna primena kao parametra deformabilnosti moguća samo u situacijama oblikovanja limova sa preovlađujućim zatežućim naponima u ravni pri čemu je obod komada potpuno blokiran ili njegovo klizanje veoma otežano ([1], [2]). Ta naponsko-deformaciona shema kod limova je nazvana "razvlačenje" (eng. stretching). U ostalim slučajevima potrebno je kompletnije ispitivanje deformabilnosti. Treba naglasiti veliki značaj "n" faktora i u tim slučajevima, i neizostavno ga treba određivati.

Za ovo eksperimentalno ispitivanje odabrane su tri metode ([3], [6], [10]), ili preciznije, suštinski dve metode pri čemu je prva (sl. 2 i 3) izvedena u dve varijante.



Slika 2. Kriva zatezanja



Slika 3. Kriva ojačanja

Prva metoda za određivanje eksponenta "n" zasniva se na preciznom definisanju dve tačke bilo na krivoj jednoosnog zatezanja (sl. 2), bilo na krivoj tečenja (sl. 3). Tačke isključivo moraju biti u oblasti homogenog deformisanja, ali što bliže početku i kraju te oblasti. Kad su tačke i odgovarajuće vrednosti definisane lako se dolazi do izraza za "n" :

$$n = \frac{ln\frac{K_2}{K_1}}{ln\frac{\varphi_2}{\varphi_1}} = \frac{ln\frac{F_2 l_2}{F_1 l_1}}{ln\frac{ln\frac{l_2}{l_0}}{ln\frac{l_1}{l_0}}} \qquad (1)$$

Treba primetiti da zapravo i nije potrebna celokupna kriva (bilo zatezanja, bilo ojačanja) nego samo odgovarajuće vrednosti (sile F_1 i F_2, dužine l_1 i l_2). Ipak, veoma je korisno uraditi kompletan test zatezanja i zbog drugih karakteristika, osim "n" faktora.

Druga varijanta prve metode podrazumeva zatezanje ne do kidanja epruvete, nego samo do postizanja maksimalne sile, što predstavlja kraj homogenog deformisanja. Zbog toga druga varijanta predstavlja jednu vrstu ponavljanja i provere.

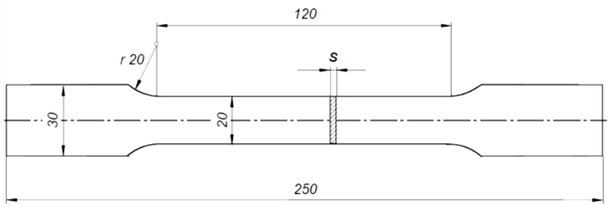
Treća metoda zasniva se na jednoosnom zatezanju specijalne stepenaste epruvete koja ima dve merne zone različitih širina (u ovom slučaju 20 i 22 mm). Slično prvoj metodi, pravi se odnos deformacionih otpora, samo što se ovde umesto vrednosti za tačke sa dijagrama uzimaju vrednosti za užu i širu zonu epruvete. Konačan izraz za "n" faktor je:

$$n = \frac{ln\frac{b_{02} l_{02} l_1}{b_{01} l_{01} l_2}}{ln\frac{ln\frac{l_1}{l_{01}}}{ln\frac{l_2}{l_{02}}}} \qquad (2)$$

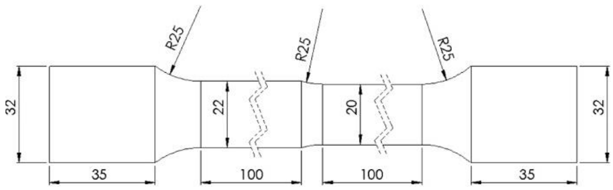
Odmah se zapaža da u izrazu (2) nema vrednosti sila nego figurišu samo dimenzije epruvete (l_0 i b_0) i izduženja obe zone (l_1, l_2). Zato nije potrebno snimati dijagram. Međutim, eksperiment je veoma zahtevan. Epruveta je složenije geometrije i ispitivanje se obično izvodi u 2 ili 3 faze. Prekid zatezanja, rasterećenje, skidanje i ponovo nameštanje epruvete može predstavljati priličnu teškoću kod velikog broja uzoraka. Problem predstavlja i potreba prethodnog definisanja stepena deformisanja za svaku fazu. Pogodno je da on bude što veći. Jedini način je prethodna eksperimentalna proba. Konačna vrednost "n" faktora je srednja vrednost za sve faze ispitivanja.

2. EKSPERIMENTALNA ISPITIVANJA

Plan eksperimenta predviđa ispitivanje limova od osam različitih materijala po tri metode koje su objašnjene. Uključujući pripremne probe, ponavljanja i konkretna ispitivanja bilo je potrebno oko 50 epruveta. Za prve dve metode koristi se standardna epruveta sa sl. 4.



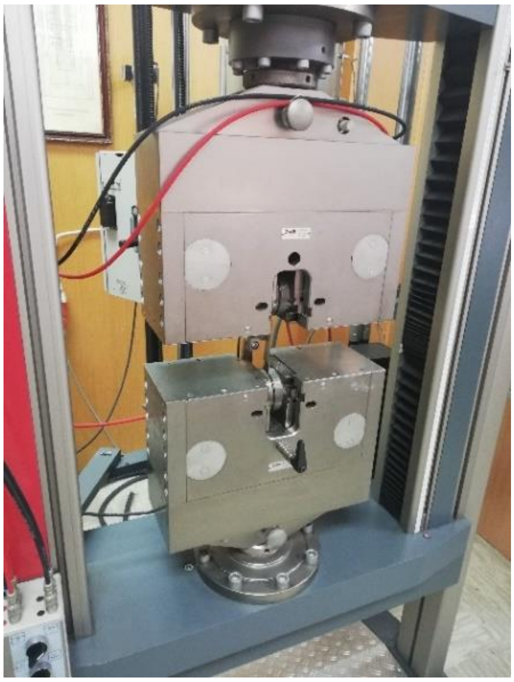
Slika 4. Epruveta za metode 1 i 2



Slika 5. Epruveta za metodu 3

Korišćeni su sledeći limovi: 1) CuZn37 (CW 508L), 2) DC04 (Č0148), 3) X5CrNi18-10 (Č4580), 4) X5CrNiMo17-12-2 (Č4574), 5) 51CrV4 (Č4830), 6) AlMg3, 7) AlCu4Mg1Mn (2024 T3 AIR) i 8) CuDHP (DVP 1 Cu.38). Zbog ograničenog prostora detaljnije će biti prikazani rezultati za odabrane materijale (pod rednim brojem 1, 4 i 7). Izrada epruveta vršena je na mašini za sečenje vodenim mlazom (sl. 6) u kompaniji "Sloboda" Čačak. Dorada mernih zona je vršena brušenjem. Neposredna ispitivanja jednoosnim zatezanjem vršena su na Fakultetu inženjerskih nauka Univerziteta u Kragujevcu u Laboratoriji za obradu deformisanjem i mašinske materijale na kompjuterizovanom mernom sistemu za ispitivanje materijala Zwick-Roell Z100 (sl. 7). Merni opseg sile je 0-100 kN, brzina deformisanja 10 mm/min i sobna temperatura ispitivanja.

Slika 6. Izrada epruveta vodenim mlazom



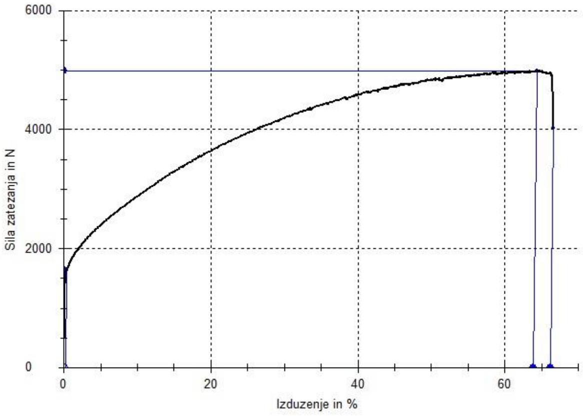
Slika 7. Merni sistem za ispitivanje materijala

3. REZULTATI EKSPERIMENTALNIH ISPITIVANJA

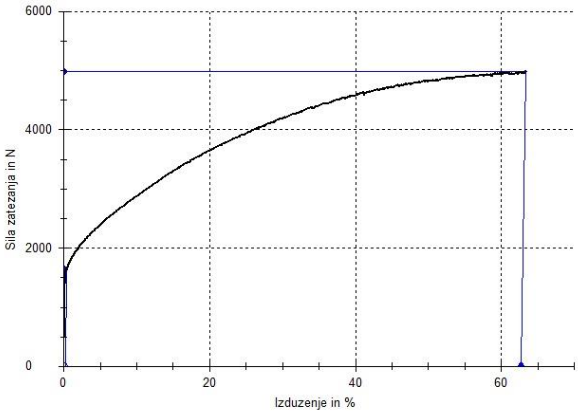
Kako je napomenuto biće prikazani rezultati za sledeće limove: 1) CuZn37 (CW 508L), 4) X5CrNiMo17-12-2 (Č4574) i 7) AlCu4Mg1Mn (2024 T3 AIR). U tabeli 1 date su osnovne karakteristike lima 1). Zatim na sl. 8 sledi dijagram zatezanja za primenu prve metode. Na sl. 9 je dijagram zatezanja za drugu metodu. Ukupan pregled svih rezultata dat je u tabeli 4, a posle dijagrama za konkretan materijal biće dati rezultati "n" faktora za svaku metodu.

Tabela 1. Osnovne karakteristike materijala

CuZn37 - debljina lima 0.8 mm						
	L_0 mm	S_0 mm^2	$R_{P0,2}$, MPa	R_m , MPa	Ag %	A %
Merenje do kidanja epruvete	120.00	16.08	101.80	309.92	63.90	66.2
Merenje do maksimalne sile	120.00	16.08	101.66	309.61	62.78	



Slika 8. Kriva zatezanja za lim od CuZn37



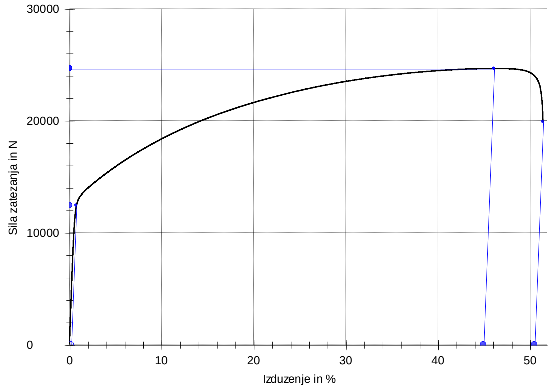
Slika 9. Druga kriva zatezanja za lim od CuZn37

Vrednosti "n" faktora za lim od mesinga CuZn37 su: po prvoj metodi 0,521; po drugoj metodi 0,455 dok su po trećoj metodi rađene 3 faze kojima respektivno odgovaraju sledeće vrednosti: 0,452; 0,535; 0,558. Detalji merenja i izračunavanja vrednosti mogu se naći u [10].

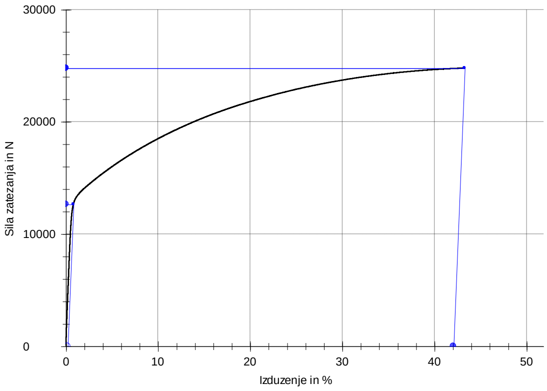
Tabela 2. Osnovne karakteristike materijala

X5CrNiMo17-12-2; 2 mm						
	L_0 mm	S_0 mm^2	$R_{p0,2,}$ MPa	$R_{m,}$ MPa	Ag %	A %
Do kidanja epruvete	120.0	40.7	305.4	605.9	45.0	50.5
Do maksimalne sile	120.0	40.7	310.1	608.8	42.1	

U tabeli 2 su date osnovne karakteristike lima od austenitnog nerđajućeg čelika X5CrNiMo17-12-2, debljine 2 mm. Na slikama 10 i 11 su odgovarajući dijagrami zatezanja.



Slika 10. Kriva zatezanja za lim X5CrNiMo17-12-2



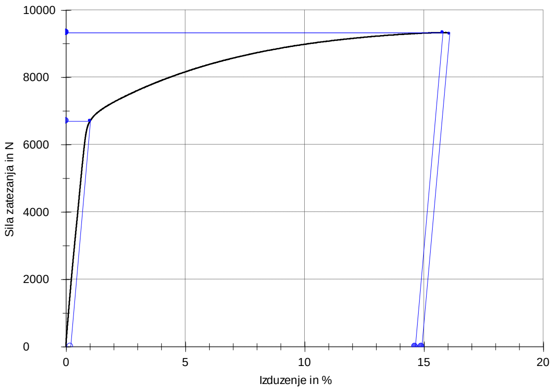
Slika 11. Drugi dijagram za lim X5CrNiMo17-12-2

Vrednosti "n" faktora za lim od čelika X5CrNiMo17-12-2 su: po prvoj metodi 0,480; po drugoj metodi 0,463 dok su po trećoj metodi rađene 3 faze kojima respektivno odgovaraju sledeće vrednosti: 0,219; 0,376; 0,400.

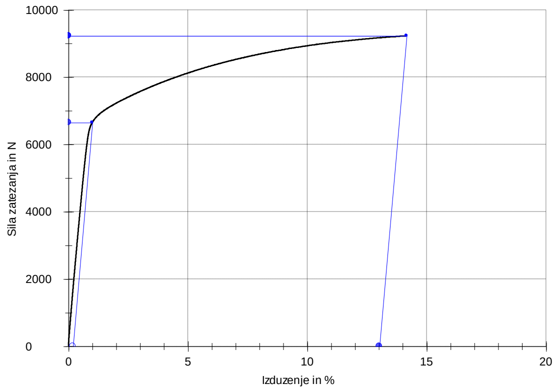
Tabela 3. Osnovne karakteristike materijala

AlCu4Mg1Mn; 1mm						
	L_0 mm	S_0 mm^2	$R_{p0,2,}$ MPa	$R_{m,}$ MPa	Ag %	A %
Do kidanja epruvete	120	20.1	334	465.1	14.6	14.9
Do maksimalne sile	120	20.1	331.8	460	13.0	

U tabeli 3 su date osnovne karakteristike lima od luminijumske legure AlCu4Mg1Mn, debljine 1 mm. Na slikama 12 i 13 su odgovarajući dijagrami zatezanja



Slika 12. Kriva zatezanja za lim AlCu4Mg1Mn

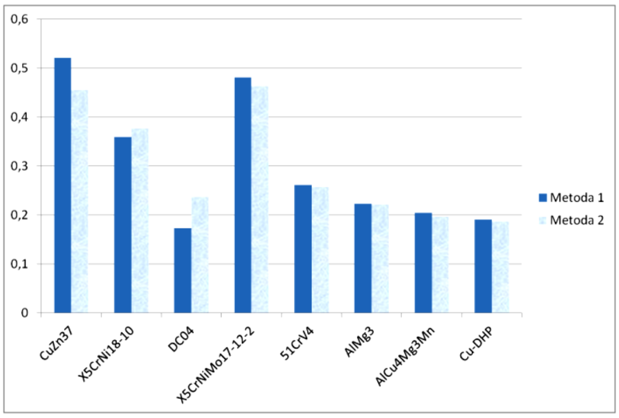


Slika 13. Drugi dijagram za lim AlCu4Mg1Mn

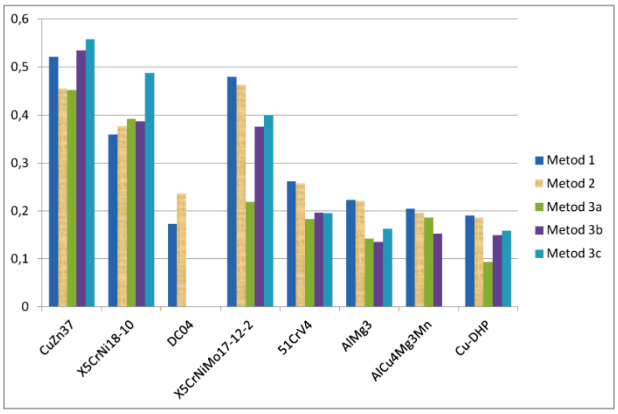
Vrednosti "n" faktora za lim od aluminijumske legure AlCu4Mg1Mn su: po prvoj metodi 0,204; po drugoj metodi 0,196 dok su po trećoj metodi rađene 2 faze kojima respektivno odgovaraju sledeće vrednosti: 0,136 i 0,152.

Tabela 4. Pregled ukupnih rezultata

1) Čelik DC04 (Č0148) - "n" faktor - Zbirni rezultati			
Prva metoda	0,173		
Druga metoda	0,236		
Treća metoda	/	/	/
2) Čelik X5CrNi18-10 (Č4850) - "n" faktor - Zbirni rezultati			
Prva metoda	0,359		
Druga metoda	0,377		
Treća metoda	0,392	0,387	0,488
3) Čelik X5CrNiMo1712-2 (Č4574) - "n" faktor - Zbirni rezultati			
Prva metoda	0,480		
Druga metoda	0,463		
Treća metoda	0.219	0.376	0.400
4) Čelik 51CrV4 (Č4830) - "n" faktor - Zbirni rezultati			
Prva metoda	0,261		
Druga metoda	0,257		
Treća metoda	0.183	0.196	0.195
5) Legura AlMg3 - "n" faktor - Zbirni rezultati			
Prva metoda	0,223		
Druga metoda	0,221		
Treća metoda	0.142	0.135	0.163
6) Legura AlCu4Mg1Mn (2024 T3 AIR) - "n" faktor - Zbirni rezultati			
Prva metoda	0,204		
Druga metoda	0,196		
Treća metoda	0.136	0.152	/
7) Bakar Cu-DHP (DVP 1 Cu. 38) - "n" faktor - Zbirni rezultati			
Prva metoda	0,190		
Druga metoda	0,186		
Treća metoda	0.093	0.149	0.159
8) Legura CuZn37 - "n" faktor - Zbirni rezultati			
Prva metoda	0,521		
Druga metoda	0,455		
Treća metoda	0.452	0.535	0.558



Slika 14. Pregled rezultata za prvu i drugu metodu



Slika 15. Pregled rezultata za sve metode

U tabeli 4 i na slikama 14 i 15 dat je pregled svih eksperimentalnih rezultata i oni se mogu upoređivati i tumačiti u dva pravca. Prvi se odnosi na procenu validnosti samih metoda određivanja "n" faktora, a drugi na procenu intenziteta ojačanja ispitivanih materijala.

Kako je pomenuto, metode 1 i 2 se razlikuju samo u tehničkom smislu i slaganje rezultata je veoma dobro, osim za lim od čelika DC04 gde je, najverovatnije, došlo do zamene uzoraka.

Primetne razlike u vrednostima za metodu 3 uzrokovane su ostvarenim stepenima deformacije u pojedinim fazama. Ako je taj stepen bio niži od mogućeg dobijala se i niža vrednost. Kod materijala velike plastičnosti razlike su minimalne. Definisanje maksimalnog stepena deformacije za pojedine faze je nedostatak ove metode. Bilo bi potrebno izvesti probna ispitivanja samo sa tim ciljem što često nije moguće. Iako je u metodi 3 sadržana sjajna ideja stepenaste epruvete uz pojednostavljivanje testa, ipak je prva metoda (sa svojim varijetetom ovde nazvanim drugom metodom) pokazala izuzetnu pouzdanost i tačnost.

Ako se razmatra osobina deformacionog ojačanja ispitivanih materijala pogodno ih je podeliti na grupe. Odmah treba izdvojiti niskougljenični čelični lim DC04 poznat po povoljnoj deformabilnosti i vrednosti "n" faktora (oko 0,25) što pokazuje dobar efekat deformacionog ojačavanja.

U istu grupu je moguće svrstati austenitne nerđajuće čelične limove (X5CrNi18-10 i X5CrNiMo17-12-2) koji imaju solidnu deformabilnost uprkos relativno velikoj početnoj čvrstoći, uz izražen efekat ojačavanja sa vrednostima "n" faktora do oko 0,45. Međutim, zbog viših vrednosti čvrstoće ovi materijali zahtevaju deformacione sile i dvostruko veće u odnosu na lim DC04.

Uzorci lima 51CrV4 su najverovatnije u žarenom ili normalizovanom stanju što pokazuju relativno niske vrednosti zatezne čvrstoće. Vrednost "n" faktora je povoljna iako ovaj materijal nije namenjen za zahtevnije procese plastičnog oblikovanja.

Preostale su legure obojenih metala i čist bakar. Treba napomenuti da se ovi materijali koriste u veoma velikom broju stanja koja su posledica prethodnog deformisanja ili termičkog tretmana, i da ova stanja suštinski određuju mehaničke karakteristike, deformabilnost i druge osobine. Stanje konkretnog lima CuZn37 je vrlo plastično. Izduženje pri kidanju je preko 60%, a "n" faktor ima vrednost oko 0,5 što označava intenzivno ojačavanje. Aluminijumske legure AlMg3 i AlCu4Mg1Mn imaju niže vrednosti "n" faktora (oko 0,2) što je sa gledišta ojačavanja relativno prihvatljivo, ali je poznata relativno nepovoljna plastičnost, odnosno deformabilnost ovih materijala.

4. ZAKLJUČAK

Obimnim eksperimentom testirane su 3 metode određivanja eksponenta deformacionog ojačavanja ("n" faktora) u hladnom stanju. Može se zaključiti da su metode 1 i 2 vrlo pouzdane i da omogućavaju tačne rezultate koji se mogu smatrati referentnim. Metoda 3 je osetljivija i zahteva vrlo tačnu izradu epruvete složenije geometrije uz potrebu prethodnih probnih ispitivanja. Konačno, može se zaključiti da su sve tri metode upotrebljive, pri čemu treba dati prednost metodi 1.

Da bi se testirale pomenute 3 metode iskorišćeno je 8 materijala: 4 čelična lima i 4 lima od obojenih metala. Karakteristike ovih materijala su potvrđene, ali se može zaključiti da treba obratiti posebnu pažnju na stanje materijala pored hemijskog sastava, pre svega kod obojenih metala i legura.

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Eksperimentalna istraživanja prezentirana u ovom radu delimično su finansirana sredstvima Ministarstva za prosvetu, nauku i tehnološkog razvoja Republike Srbije preko projekta TR 34002, na čemu su autori veoma zahvalni.

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STRAIN HARDENING EXPONENT DETERMINATION FOR DIFFERENT SHEET METALS

Abstract: *In this paper presented were results of experimental investigations from the field of formability, especially sheet metals and alloys formability at room temperature.*
One of main goals in this work was reaffirmation of strain hardening exponent ("n"- factor) like very important formability parameter.
Extended experiment was planed with three methods of "n"- factor determination and application of this methods on eight different ferrous and nonferrous metals and alloys. Methods were based on using of modern computerized equipment. Chosen were following sheet metals: brass CuZn37 (thickness 0.8 mm), stainless austenitic steel X5CrNi18-10 (1.5 mm), low carbon steel DC04 (0.8 mm), stainless austenitic steel X5CrNiMo17-12-2 (2.0 mm), spring steel 51CrV4 (0.6 mm), alloy AlMg3 (1.5 mm), alloy AlCu4Mg1Mn (1.0 mm) and pure copper Cu-DHP (0.8 mm).

Evaluated was experimental methods for "n"- factor determination as well as obtained values for investigated materials. Can be conclude that applied methods were very accurate and successful, and obtained "n"- factor values for tested materials were very useful for understanding hardening phenomena.

Keywords: *formability, sheet metals, strain hardening exponent.*

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SYNTHESIS AND APPLICATION OF NANOMATERIALS IN TECHNICS

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Abstract: *Nanotechnology provides highly promising potential for the replacement of conventional energy sources such as fossil and nuclear fuels and renewable energy sources like geothermal energy, sun, wind, water or biomass. Nanotechnology is applied in various electrical components such as nanowires, insulators, transformers and dielectric fluids with possible future applications. Nanotechnology goes for machines under the nanometer scale. Applications of nanotechnology can be implemented using the synergistic mechatronics innovation. New trends in Micro-nano mechatronics are in material science, measurement, control, manufacturing and their applications in biomedical engineering. Synthesis of nanosized particles was performed through the thermal decomposition of the droplet generated by ultrasonic transduction. Results of synthesis of nanosized powder confirm spherical morphology, easy preparation of the powder with the complex composition, relatively homogeneous composition, easy manipulation of particle size, narrow particle size distribution, and a lot of different application of prepared nanosized particles. We concluded that ultrasonic spray pyrolysis is very successful method for synthesis of nanosized powders, which are used in mechatronics and electrotechnics.*

Keywords: *nanomaterials, synthesis of powders, ultrasonic spray pyrolysis, electrotechnics, mechatronics*

1. INTRODUCTION

Nanoparticle synthesis through aerosol routes such as ultrasonic spray pyrolysis enables the generation of fine, submicronic to nanoscale, either single or complex, powders from a variety of precursor solutions. The process includes formation of discrete droplets of precursor solution in form of an aerosol and the control over their thermally induced decomposition and phase transformation. Synthesis of metallic, oxidic and composite nanosized and submicronic particles by ultrasonic spray pyrolysis was mostly described in studies by Stopic et al. [1 -3]. The influence of different parameters: temperature, residence time, ultrasonic frequency, and concentration of solution on particle morphology was explained in details. Then, J. Bogovic [4] has explained the mechanism of the metal/oxide core-shell Ag/TiO_2 and Au/TiO_2 nanoparticle formation via one-step ultrasonic spray pyrolysis (USP) by establishing a new model. The general knowledge on the standard "droplet-to-particle" (DTP) mechanism, nucleation, and growth processes of noble metals, as well as physical and chemical properties of core and shell materials and experimental knowledge, were utilized with the purpose of the construction of this new model.

Spherical nano-crystalline Co–Fe and Ni-Fe particles were produced by ultrasonic spray pyrolysis (USP) of aqueous solutions of cobalt chloride, nickel chloride and iron chloride followed by thermal decomposition of generated aerosols in hydrogen atmosphere as reported by Gürmen et al. [5, 6]. The effect of the precursor solution in the range of 0.05 M, 0.1 M, 0.2 M and 0.4 M on the morphology and crystallite size of the Co–Fe and Ni-Fe alloy particles are investigated under the conditions of 1.5 h running time, 800°C reduction temperature, and 1.0 l/min H_2 volumetric flow rate. In order to increase to particle production scale up of ultrasonic spray pyrolysis was perfomed using special equipment with five reaction tube, as mentioned by Alkan et al. [7]. The five generators are connected with five parallel transport tubes inside the reaction furnace for hetero-aggregates formation with a length of 4.5 m. Separate inlets for the reaction gas are positioned at the appropriate place for each transport tube. The tubes lead to the collection system with a reservoir for hetero-aggregates suspensions and an electrostatic filter for collecting residual particles, which were not dispersed in the suspension.

Electrical and mechatronics engineers using nanotechnology concept and make nanostructured value-added products with high superior qualities. Nanomaterials have unique, beneficial chemical, physical and mechanical properties and these properties are used for a wide range of applications in the industrial environment [8]. These applications include, but are not limited to the following; photovoltaic applications (Solar Cells), automotive and chemical industry, electrical engeneering, mechatronics (sinergy of mechanic, electronic and software engineering).

The main aim of this paper is not only to explain ultrasonic spray pyrolysis as synthesis method for preparation of metallic, oxidic and composite powders, but also to offer an application of nanosized powers in technics.

2. ULTRASONIC SPRAY PYROLYSIS SYNTHESIS

2.1. Procedure

Synthesis of metallic, oxidic and composite nanosized powder was performed by one step Ultrasonic Spray Pyrolysis which means all precursors solutions of initial precursors were atomized in an aerosol generator in an ultrasound field of frequency 1.75 MHz (PRIZMNano, Kragujevac, Serbia), as shown at Figure 1.

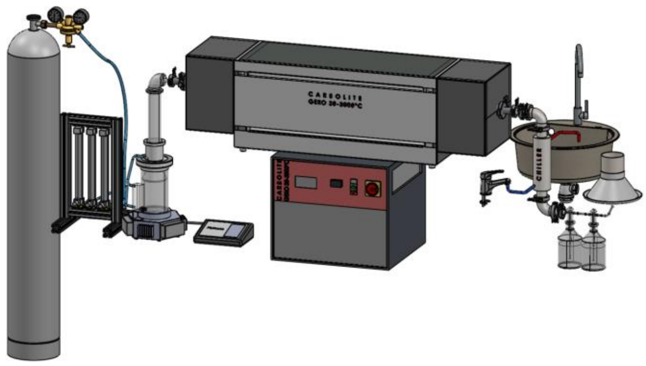

Figure 1. Newest ultrasonic spray pyrolysis lab-scale horizontal equipment (max synthesis temperature- 1300°C); main parts: gas flow regulation; ultrasonic aerosol generator; furnace with the wall heated reactor; quenching system with collection bottles

The formed aerosol droplets were transported with a carrier gas to a reactor in order to obtain nanosized particles after an evaporation, precipitation, chemical transformation and sintering of particles. The collection of particles was performed in two bottles with water or alcohol.
The most important parameters for nanoparticle synthesis are: concentration of solution, temperature, residence time, ultrasound frequency, and surface tension and viscosity of solution.
A disadvantage if process is very small production rate (few grams per hour). Because

of the small residence time in USP, the synthesis of SiC, ZrW_2O_8 and WC-Co particles is very difficult.

2.2. Results

Using ultrasonic speay pyrolysis (USP) method enables preparation of metallic, oxidic and composite powders from different water sollution of metallic powders [9]. The morphology of particles (spherical and cylindrical) leads to different application of powders. The nanoparticles with magnetic characterists are mostly used in technics.

The submicron powders based on mixture of Nd_2O_3, Dy_2O_3 and Pr_2O_3 were prepared during hydrometallurgicall treatment of spent NdFeB-magnets and subsequent ultrasonic spray pyrolysis of water solution, based on nitrate, as shown at Figure 2.

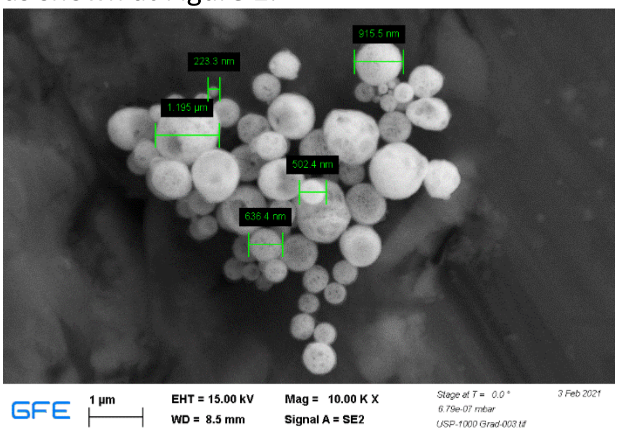

Figure 2. Oxidic powders obtained by USP

Synthesis of metallic powders was successfully performed for Cu (as shown at Fig. 3), what have very good conductive and antibacterial properties.

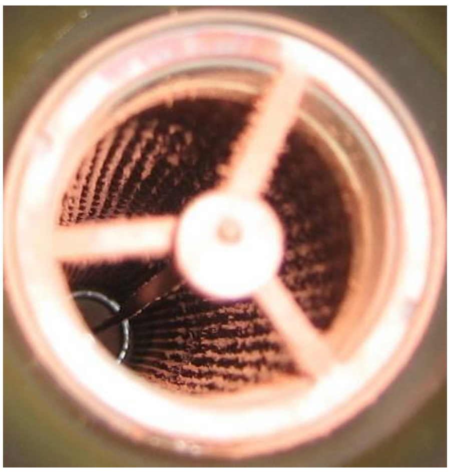

Figure 3. Nanosized copper produced by USP

3. APPLICATION OF NANOMATERIALS

General application of nanomaterials is medicine, textile, food, electrical and electronic industry, environmental protection and energy sources, as shown at Figure 4.

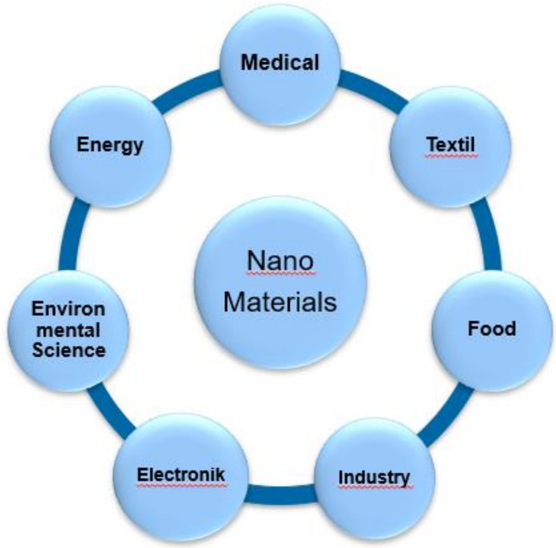

Figure 4. Application of nanomaterials

Electrical engineering material science is associated with the study of composition, structure, characterization, processing, properties, application and performance of electrical engineering materials**.** The following application is mostly found:

Conductors: silver, copper, gold, aluminum

Semiconductors: germanium, silicon, GaAs

Magnetic materials – iron, cobalt, silicon steel, AlNiCo, NdFeB.

Neodymium(III) oxide is used to dope glass, including sunglasses, to make solid-state lasers, and to colour glasses and enamels. Neodymium-doped glass turns purple due to the absorbance of yellow and green light, and is used in welding goggles. Because of dysprosium's high thermal-neutron absorption cross-section, dysprosium-oxide–nickel cermets are used in neutron-absorbing control rods in nuclear reactors.

4. CONCLUSION

Applications of nanotechnology in electric engineering is reality and big demand (magnets, conductor, semiconductor, insulator, transformer). Rare earth elements based on

Nd, Dy and Pr are mostly used in magnetic materials in automotive industry and new energy sources. Synthesis of nanocopper for conductors and oxidic powders of rare earth elements was performed through the thermal decomposition of the droplet generated by ultrasonic transduction. Collection of nanosized powders was successfully performed using an electro-filter in USP-synthesis.

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TEACHING ABOUT POLYMER AND HYBRID NANOCOMPOSITIES IN ENGINEERING DEGREE COURSES AT TU-GABROVO, BULGARIA

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Abstract: *This paper aims to share experience about specialized engineering training in the field of nanocomposites under the project "Modern educational technologies in language and specialized training", developed at UCRT of TU-Gabrovo, BG. Learning material from students' training in specialized disciplines is presented and implemented research developments of the team working on the topic are cited. Educational and methodical materials have been developed and presented. Modern polymer and hybrid nanocomposites and manufacturing methods are considered, and examples of their application are given.*

Keywords: *Modern educational technologies, specialized training, polymer and hybrid nanocomposites*

1. INTRODUCTION

The main goal of the specialized engineering training is to acquaint the students with the modern achievements of the technique, of which the nanocomposites are an undoubted part. This topic is one of the most frequently introduced new disciplines in practice. The training at the Technical University of Gabrovo, BG is carried out mainly in the specialties for Bachelor's degree in Mechatronics, Technology of Materials and Materials Science, Industrial Management and others, as well as in Mechatronics for Master's degree [1]. In the developed curricula and characteristics of the disciplines "Advanced technologies in mechatronics" and "High energy technologies" (elective) for the specialty "Mechatronics" (EQD bachelor) In 2017 and "Micro- and nanomechatronics and technologies" for EQD master from 2016 are set and lectures are held on: materials in micro- and nanomechatronics, changing the properties of materials and types of nanocomposites [2, 3]. Their physical and mechanical properties are studied in exercises [4]. The research work includes the project [5], diploma theses, applied works and is presented in [6, 7, 8, 9, 10, 11, 12, 13 and 14].

2. MAIN HEADING

<u>Definition</u> - Nanocomposites are solid multiphase materials in which one of the components has at least one size less than 100 nm. In the scientific publication "Nanocomposite Science and Technology" (Wiley-VCH, 2003), nanocomposite is defined as multicomponent solid materaial, where one of the components in one, two or three dimensions has a size of not more than 100nm. The term "nanocomposites" also means structures consisting of many

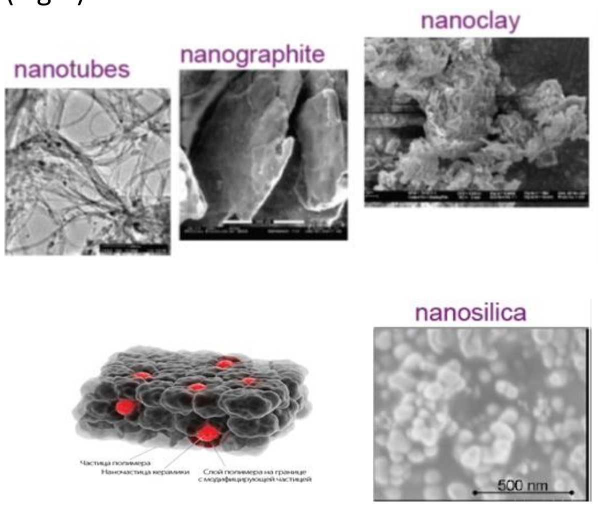
repeating components - layers (phases), with the distance measured in tens of nanometers [15, 16].

The mechanical characteristics of nanocomposites differ from conventional composites due to the extremely high volume ratio of the reinforcing phase. The reinforcing material may consist of particles (e.g. minerals), sheets (e.g. expanded mass) or fibers (e.g. carbon nanotubes). The surface area between the matrix and the reinforced phase is usually one order of magnitude larger than with conventional composite materials. The reinforced phase can be divided analogously to the nanomaterials into 3 groups: nanoparticles (0-D in size and distribution), nanotubes (1-D) and nanolayers (2-D). For the mechanical properties, the changes in the modulus of elasticity and tensile strength strongly depend on the degree of interaction between the particles and the polymer.

The development of materials based on superlattices can be considered as a new direction in materials science - crystal engineering. It leads to the discovery of new physical properties and to the discovery of wide possibilities for application. The composition of the materials on the physical and mechanical properties is essential on the properties of the nanocomposites. The content of impurities or components forming phases with a covalent bond (saturated, solid bonding adjacent atoms) affects the hardness, brittleness, reduction of ductility, etc. The general approach to increase the strength is optimization of the composition, ensuring structural and chemical homogeneity through crystallites, formation of additional fine phases for filling the spaces in the crystal lattice, modification (saturation) of the surface layer by chemical-thermal treatments and development of composite materials based on and in combination of different matrices and a clear volume or weight ratio of the ingredients. In this way, the properties of modern nanocomposites are determined on the basis of a number of variables, especially matrices. From this point of view, they are subdivided into nano-composites with ceramic matrix, metal matrix, polymer and hybrid structure. The subject of this publication are modern polymer and hybrid nanocomposites.

2.1. Polymer nanocomposites

Polymer-matrix nanocomposites consist of a matrix composed of a polymeric material (Fig.1).



1 2 3

Figure 1. Polymer matrix nanocomposites [17]

Legende: 1-polymer particle, 2-nanoparticle ceramics, 3-polymer layer at the interface with the modifying particles.

As a matrix, the nanocomposites use polypropylene, polystyrene, polyamide or nylon, and nanocomponents with particles of alumina or titanium or silicon or carbon nanotubes and fibers. They are made of thermoplastic, thermosetting and elastomers or polymers, reinforced with 2-5% layers of layered silicates, which lead to the same effect that is obtained at 40% reinforcement in classical composites, as well as increased fire resistance. Thermoplastic composites are plasticized when the temperature reaches above the crystallization temperature Tg and can be formed upon cooling (Fig. 2), this process can be repeated with recyclability. Thermosetting materials remain constant after crosslinking above the temperature Tg and cannot be re-molded by plasticizing, but must be processed during the crosslinking process. Elastomeric resins are slightly cross-linked polymer systems and have intermediate properties between the previous two types. They are developed as polymers reinforced with nanoparticles, which are made of ceramics, glue or especially carbon nanotubes with controlled dispersion by sound, chemical (polymerization) or mechanical treatment (Fig. 3). Hierarchically structured and self-assembled polymer composites are the last species in this group.

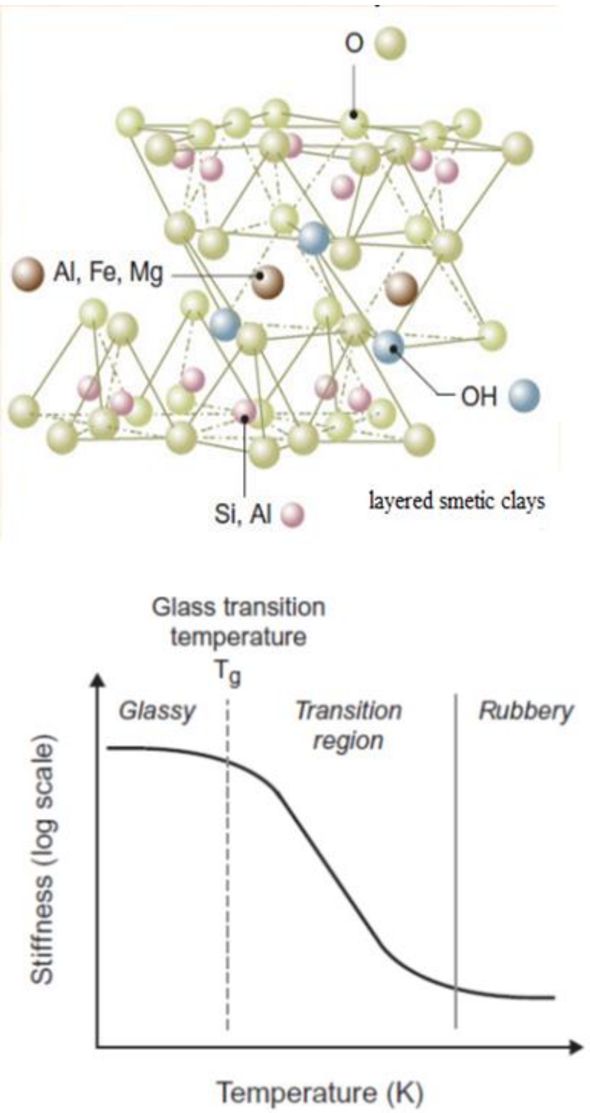


Figure 2. a). Layered silicates as 2D nanocomposites b). Plasticization diagram [17]

Methods for the production of layered silicate composites (nanosin/glue) are described in detail in [15]:

- dissolving the silica with a solvent;
- on-site polymerization;
- insertion of molten polymer.

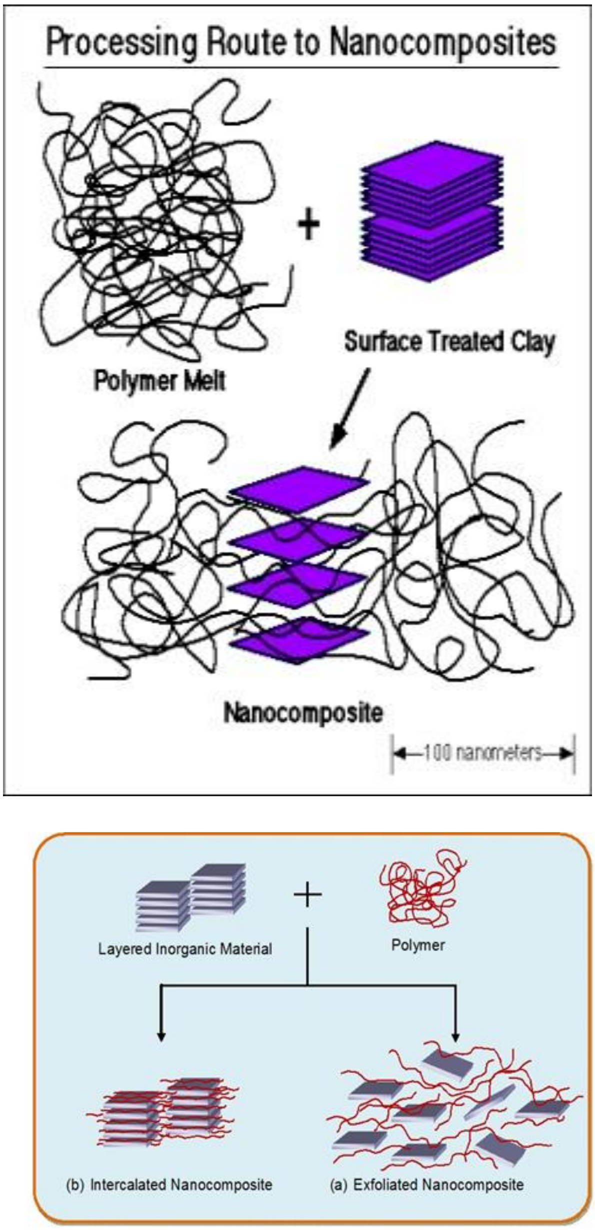


Figure 3. Methods for development of polymer nanocomposites

The advantages of nanocomposites with a polymer matrix are (Fig. 4):

- Increased strength (including between layers), stiffness and toughness;
- Reduced permeability to gases and liquids;
- Increased thermal resistance and fire resistance;
- Chemical resistance;
- Better surface quality;
- Improving the optical properties;
- Low specific weight.

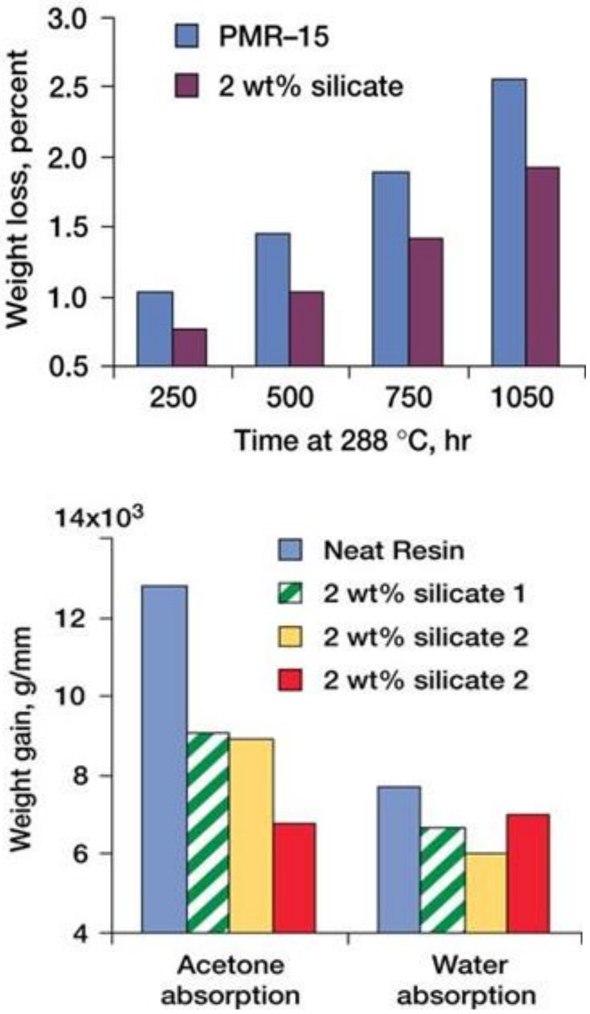


Figure 4. a). Comparison of weight loss in pure polymer and nanocomposite at high temperature;
b). Comparison of water and acetone uptake from pure polymer and nanocomposite

Polymer matrix nanocomposites also include fiberglass. Fiberglass is a composite material; composed of glass fibers and a polymeric binder. Glass fibers are usually woven in the form of a fabric, and thermosetting or thermoplastic polymers are used as a binder. Fiberglass is a light and extremely strong material. The ability to be made in various shapes and colors, as well as the high resistance to weathering and chemicals, makes it suitable for the manufacture of all kinds of applications and sizes of products ranging from small details to ship hulls (Fig.5).

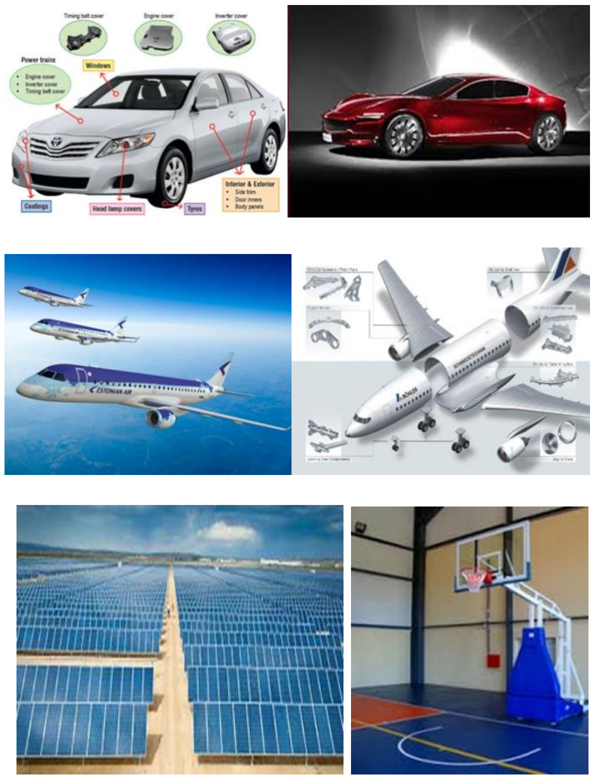


Figure 5. Application of fiberglass

2.2. Hybrid composites

Consolidated or bonded materials are layers, coatings or compact molecules of metals, alloys and compounds obtained by the methods of powder metallurgy, intense plastic deformation, controlled crystallization from the amorphous state and the various techniques for applying layers and coatings. Those molecules are embedded in plastics in order to increase their barrier and mechanical properties. These include organic fibers reinforced with carbon nanotubes, carbon fibers with "grafted" nanotubes, combined composites with SiC fabric, new polymer resins such as cyanate esters and others. Regarding composition, in addition to the matrix, they are frame (interpenetrating) and one-component / partially consolidated poly-crystals. The latter are nanoceramics obtained after forming, pressing and firing non-metallic powders with a particle size of less than 100 nm. It is divided into structural and functional ceramics. There are also nanoclusters - an element, network or ensemble of atoms, molecules or ordered particles (ions) in a specific area-agglomerate, which is obtained by fragmentation of a macroscopic object, layer or nanostructuring. Supermolecular materials are nanostructures obtained as a result of the so-called non-covalent synthesis with the formation of weak Van der Waals bonds between molecules and their ensembles (related formations). Composite hybrid materials are increasingly used due to the changed variety of properties, as well as the fact that they constantly meet the growing requirements of different users (Fig. 6).

Future structures with nanocomposites:

- "intelligent" composites and materials with built-in sensors, monitoring the "health" of their structure;
- transparent structures with built-in electronic displays and nanocrystals;
- “active” structures and biochips;
- micromechanical elements with application in mechatronics for prototyping of details by 3D printing;
- coatings reinforced with carbon nanotubes;
- hybrids that contribute to the improvement of food packaging.

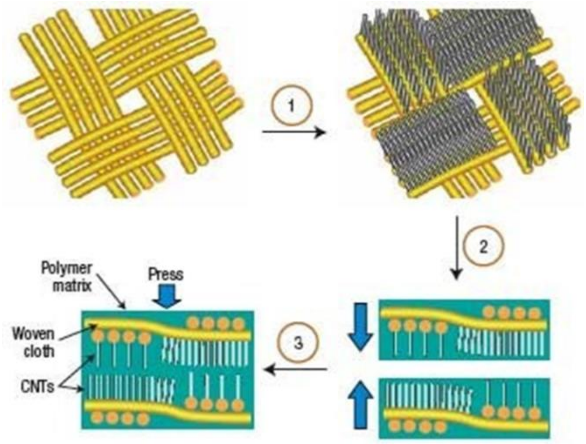


Figure 6. Hybrid nanocomposites

3. CONCLUSION

The presented specialized training is part of the project "Modern educational technologies in language and specialized training", developed at the UCRT of TU-Gabrovo, BG [18]. The project is directly related to the National Development Program "Bulgaria 2030", which is a framework strategic document of the highest order in the hierarchy of national programming documents, determining the vision and overall objectives of development policies in all sectors of government, including their territorial dimensions. The project is also related to the Internationalization Strategy of the Technical University of Gabrovo for the period 2020-2030. The international research team of this project, in which involves colleagues from the NNU National University “V. Sukhomlinsky ”in Nikolaevsk, Ukraine, determines the interuniversity nature of the research. Through systematic use of the developed scientific and methodological bases for building training plans and programs, seminars in fundamental, special and technological disciplines in the training of future specialists with higher technical education, the project team aims to increase the effectiveness of vocational training while reducing classroom employment and using modern educational technologies to intensify the learning process and formation of professional competence in students. The topic of nanocomposites is one part of all this.

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INFLUENCE OF FLUORINE-CONTAING MOUTHWASHES ON NiTi ALLOY CORROSION

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Abstract: *Evaluation of NiTi alloy corrosion behaviour in fluorine-containing media still remains a great characterization challenge. Such characterization is commonly simplified by using aggressive media with a high concentration of fluorine. Accordingly, the difficulties in the characterization of material changes on a nano-level are avoided. However, these results do not sufficiently resemble the real situation. Therefore, the motivation of this work was to perform a non-accelerated corrosion test, characterize the nano topographic changes, and to evaluate the obtained results by statistical methods. In this study, we examined the behaviour of NiTi alloy archwires exposed for 21 days to artificial saliva and fluorine-containing mouthwash Aquafresh My Big teeth®. Atomic force microscope (AFM) Veeco CP-II, and scanning electron microscope (SEM) Hitachi TM3030, were employed for characterization of changes in surface topography, on the areas of 80x80 and 10x10 µm. Before and after the corrosion tests specimens were evaluated at 5 locations of 80x80 µm. Topographic images were analysed by image analysis software (Spip 6.2.0) and surface roughness parameters (Sa and S10z) were calculated. The changes in chemical composition were evaluated by energy-dispersive X-ray spectroscopy (EDS). Paired T-test and one-way ANOVA statistical analysis were employed for the evaluation of the changes observed in surface roughness parameters and chemical composition. Changes in surface topography observed in AFM and SEM images (80x80 µm) are negligible for both specimens. Analysis of AFM topographic images (10x10 µm) revealed that only specimen exposed to Aquafresh My Big teeth® exhibited nano changes in surface topography. For artificial saliva negligible changes were observed, while Aquafresh My Big teeth® exhibited notable changes in Sa and S10z parameters. Statistical analysis of data revealed that changes in roughness parameters are significant only for specimens exposed to Aquafresh My Big teeth® ®. This indicates that the presence of fluorine in mouthwash increases the NiTi corrosion. Statistical analysis methods and AFM have been proven as a valuable tool in the characterization of nano topographic changes caused by corrosion in real conditions.*

Keywords: *biomaterial, NiTi, corrosion, AFM, nano topography, ANOVA, paired T-test.*

1. INTRODUCTION

Ni-Ti alloy is a biomaterial that is widely applied for dental application due to its good corrosion resistance and special mechanical properties [1].

During orthodontic treatment with NiTi alloy appliances, practitioners recommend their patients to use fluoride mouthwashes to prevent dental caries and enamel [2]. However, application of fluoridated mouthwashes could lead to corrosion and release of metal ions into the body [3]. The release of metal ions from dental alloys may have an adverse biological effect, depending on the ion species and their concentrations [4]. It has been shown that Ni ion release caused by corrosion process lead to allergenicity, toxicity and carcinogenicity [2,5]. Additionally, ion release inevitably induces NiTi material corrosion, degradation of its surface (topography) and tribological characteristics [6,7]. Therefore, the characterization and quantification of topographic changes induced by the corrosion processes is very important for reduction of their effect on patient health and improvement of material performance in application [1,4,6,7].

Investigations with electrochemical [2,8], and non-electrochemical tests with higher fluoride concentration (> 1400 ppm) [9,10], revealed a significant decrease of NiTi corrosion resistance in commercially available mouthwashes. By employing accelerated tests, with support of electricity or concentrated corrosive media, difficulties in the characterization of nanostructures and nano topographic changes of the surface are avoided. However, these tests do not sufficiently resemble the real situations.

Therefore, the aim of this work was to perform a non-accelerated corrosion tests of NiTi wires in artificial saliva and commercially available fluoride mouthwash, with a goal to characterize and quantify the changes that occur in surface topography and chemical composition.

2. MATERIALS AND METHODS

The corrosion performance of NiTi orthodontic wires (Denataurum, Germany) was evaluated in this study. Two prismatic specimens were prepared of the wire in as-received condition. In order to easily locate the same area after the tests, 5 scan locations on each specimen were marked by scratches on the surface before the corrosion tests. Each specimen was exposed to corrosive media for duration of 21.5 day at room temperature. The specimen denotations and corresponding corrosive media used in test are presented in Table 1.

Table 1. Specimen's denotations and the employed medium.

Specimen	Corrosive medium
Specimen 1	Artificial Saliva (pH 7.1)
Specimen 2	Aquafresh My Big teeth® (GSK Consumer Healthcare) 0.05 % (250 ppm) NaF

Corrosion was characterized by means of changes in surface topography. For these purposes, each specimen was analysed in 5 predefined locations, before and after the corrosion test, by employing atomic force microscopy (AFM) (CP-II di, Veeco) and scanning electron microscopy (SEM) (TM 3030, Hitachi, Japan). AFM measurements were performed in contact mode, using symmetrically etched Silicon-Nitride tip. The scanning parameters were as follows: fast scanning direction X-axis, scanning area 100 x 100 µm, setpoint 225 nN, scanning rate 0.5 Hz and gain 0.5.

Imperfections in the probe movement mechanism caused a mismatch in scanning location, before and after the test. Therefore, in order to evaluate the effects of corrosion on exactly the same location, the areas of 80x80 and 10x10 µm were extracted from original measurements, and further analysed.

Scanning Probe Image Processor (SPIP) image analysis software was employed for the analysis of topographic images, extracting areas of 80x80 µm and 10x10 µm and the calculation of surface roughness parameters.

X-ray energy dispersive spectroscopy analysis (EDS) (TM 3030, Hitachi, Japan) was employed for the analysis of chemical composition of specimens.

After the corrosion tests, the change in observed surface roughness parameters and

comparison of difference in change of roughness parameters were analysed using paired T-test (T-test) and one-way ANOVA, respectively. All statistics analyses were performed with Minitab 16 software at a significance level of 5%.

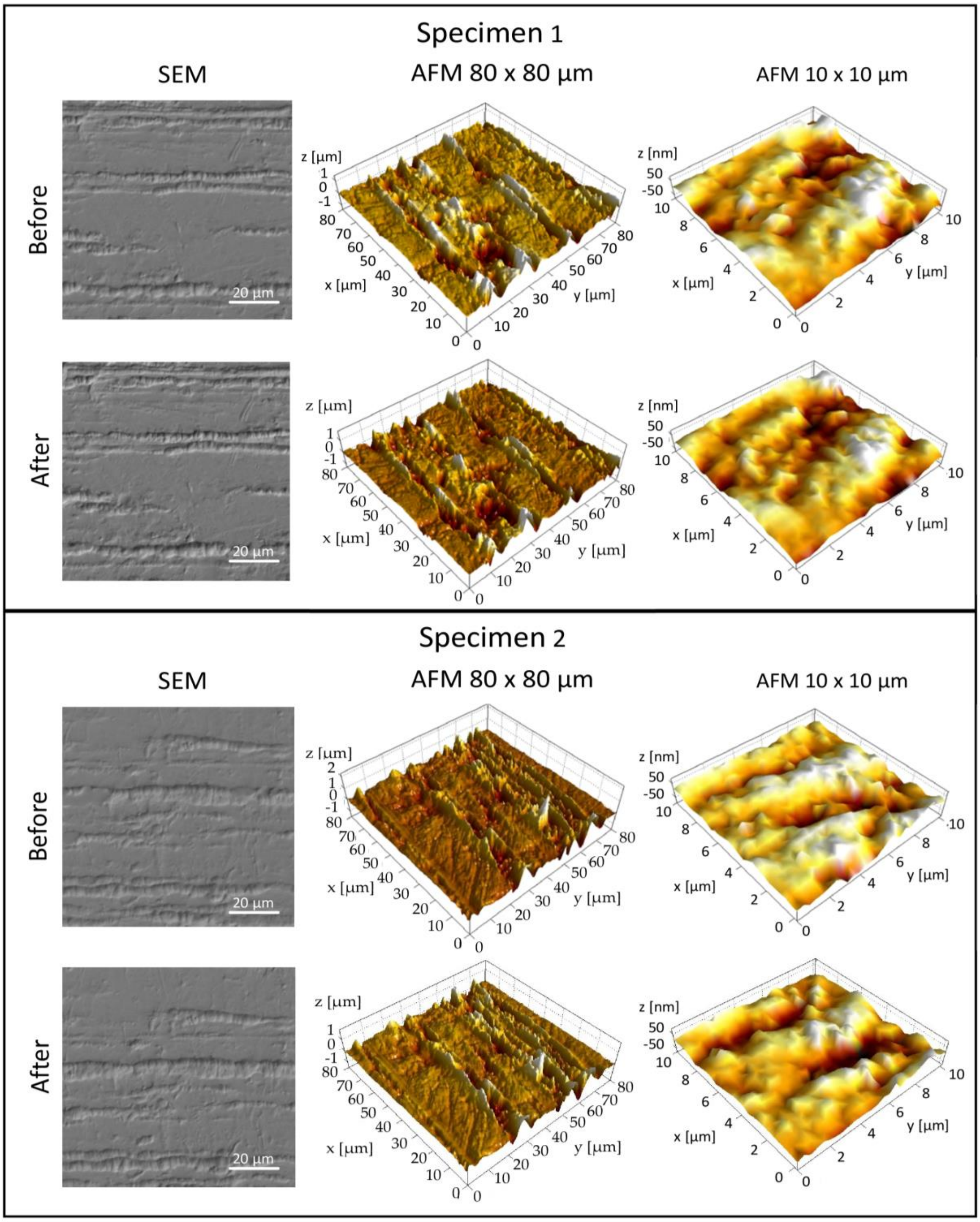

Figure 1. Representative AFM (80 x 80 µm and 10 x 10 µm) and SEM(80 x 80 µm) images for Specimen 1 and 2, before and after corrosion test

3. RESULTS

Representative SEM and AFM images of specimen surfaces before and after the corrosion tests are given in Figure 1. The initial surfaces of the specimens are characterized by relatively parallel deep grooves. The area between the grooves is much smoother. When comparison is made between the SEM and AFM images of 80 x 80 µm areas (Figure 1), of surfaces before and after the corrosion tests, differences in topography cannot be noticed.

However, when the small areas (10 x 10 µm) between the grooves of Specimen 2 (Figure 1) are compared, changes in nano-topography induced by corrosion are evident.

The specimen's chemical composition was investigated by EDS. The initial specimen chemical composition comprises of averagely 40 % of Ti and 60 % of Ni. Results of ANOVA revealed that chemical composition of all specimens after the test did not change significantly.

Table 1 presents the average values of Sa and S10z parameters, determined on the areas of 80 x 80 µm before and after the tests, for all investigated specimens. Although all specimens were produced of a same archwire, differences in the initial surface roughness parameters, of ~ 20 %, are observed. Also, it must be noted that the values of confidence interval after the corrosion tests, exhibited only a minor change.

Table 1. Values of surface roughness parameters Sa and S10z, before and after corrosion test, of surface areas 80x80 µm areas. Note: Values in brackets are confidence intervals.

Element	Surface roughness parameters			
	Sa_{before} [nm]	Sa_{after} [nm]	$S10z_{before}$ [µm]	$S10z_{after}$ [µm]
Specimen 1	136 (56.7)	129.7 (38.3)	1.957 (1.17)	1.781 (0.63)
Specimen 2	133.5 (74.1)	125.7 (66.3)	2.065 (1.010)	2.668 (0.907)

Results of T-test and ANOVA revealed an insignificant change, and difference in change of surface roughness parameters determined for the areas of 80 x 80 µm. These results indicate that all investigated corrosive media did not impose a significant change of specimens' Sa and S10z parameters on these "large" evaluated areas.

Table 2 presents the average values of Sa and S10z parameters of 10 x 10 µm areas, determined before and after the corrosion tests, for all investigated specimens. A variation of ~ 25% in the initial surface roughness parameters, determined for the areas of 10 x 10 µm, is noticeable. A small change in the average values of parameters Sa and S10z can be observed. It can be noticed that trend of change for both roughness parameters is the same. It also can be noticed that values of confidence intervals suffered only a negligible change after the corrosion tests.

Table 2. Values of surface roughness parameters Sa and S10z, before and after corrosion test, of surface areas 10x10 µm areas. Note: Values in brackets are confidence intervals.

Element	Surface roughness parameters			
	Sa_{before} [nm]	Sa_{after} [nm]	$S10z_{before}$ [nm]	$S10z_{after}$ [nm]
Specimen 1	14.5 (6.9)	14.2 (6)	88 (37.4)	88 (37.3)
Specimen 2	15.1 (3.3)	20.2 (5.8)	109 (23.9)	142 (29.3)

Results of T-tests performed on Sa and S10z parameters, determined for 10 x 10 µm areas, are presented in Table 3. The specimen treated with artificial saliva (Specimen 1) again did not show a significant change in the observed surface roughness parameter. On the other side, specimens treated with fluoride containing mouthwash (Specimen 2) significantly changed the value of both surface roughness parameters ($p < 0.05$).

Table 3. Results of T-test for comparisons of roughness parameters before and after exposure.

Specimen/Results of paired T-test (P-Value)	Results of Paired T-test (P-Value)	
	Sa	S10z
Specimen 1	0.451	0.884
Specimen 2	0.036	0.041

Results of ANOVA for comparison of the differences in change of surface roughness parameters revealed that the difference in change of parameters between Specimen 1 and 2 is significant.

4. DISCUSSION

The analysis performed in this study revealed that nano topographic changes of

NiTi induced by corrosion processes can be successfully revealed by AFM.

Analysis of AFM and SEM images, surface roughness parameters, and chemical composition of Specimen 1, before and after the corrosion test in artificial saliva, indicates an insignificant change of topography. This means that artificial saliva with pH 7.1 during the period of 21.5 days, do not induce observable corrosion of NiTi, by means of changes in surface roughness. This agrees with finding of Huan et al. [11], who found, that artificial saliva with pH value as high as 7.1 does not induce corrosion of Ni-Ti alloy.

An insignificant change of roughness parameters, topography and chemical composition, evaluated for areas of 80 x 80 µm, indicate that the medium employed for testing of Specimen 2 did not cause corrosion effects. However, the corrosion effects of the employed medium on specimen 2 are evident for the area of 10 x 10 µm. We assume that this discrepancy is caused by large variations in roughness of specimen at areas of 80 x 80 µm. These variations act as a noise in signal and overlap the nano topographic changes caused by corrosion processes. Results for specimen 2 indicate that a medium with 0.05 % NaF (250 ppm fluoride) causes the corrosion effects of NiTi which are observable on a nano scale. This finding was also confirmed in previous investigation [2,6], with electrochemical tests, where is reported that similar concentration of fluoride in medium causes a decrease of corrosion resistance and induces corrosion effects on the surface.

Changes that occurred on the surfaces indicate that the employed medium for specimen 2 causes material loss from the surface. This type of change causes a significant increase in concerned surface roughness parameters. These results lead us to the following findings. First, the increase of surface roughness (Sa) of the specimen is caused dominantly by material loss beneath the surface mean plane. Second, an increase of surface roughness parameter (S10z) indicates that the employed medium causes deepening of the existing grooves. Third, despite the fact that this investigation used medium with considerably lower concentration of fluoride than the one used in investigation [9], the same trend of change was observed. This indicates that the reduced fluoride concentration in medium did not cause a significant change of the operating corrosion mechanism. Fourth, we assume that a significant change in parameter Sa is not linked with an increase in depth of deepest grooves and its lower sensitivity to these changes. But, to the uniform changes that occur beneath the mean plane. Minor changes in values of confidence intervals are indications of uniform changes in specimen nano topography. Kassab et al [12] came to the same finding that fluoride containing media cause formation of evenly distributed pits on the surface (uniform corrosion).

The results of ANOVA (10 x 10 µm) can be an indication that the presence of NaF in mouthwash leads to corrosion effects. Again, this confirms the previous findings of Huang et al. [8], that the presence of NaF in solution leads to the increased corrosion effects of NiTi.

It is reported that exceeding the allowable mass loss limit of 0.5 µg / cm^2 / week of Ni ion release leads to allergenicity, toxicity, and carcinogenicity [2,5]. Change in the surface topography can be used for approximation of material loss caused by corrosion. The material loss that occurred on the surface can be approximated by employing the Sa parameter. Multiplying the difference of Sa parameter (Sa_{before}-Sa_{after}) with the area of the examined location will give an approximate value of a change in a volume. If we assume that all change in volume was caused only by release of Ni ions, a mass loss of 0.15 µg/ cm^2 / week can be approximated. Observing the approximation in material loss it can be noticed that it does not exceed the allowable mass loss limit. Although the observed changes do not exceed the limit, the occurred material loss is an order of magnitude of allowable limits. Therefore, the application of this mouthwash should be used in recommended dosage.

5. CONCLUSIONS

The corrosion behaviour of NiTi alloy in artificial saliva and fluoride containing mouthwash was investigated. Analysis of the obtained results leads us to the following conclusions:

- The changes in surface topography, that are induced by corrosion processes in non-accelerated tests, can be observed only on micro-areas such as 10 x 10 µm.
- Artificial saliva with pH 7.1 does not cause a change of NiTi alloy surface topography nor its chemical composition.
- Fluoride containing mouthwash (Aquafresh My Big teeth®) with the concentration of 0.05% NaF (250 ppm) causes a uniform corrosion of the surface which manifests with increase in surface roughness.
- According to the approximation of volume loss calculation, the application of Aquafresh My Big teeth® did not exceed the allowable limit of Ni ion release.
- Statistical analysis methods and AFM have been proven as a valuable tool in the characterization of nano topographic changes induced by corrosive media present in oral environment and health.

ACKNOWLEDGEMENT

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IMPROVEMENTS IN SPC PROCESS WITH BPMN AND SIMULATION IN A HVAC HEAT EXCHANGER FACTORY

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Abstract: *Manufacturers of white goods, electric appliances and HVAC systems in Brazil are facing challenges to keep competitiveness of their operations, considering the world class players that are continuously improving their products and processes to deliver better quality products with lower production costs. To achieve this target, new opportunities for continuous improvements in management and operation system are welcome. This paper evaluates the statistical process control data acquisition system in Company ABC in Brazil for heat exchanger manufacturing, by using BPMN for Process Map As-Is state and a creation of a simulation model. Options for improvements were proposed for To-Be state, considering improvements in quality and resource reduction and each of them was simulated to decide what scenarios to apply. Simulations results were compared with real results after application of each scenario in real world considering Resource Utilization. Although there are differences between simulated and real data, the analysis brought process improvements and resources reduction used to collect process data.*

Keywords: *Statistical Process Control, BPMN, Simulation, Industrial Engineering, Bizagi*

1. INTRODUCTION

The Brazilian industry has been going through a challenging period, by experiencing a period of extreme international competitiveness. Countries with lower production costs (such as China, India, Thailand and others) have attracted industries established in Brazil [1].

We are also experiencing a moment of change with industry 4.0, which promotes several impacts on the sector, from development of new business models to increase in consumer demand. Therefore, the industrial model must be enhanced in order to serve new markets and improve quality and reliability of products [2]. Additionally, unexpected world events can cause more adverse scenarios in economics. The outbreak of coronavirus disease (COVID-19) is making a recession effect by economy contraction, causing demand decrease, and supply chain disruption. According to Fernandes [3], possible recovery periods are uncertain and it will depend on many factors for economic activities resumption, which causes new initiatives for process improvements to be pointed and evaluated.

The manufacturing process needs to assure product and process quality, by monitoring key quality characteristics (KC), which are collected periodically, and controlled through statistical analysis. This process demands resources from the quality department and has associated costs that need to be controlled and, if possible, reduced.

This paper will present a case study of a HVAC components' assembly, and scenarios for improvement through, a research to consider refrigeration systems and components fabrication, quality management, lean thinking and industry 4.0 approaches. Then as-is state is described by using BPMN map and a simulation model is constructed. Improvements scenarios are raised and decision of which scenarios to be applied is made by using to-be simulation. Finally, real data is compared with simulated data and KPI for quality and productivity will be evaluated.

2. CONTEXT AND METHODOLOGY

Considering the actual landscape described in previous section, new alternatives for quality improvements, cost reduction and production increase are requested to these companies to be more competitive.

This paper will use the Action-Research (AR) methodology in Company ABC in Brazil from white line segment, which corresponds to products as refrigerators, vertical and horizontal freezers, air conditioners, dishwashers, washing machines, dryers, microwave ovens and others.

There are many examples of application of AR such as presented by Santos [4] showing how a Statistical Process Control (SPC) can be improved by using AR cycle, firstly recognizing the actual situation, then apply the planned action plan in practice. The next step is follow up on the ongoing actions and, finally monitor the results and if necessary plan a new cycle, starting with the first step. Authors were able to select lean office approach as more appropriate and identify improvement opportunities transportation, standardization, inventory and others, and it was possible to increase daily KPI in around 85% in their executions.

3. PROCESS DESCRIPTION

3.1 Process Map and Key Characteristics

Process has been described, according to the flowchart, and main steps are: *U-Bender* receives copper tubes in rolls and conforming to a “U” shape with specific dimensions, according to the product model. The KC for this process is the difference between the lengths of tubes (Peg-Leg); *Fin Press* receives steel sheet coils for cutting the blades and shaping them with specific dimensions and shapes. The KCs monitored are the height and diameter of the holes for the tubes; *Package Assembly* to mount fins in specific quantities on the tubes to form the heat exchanger; and *Expander* where diameter of the tubes is increased to leave the fins and tubes permanently connected, through an interference fit to allow heat transfer in the final product. The KCs controlled are the number of fins per inch (FPI) and the height of the tube.

3.2 BPMN and Simulation

To detail the data collection process, the BPMN tool was chosen to map the business process. At this point, some improvement opportunities were identified, such as: data collected from some KCs is not always reliable or incorrectly recorded, the method that the Control Charts show the data does not make it clear to the operator which adjustment should be made on the machine, manufacturing operators manually write data on paper, quality operator goes to each machine to collect data and takes too long to manually write all data collected on a spreadsheet.

For the choosing of which improvements will be applied, a virtual model was created for the simulation of occupation of the resources allocated in the process. The BPMN flow was taken as the basis for the model, which was developed in Bizagi software version 3.1.0.011, as shown in figure 1.

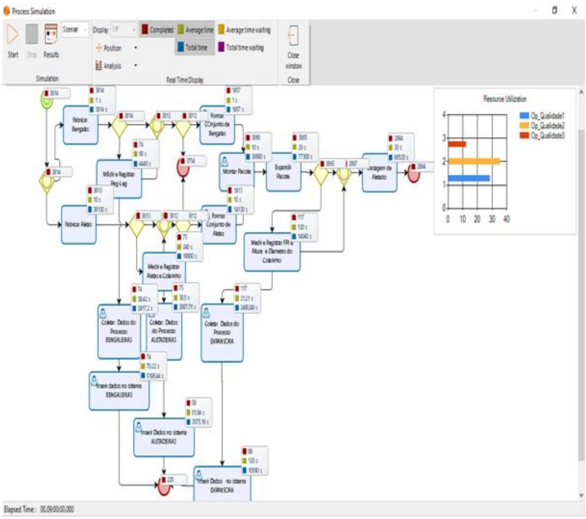

Figure 1. Simulation Result in As-Is Condition

In the software, it is necessary to insert each information in respective elements in each of the associated steps, namely: process validation, time analysis, resource analysis and calendar analysis.

After inserting all the information into the model, a simulation was made, considering 1 day of production and all the process times and available resources (quality operators). Considering the excessive time required for the quality operator to travel and for entering data, the proposed solution for reducing both times was to change the manual control chart to an electronic form where the process operator would insert the measured information on this form. This improvement is called scenario 01 (C1).

Due to the characteristics of the expanders control charts and FPI assessments, it is not possible to immediately apply the electronic form to the process. In addition, this process has the longest processing time and has the most critical characteristics for product performance. The information entered incorrectly will generate incorrect conclusions and innocuous actions.

To solve the points mentioned above, it was proposed to improve the KC measurement system of the expanders, with the measurement of FPI KC and collar height and diameter through an image acquisition and processing system, with data storage in the system. We call this improvement as scenario 02 (C2).

All scenarios were simulated in Bizagi, and their resource utilization rates compared. A briefing of each scenario and simulation of resource utilization can be seen in table 1 below:

Table 1. Summary of simulated scenarios

		Op 1	Op 2	Op 3
C0	No improvements Applied	28%	36%	12%
C1	Electronic Forms	44%	32%	-
C2	Electronic Form and Measurement system by image	38%	-	-

4. SCENARIO APPLICATION AND RESULTS

For scenario 1, electronic forms were developed to reduce processing time of the measurement data registration process, data collection and insertion process in the repository, as well as the reduction of paper consumption (paperless concept).

For scenario 2, a system was designed to make the acquisition of images, making a comparison with a known standard so that the main information is obtained. In the case of FPI measurement, as well as height and collar diameter, the software must have pattern detection requirements (in case of this application, edge detection) to accurately obtain the dimensions of the components.

The resource utilization of quality operators is defined as the ratio between the sum of all activity times (performed by the operator), and the total time available.

The figure below shows the distribution of resouce utilization of quality operators per week in a box-plot graph. In each week there were variations in the occupancy rates of each operator, due to factors such as difficulties in collecting data in the process, variation in the time of data insertion in the repository and other factors. Another point worth noting is that after applying the scenarios, there was a greater variation in the occupancy rate each week. This happened because each change required training and time to adapt for each operator.

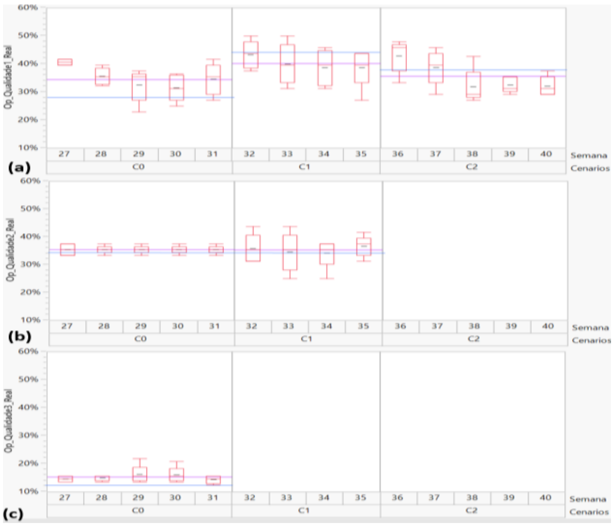

Figure 4. Observed results of occupancy rates for (a) Quality Operator 1 (b) Quality Operator 2 and (c) Quality Operator 3.

5. CONCLUSION

The process of statistical process control is very important to guarantee customer satisfaction. It is through the collection of sample data of KC, its periodic trend analysis, identification of failures and the application of corrective and preventive actions that we can achieve customer satisfaction and the fulfilment of project specifications. However, according to the Lean approach, by customer point of view this is not a value-added process, so there should be no resources assigned and this process should be eliminated.

Therefore, the resources made available to the process were optimized to the appropriate quantity, previously requiring 3 quality operators, now only 1 operator is necessary to perform this process.

The current state mapping was done using a process map that showed the main characteristics that influenced the product's quality and performance, and the indirect data collection process was mapped with the BPMN tool.

The simulation model was extremely important to estimate the behaviour of the future state, and it was able to simulate the behaviour of the process and the reduction of 3 operators to 1 operator. However, Bizagi software showed variations between the simulated result and the real result. These variations had an average of 10% reaching a maximum of 17% difference between real results and simulated results. This difference occurred because the model was unable to reproduce all operating conditions of the process.The proposed improvements have considered the pillars of industry 4.0 and it was decided to implement a questionnaire for agile data collection and a system for measuring components by image processing, which were implemented at two different times as scenario 1 and scenario 2, respectively.

The data collection systems were implemented and have been very well adapted. The image measurement system was developed for the product manufactured by the company and it was approved for use.

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MODELING AND SIMULATION OF HYDRAULIC SYSTEMS IN SIMSCAPE FLUIDS

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Abstract: *Modeling and simulation of hydraulic systems is necessary in order to acknowledge the drawbacks and advantages before starting a design of a system. The paper represents the modeling and simulation of a basic hydraulic water supply system. In this purpose there have been considered the basic hydraulic models of certain selected hydro elements: pump, power unit, pipeline, tanks and valve. For the fluid flow control a gate valve was chosen which can be used for monitoring the movements of fluid and related parameters of the system. The main components of this system were modelled. The models are shown as block diagrams adapted to the package requirements. Performed model was implemented in simulation software Simscape Fluids and its dynamic performance was tested.*

Keywords: *hydraulic system, modeling and simulation, Simscape Fluids.*

1. INTRODUCTION

Fluid power has the highest power density of all conventional power-transmission technologies. Numerous production machines in many industrial sectors use hydraulic systems. Hydraulic systems are used when a lot of power and a quick response are required. There are different computer programs for mathematical simulations of behaviour of hydraulic systems. From the user's perspective, the physical modeling is appropriate. The real system can be tested under several conditions to ensure that it is suitable for a given application. It also enables the analysis of different model setups for the behaviour of a single parameter, revealing its impact on the final output over time. Numerical simulations can be used to create appropriate hydraulic system optimizations without requiring physical intervention. This method of hydraulic system design and modification is used to evaluate the performance of systems prior to their implementation [1].

Simulation and modeling of hydraulic systems is gaining interest in scientific community [2-5]. In this paper computational modeling results of a hydraulic system which is commonly used for the water supply systems is presented. Simscape Fluid, a module of Matlab software, was used to simulate the dynamic behaviour of a system. The simulation model is made up of blocks that correspond to basic hydraulic elements, such as pump, tanks, pipes and valve. The blocks are specified by mathematical equations and can be found in computer software libraries. The results of the simulation are presented through series of line charts, each presenting work of specific part of the model.

2. SIMSCAPE FLUIDS MODELS

Simulink is a graphical extension of MATLAB for modeling and simulation of systems. Simulink displays systems as block diagrams on the screen. A Simulink block is a model element that defines a mathematical relationship between its input and output. In general, the mathematical equations representing a given system that serve as the basis for a Simulink model can be derived from physical laws. When Simulink blocks are connected, the outcome is a diagram that is equal to a mathematical model, i.e. it describes the system being projected.

Simscape is a MATLAB add-on tool that may be accessed through the Simulink library browser in the Simulink environment. Simscape is a software program that is used to simulate and model real engineering systems in a variety of domains. It comes with a foundation library that comprises components for electrical, hydraulic, magnetic, mechanical, physical signals, pneumatic, and thermal systems. More specialized toolboxes for physical modeling, such as Driveline, Electrical, Fluids, and Multibody, are now regarded part of the Simscape product family, despite the fact that some of them existed before in Simscape.

Simscape uses blocks that relate to the physical components of the system instead of the mathematical blocks used in Simulink to generate a system model. The model's structure matches the structure of the real system because functional linkages are made between the components. The user chooses appropriate blocks from the library and connects them with lines that follow the system's structure.

An important difference between Simscape and Simulink is that the models created in Simscape represent real physical structures, unlike Simulink in which the models represent equations. Simscape's simulation model is made up of components that represent real system components, therefore the component's mathematical model is embedded in the component itself.

Each component in Simscape is represented by an interface, which is specified by the number and type of ports. Ports are the points where energy or signal enters and exits a component. Energy ports are physical connectors that allow for lossless two-way energy transmission. The signal ports between blocks are one-way transmission ports. Depending on the energy domain, many types of energy ports exist.

Simscape Fluids is a Matlab toolbox which provides component libraries for modeling and simulating fluid systems. Simscape Fluids is a Matlab toolbox for modeling and simulating fluid systems. Simscape Fluids use a physical network approach to modeling, with elements (blocks) corresponding to physical components such as pumps, motors and valves, tanks, etc, and lines related to physical connections through which the power is transferred.

This form of representation enables the system to be described without the need for a fundamental mathematical description. Simscape Fluids makes it simple to create hydraulic system simulation models that may be used for sizing and selecting system components, analyzing and determining system parameters, modeling the control system, and analyzing the complete system. All of the components are set up such that the user can enter parameters that are commonly found in technical documentation.

2.1 Modeling of hydraulic system

The pump is one of the most important parts of any hydraulic system. The pump model in Simscape Fluids has three ports, as illustrated in Figure 1: P and T indicate the output, i.e. the pump intake, and S represents the pump drive shaft, which is connected to the motor. The primary assumptions of the pump model are that the fluid's compressibility is ignored, and that the mechanical characteristics of the shaft, such as inertia, friction, elasticity, and so on, are neglected [6].

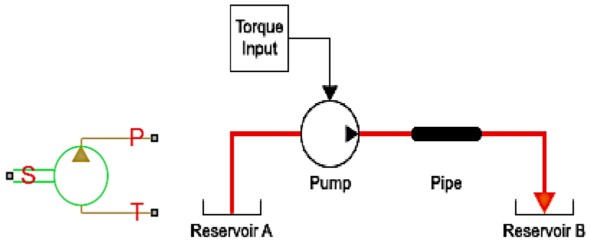

Figure 1. Pump block and scheme of the pipeline

The parameters of the pump model used in the modelling are the unit volume flow of the pump, the volume efficiency, the total efficiency, the working pressure, the rotational speed, the kinematic viscosity of the fluid and the density of the fluid. All of these parameters are usually provided in the pump's technical documentation.

In hydraulic systems, the power unit is the most common component. Its primary purpose is to provide the needed amount of fluid at a specified pressure. Figure 2 shows a typical hydraulic system power unit, which includes a fixed- or variable-displacement pump, reservoir, pressure-relief valve, and a prime mover that drives the hydraulic pump. Simscape libraries provide a set of blocks that can be used to simulate any aggregate configuration.

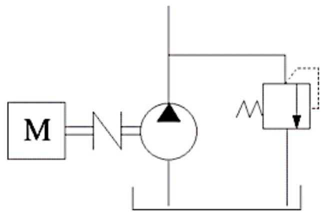

Figure 2. Typical hydraulic power unit

In many simulations, the electric motor model is not used for pump power. Instead of electric motor an ideal source of angular speed is often used. If the angular speed of the motor is constant or varies slightly during the simulation, the entire drive shaft subsystem can be replaced by the Ideal Angular Velocity Source block, which output is set to a constant value. This source is ideal since it is expected to be capable of maintaining the fixed speed regardless of the torque supplied to it.

The properties of the fluid must be defined in order to carry out the hydraulic system simulation. A block that represents a set of fluid parameters can be used to define fluid selection. The program allows the user to enter fluid parameters or choose among list of 24 fluids.

2.2 Case study - Hydraulic system with pump and two constant head tanks

Figure 3 shows a hydraulic system which is modeled with MATLAB Simulink and the Simscape Fluids library. The hydraulic system is made up of a pipeline and a pump that connects the open tank A and the closed tank B, with a gauge pressure of p_m=50 kPa above the liquid's surface. The tanks are at various heights and are connected by a water supply pipeline (length L=50 m, diameter d=20 mm). The values of local resistance coefficients are assumed to be equal to 10% of the friction losses. Other geometric parameters are described in the block descriptions where they are defined. The example illustrates a fundamental fluid transportation problem: determining flow rates, pressures, and fluid volumes in a system composed of two constant head tanks.

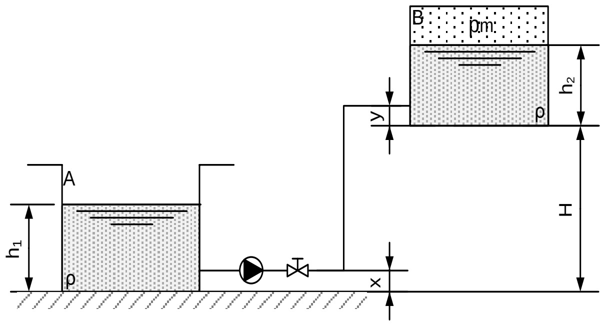

Figure 3. Hydraulic system with pump and two constant head tanks

Adjustment of the centrifugal pump parameters is possible for any type of pump model based on the technical data of the manufacturer. Three options are available to characterize the pump: (1) an approximate polynomial, (2) the pressure drop and power as a function of flow, and (3) the pressure to power ratio for different angular velocities relative to the pump flow. In this modelling, standard centrifugal pump parameters and 1D Tables parameterization of the pump model were utilized.

The Hydraulic Fluid block is used to define the kind and properties of the liquid. For all components connected in the loop, the block assigns a working fluid to the model. The loop is automatically detected, and if a block is hydraulically connected to at least one loop component, it is considered a part of the loop.

The tank is defined by the Constant Head Tank block. This block is a tank which contains liquid at a given pressure. The tank is assumed to be large enough to ignore pressure and fluid level fluctuations caused by changes in fluid volume. This block specifies the height of the liquid level in relation to the tank's bottom, as well as any pressure loss in the connecting pipe due to a filter, a branch, or other local resistance. The pressure loss coefficient determines the amount of loss.

The Constant Head Tank block contains two ports: T and V. Port T is a connection to a pipeline or pump, whereas port V is a connection to a signal that reads the volume of the tank. The block determines the liquid volume in the tank and sends it out through physical signal V. If liquid flows into the tank, the flow is rated positive. During simulation, the fluid volume may turn negative, indicating that the fluid volume is insufficient for the system's normal operation.

The Simscape Fluids block library contains different types of pumps. In this example, a Centrifugal Pump block was used which has three ports: S, P, and T. The pump suction port T is connected to the T tank connection, whereas the pump pressure port P is connected to the valve. The pump shaft is represented by port S, which is connected to the source of rotating mechanical movement i.e. with the motor defined by the Ideal Angular Velocity Source block (R port). The motor block contains two more ports: port C connects the engine to the environment, i.e. to a Mechanical Rotational Reference block, while port S connects to the motor speed signal. The angular velocity in this example is set to constant connecting with the S port of the motor via the Simulink-PS Converter block, which converts the Simulink input signal into a physical signal.

A gate valve is modelled by a thin flat plate with an aperture and a round sharp-edged orifice in the housing in the Gate Valve block. The radius of both orifices is the same. The plate displacement is used to manage the valve passage area. The valve is totally closed in its initial position. The passage area and the pressure differential across the valve are related to the flow rate through the valve. The flow rate through the valve is proportional to the valve opening and to the pressure differential across the valve.

By monitoring the Reynolds number, the model accounts for laminar and turbulent flow regimes. Hydraulic ports linked with the valve inlet and outlet are conserved by ports A and B, respectively. Port S is a physical signal port that is linked to the valve control member's motion. In this example, a form of sinewave function is used as a signal port, which totally opens and closes the gate valve repeatedly. The positive direction of a block is from port A to port B.

The Resistive Pipe LP block is used to model hydraulic pipes with circular and non-circular cross-sections, where only friction losses are considered. Because the block is designed to simulate systems that operate at low pressures, it requires the elevation of both inputs to be specified. To reduce the complexity of the model flow is assumed to be fully developed along the pipe length and fluid inertia, fluid compressibility, and wall compliance are not taken into account. To account for local resistances, such as bends, fittings, inlet and outlet losses, the resistances convert into their equivalent lengths, and then sum up all the resistances to obtain their aggregate length and add to the pipe geometrical length.

The Solver Configuration block is a necessary block for all Simscape models. Unlike other Simscape blocks such as pump or motor, it does not represent a physical part in the overall system. Instead, it is used to specify simulation options for physical system, such as the type of solver to use, initialization options, and the sample time for the simulation [7].

After specifying all of the hydraulic system's components, the Simscape model illustrated in Figure 4 is created.

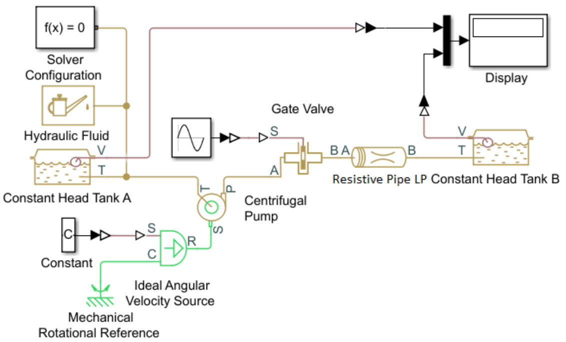

Figure 4. Simscape Fluids model of the hydraulic system

2.3 Simulation results

After the simulation system is developed and executed, the results of the simulation are shown in Figure 5-9. To analyse the system, it is essential that the pressure drop and flow rate behaviour are simulated over time.

The simulation was performed over time with the sine function as the signal for the opening and closing of the gate valve. Referring to Figure 5 and Figure 6, a movement of the gate valve and flow rate through the pipe can be monitored. The valve starts with zero orifice area and increases to fully opened during the first half of a sine function period (π=3.14 seconds). As the gate valve opens the flow of liquid through the system increases to $2{,}3\cdot10^{-3}$ m^3/s, after which it decreases to zero when the valve is completely closed (2π).

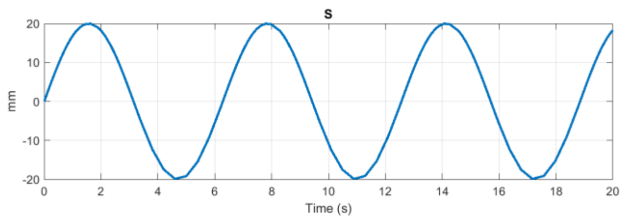

Figure 5. The position of the gate valve

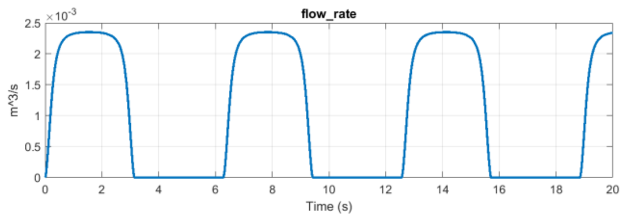

Figure 6. The flow rate through the system

Since the hydraulic system is used to transport fluid from tank A to tank B, Figures 7 and 8 show the volume changes in the tanks. The figures show that the change in volume is a linear function, and that the change in volume in the tanks is $0{,}007\cdot10^{-3}$ m^3 (7 litres) for each period the valve is opened.

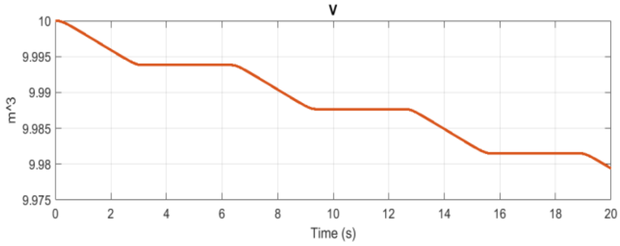

Figure 7. Change of volume in the tank A

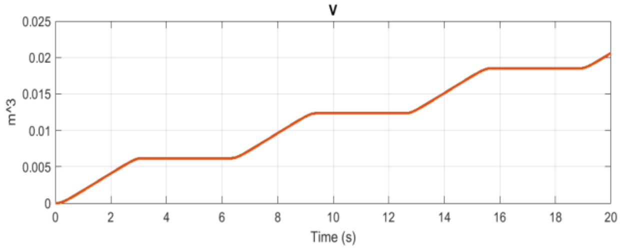

Figure 8. Change of volume in the tank B

The pressure drop across the pipe drives the flow of liquid from a high pressure to low pressure. The pressure drop is related to the flow rate passing through it, i.e. the greater the flow rate the higher the pressure drop and vice-versa. The Figure 9 shows the variation in pressure through the pipeline. The largest pressure drop occurs when the valve is fully open and is $15.7\cdot10^5$ Pa. In the periods when the valve is closed, there is no fluid flow through the system, and the pressure drop in the pipeline is not registered.

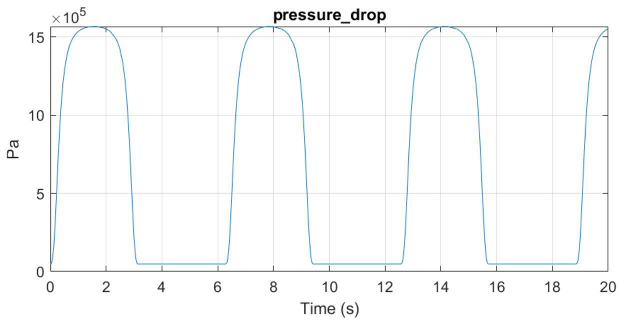

Figure 9. Pressure drops through the pipeline

3. CONCLUSION

Simscape is a powerful tool that allows users to develop new customized components, no matter how complicated they are, in order to match actual physical components used in simulation. The goal of modern science and engineering is to improve efficiency and functionality of any given system. Simscape Fluids is a powerful tool for simulating hydraulic systems. The advantages of using the FluidSim toolbox for system simulation can be noticed in the easy access modeling and user-friendly features.

This paper shows the behaviour of hydraulic system components which is simulated in Matlab Simscape Fluids. The presented model, although simple in its nature, represents starting point for further modifications and optimising in order to achieve greater effectiveness of hydraulic systems.

ACKNOWLEDGEMENT

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AUGMENTED REALITY IN INDUSTRY 4.0: INSTRUCTION FOR MAINTENANCE OPERATIONS FOR HIGH VOLTAGE EQUIPMENT

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Abstract: *Augmented Reality technology is considered as one of the pillars of the Industry 4.0. Its use in different domains, such as maintenance, assembling, teaching, and training, quality control, product design, knowledge capturing etc., can greatly facilitate and improve performance of a human in the working environment. The paper reports about a prototype AR application developed to help operators to maintain high voltage grid equipment in the field. Given the high risk of performing that kind of operations, the safety and efficiency of the operators are essential. The preliminary tests of AR app prototype done in a quasi-realistic environment showed that it can make operators in these hazardous environments safer and more productive, to improve the quality of performance and their agility to react promptly in a no-well-known situations. Comparison between the working performance of an operator with and without the AR system was presented.*

Keywords: *Augmented Reality, Industry 4.0, Maintenance, Productivity, Quality assurance, Agility.*

1. INTRODUCTION

The “fourth industrial revolution”, or so-called Industry 4.0 as it is referred to also, changes the way companies manufacture and distribute their products. By integrating new digital technologies, such as Internet of Things (IoT), cloud computing and analytics, Artificial Intelligence (AI) methods, especially *machine learning* methods, etc., companies can improve the quality, productivity, and agility of their operations significantly. In manufacturing domain, the Industry 4.0 is based on the concept of the *smart factory,* which is characterized by use so-called Cyber-Physical Systems (CPS). These systems connect all entities involved in smart factories, such as people, machines, sensors, software, etc., for the purpose of collecting, monitoring, and analyzing the real-time information [1]. The real-time information is then used for better and faster decision making. Ideally, manufacturing processes should be controlled and improved automatically and intelligently using CPS.

R.Pierdicca et al [2] say that Industry 4.0 is enabled through nine pillars of technologies, with one of the pillars being Augmented Reality (AR), often called Mixed Reality. AR superimposes digital objects onto the real world, so that the digital and real objects coexist in the same space. As D.W.F van Krevelen and R. Poelman [3] observe, the AR system must combine real and virtual objects in a real environment, align virtual objects with real objects, run in three dimensions and in real time, with the possibility of interaction. By combining AR technology with other pillars of the Industry 4.0, such as Internet of Things (IoT) or Cloud technologies, information and data can be easily stored, accessed and displayed to anyone, at the right time in which the information is needed. D.W.F van Krevelen and R. Poelman [3] also suggest that AR could not only encompass sense of sight, but other senses also. Hearing, touch, and smell can also be part of the AR. Also, regarding visual experience, AR solutions are not restricted to particular display technologies, such as a flat touch display or HMD (head-mounted display) – one should expect new visualizing technologies in near future.

The AR technology can be used in different domains of Industry 4.0, such as: [4]: Product design; Manufacturing; Assembly; Maintenance; Inspection; Training, etc. Of course, AR is not limited to the application within industrial environment only. There are a plenty of cases of AR application in other domains [3]: Personal assistance and advertisement; Navigation; Touring; Military (design, combat and simulation); Medicine; Entertainment (sport broadcasting, Gaming); Education and training. An interesting exemplar of AR application that is not aimed for the industry is described in [5]. Jason Hashimoto and Hyoung-June Park developed an AR application for real-time fenestration design (design of windows and doors openings in buildings), which allows the user to visualize the daylight metrics, add, delete openings, modify their size and transfer them to other locations all in the real environment.

Even though the potential use of the AR is wide, the numerous challenges regarding the ergonomics of AR devices, then regarding continual calibration of AR software to the objects in real space, the compensation of cameras' optics aberrations, depth perception, limit the use of AR in industry in everyday life. Nevertheless, the AR technology is constantly advancing, and there are many examples and uses of the AR technology already, as well as numerous published papers regarding this topic. In section 2 we chose some interesting solutions and papers that deal with the use of the AR technology in the Industry 4.0 environment to present. In section 3 we present an in-house-developed AR application aimed for the maintenance operators of high voltage equipment in the field that aims increasing of productivity, improving of quality assurance, and providing greater maintenance operations agility. In section 4, results from the comparison test of maintenance tasks, done with and without the developed AR system are presented.

2. EXAMPLES OF THE AR USE IN TODAYS INDSUTRY 4.0

With overview or survey papers, we can gage the overall state of the particular field of interest. D.W.F van Krevelen and R. Poelman) [3] give a comprehensive overview of different AR devices, software, limitations, and applications of AR, as well as some examples of AR application. Eleonora Bottani and Giuseppe Vignali [4] examined the state of the art of AR technology in the period of 2006 to 2017.

In the field of teaching and training ([6], [7], [2]) one of more interesting works was done by S. Cukovic et al [6], in which the AR integrated CAD practice book was presented. Every 2D drawing of parts in the book has its own markers, so when the camera of an Android device detects it, the AR application superimpose the virtual 3D model over 2D drawing. Unity 3D engine was used to develop the application, and all 3D models were created in Catia v5 software. In the maintenance domain ([8], [9], [10], [11], [12]) remote maintenance is a popular topic, which is why R. Masoni et al [8] designed and implemented a tool for remote maintenance based on off-the-shelf mobile and AR technology. By using this tool, operator who is working in the place where failure has occurred, sends pictures to the expert, through the AR device. The expert can than send instructions (in form of 2D instruction symbols and text projected onto real environment) to the local operator.

In the domain of assembly, R. Pierdicca et al [2] developed the AR android application that helps operators with training-on-the-job purposes of assembly tasks. The application was used through Head Mounted Display (HMD) devices. They also conducted a case study which proved that this AR application reduces the execution time of tasks, and that HMDs provide an advantage of being able to have both hands free.

Main feature of the AR technology is data and instruction visualization. Therefore, many papers only deal with this topic ([13], [1], [14], 15]). H. Subakti and J.R. Jiang [1] present the design and prototype test of an indoor markerless AR system that displays different machine information, depending on the proximity of the smartphone camera to the machine. The system is composed of SCADA system and Asus Zenfone (which has depth cameras, Google Tango software and TensorFlow deep learning engine).

The AR technology can be a great tool for knowledge capturing ([16], [17], [18]) as well, which is why D. Amagmostakis et al [16] provide a review of the existing inspection planning systems and discusses the barriers and challenges of knowledge capture and formalization of knowledge. In addition, a methodology and an early-stage system prototype was presented, which is used to capture, digitize, and represent implicit knowledge in inspection planning with Coordinate Measuring Machines (CMM).

From the examples showcased above, it can be seen that AR is used in many different areas of Industry 4.0, which is why we will next present, in more detail, one example regarding the maintenance task, and discuss how the AR technology improved the presented process.

3. AR INSTRUCTION FOR THE MAINTENANCE OPERATIONS

The example that will be shown hereinafter is the AR application developed for instructing the operator in the field to perform maintenance operations with high voltage equipment, developed by Netico Solutions and Faculty of Mechanical Engineering University of Niš. The AR application provides visual instructions through 3D animations of the maintenance operations that are relevant to the particular operation step. The application is developed for MS HoloLens 1 device by using Unity3D engine.

The process of usage of AR app begins when an operator scans the identification QR code of the equipment that needs maintenance by AR vizor (MS HoloLens 1) - Figure 1. QR code size and its location on the predefined place of the equipment provide the necessary reference for the AR app to initially virtualize digital model of the equipment in the space right over the corresponding real object providing proper perspective at the same time.

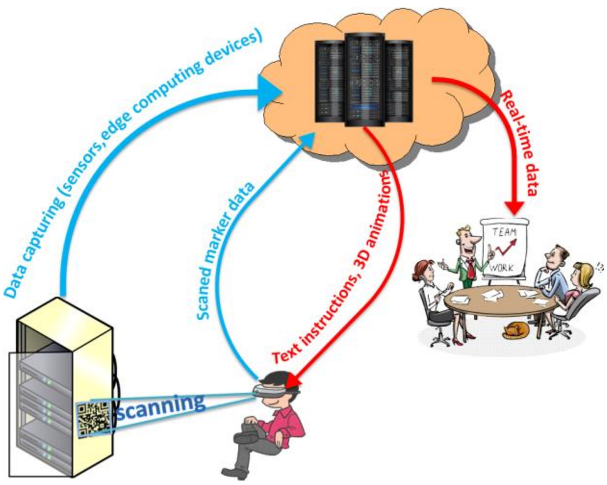

Figure 1. Diagram of the AR system

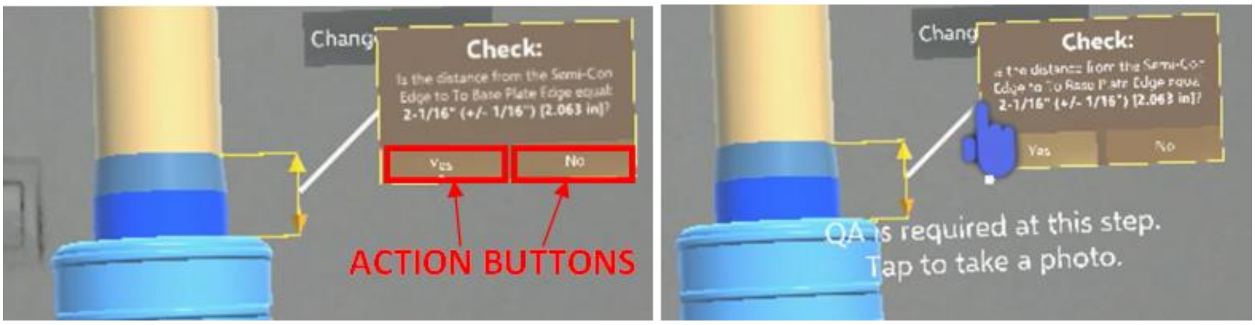

Figure 2. Following the instructions, operator provides additional information about the quality of the sub-sequence that is being performed

All the data relevant to the particular piece of equipment (identified by its QR code) are stored in the cloud, so AR vizor gets all the prepared 3D models of the equipment, scenarios and animations for the corresponding maintenance instructions. In addition, all the data captured by the sensors located inside and around the equipment, processed by the edge computing device and servers in the Cloud, which are relevant to the operation is being performed, are visualized to the operator in the field through AR visor, continually. At the same time, all the data that is being gathered is available to the operation management staff so they can trace operation conduction as well as all the relevant data including lead time. Of course, a permanent flow of data that is being acquired from the equipment sensors can feed the proper AI methods designed to process data thoroughly, helping decision making. The content of the AR application consists of three classes of ingredients: 3D objects, 3D scenery, 2D interface objects located in the appropriate space of the scene. The elements of the 2D interface are very similar to what we have on touch screens.

By identifying the equipment, the AR application offers the operator to choose which of the maintenance operations he wants to perform, or it can offer him to perform the one that is recognized as first needed (based on the scanned data from the equipment sensor). Operator selects the operation by the fingers' gesture and starts the maintenance task performing (Figure 2).

Maintenance operation (task) is composed of at least of one, but more often of two or more steps or sequences. Additionally, each sequence can be consisted of one or more sub-sequences like it is showed here: the sequence of Base plate installation is consisted of following sub-sequences: Preparing the base plate, Sliding the base plate onto the cord, Tightening the bolts of the plate, Extending the spring, etc. To ensure each (sub-) sequence of the maintenance/assembling operation is completed correctly, the operator is required to confirm that the task has been done and if it is required by the quality assurance (QA) instruction, to take a photo of the status of equipment after the sequence is completed (Figure 3).

As was stated in the first section of this

Figure 3. Selection of the device model (left) and the maintenance sequence (right)

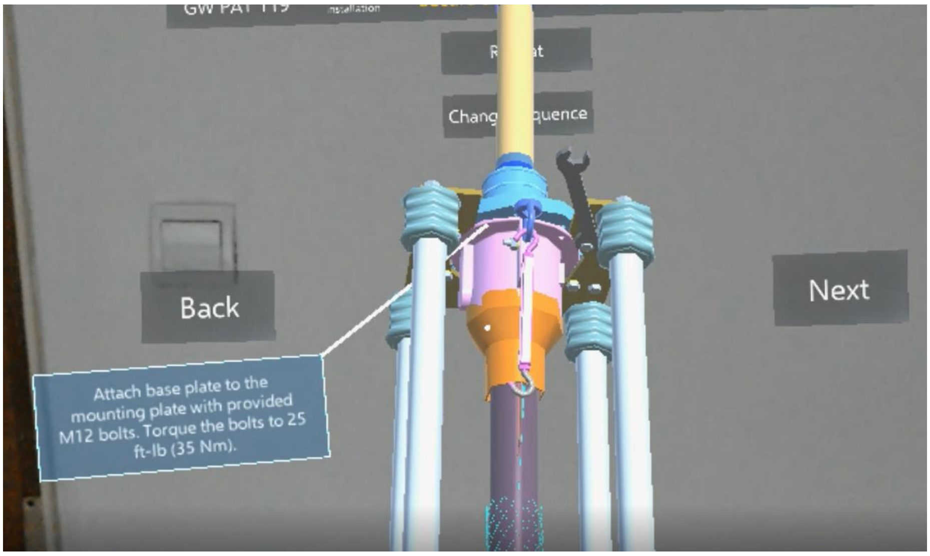

Figure 4. One sub-sequence of the maintenance operation, where the operator needs to tighten the screw on the bottom of the mounting plate, with the wrench

paper, the AR application improves the operators' productivity, performance quality and safety, and operators' agility (to safely apply newly defined procedure in a case of specific equipment requirements). Well prepared (detailed) visualization of the maintenance/assembling instructions enriched with 3D models of equipment, tools and animations of sequences guides the operators through the process smoothly (Figure 4).

Good visualization of spatial manipulations, which abound in assembly and maintenance operations, makes it possible to avoid often incomprehensible and unsuitable for use in the field instructions on paper. Following the instructions through AR visor, operators are able to perform their task in shorter period of time and with less corrective operations. At the same time, ensuring better workers' *productivity* is essential for the workers safety.

Specially developed QA checklists in AR environment for each step, enriched with additional content that can argue the operation output (by taking relevant photo or voice records), enables improvement of the operating quality. This way, AR application may help to avoid skipping of any sequence and or oversight or other mistakes. Agility of the operators can be indicated as a readiness to perform a specific maintenance operation (e.g., reassembling) in the field, that is not so usual. In this case, operator needs additional time to prepare (relearn) the operation. By using AR application, the time to do relearn any operation no matter how occasional it may be, i.e., to prepare himself to do little-known operation is reduced significantly.

In the next section, the results of the comparison test of operators working without and with the AR system, regarding productivity, high quality assurance and agility will be shown, as to prove starting theses that the proposed AR system can help the operators in all three aspects.

4. RESULTS

To determine and indicate capabilities of usage of AR in such a kind of operations, a series of tests of similar tasks was performed with and without using AR application. Having on mind that the experiments are done in a quasi-realistic environment, by performing just a part of an operation, the real data (absolute values, e.g., time in seconds for an operation) are not presented. However, it was interesting to present the data in the normalized form (Figure 5). Table 1 presents definitions of indicators for productivity, quality assurance and agility, unites by which they are defined with, as well as their normalized forms, and the diagram of the results can be seen in the Figure 5.

Table 1. Definitions and normalized forms of productivity, quality assurance and agility, selected for the data showcase

	Definition	**Normalized form**
Productivity	Time needed for the well-known operation realization, expressed in minutes (min)	***n*P*** – 100% without the AR system
		P – with the AR system
Quality assurance	Repeating the maintenance sequence due to errors, expressed in number of repetitions	***n*Q*** – 100% without the AR system
		Q – with the AR system
Agility	Time needed for preparing the operator for the new operation, expressed in minutes (min)	***n*A*** – 100% without the AR system
		A – with the AR system

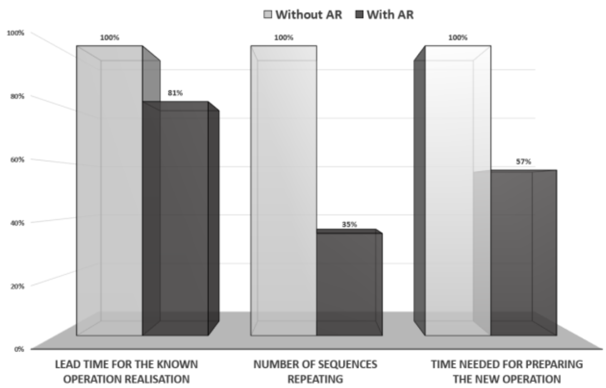

Figure 5. Comparison of normalized values for indicators regarding productivity, quality, and agility

From the interviews of test AR users, it was founded that the most difficulties of using AR come from AR visor low ergonomics. Most of the users claimed that they performance could be better if they had a wider visual field and the disposition of the masses of the visor is more balanced.

5. CONCLUSION

As more and more companies try to apply the doctrines inherent in "Industry 4.0", the application of augmented reality technology is becoming more and more present in real practice. The example briefly presented in the paper shows obvious benefits of using AR in manufacturing environments. Despite current issues of adopting AR due to insufficient ergonomic features of AR devices, it is clear that noticed benefits will intensify development of AR technology in near future. Potential savings that could arise by applying AR are significant. The prototype AR application aimed for the maintenance and assembling operations (of high-voltage grid equipment) showed that the productivity could be improved for at least 20%, and the quality for more than 60%. The agility of an operator to cope with operations for which is not well trained is increased for more than 40%.

Combined with the numerous equipment sensors, 5G network, edge computing devices and cloud computing services enriched with AI methods, it seems that augmented reality becomes the most preferable interface between human and industry 4.0 environment.

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PROFESIONALNO OPREDELJIVANJE MATURANATA – KAKVA JE POZICIJA MAŠINSTVA?**

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Apstrakt: *U ovom radu istraživano je koliko su maturanti zainteresovani za studije mašinstva i koji su to razlozi za potencijalni izbor mašinstva kao buduće profesije. Pored toga, cilj rada je utvrditi i da li postoje značajne razlike u školskoj uspešnosti maturanata i proceni značajnosti razloga za odabir studija između učenika koji su birali mašinstvo i onih koji su planirali studije u drugim oblastima. U istraživanju je učestvovalo ukupno 997 učenika četvrte godine srednjih škola (gimnazija i srednjih stručnih škola). Glavni rezultati ovog istraživanja ukazuju na to da maturanti srednjih stručnih škola pretežno nisu zainteresovani za studije mašinstva, dok su maturanti gimnazija umereno zainteresovani. Oni učenici kojima je mašinstvo jedna od opcija pozitivno vrednuju mogućnosti studiranja i zaposlenja u ovoj oblasti. Nisu utvrđene statistički značajne razlike u školskoj uspešnosti učenika koji su se opredelili za mašinstvo i onih koji su odabrali druge oblasti studija. Takođe, nisu utvrđene statistički značajne razlike u proceni značajnosti razloga za odabir određenih studija između ove dve grupe maturanata. Implikacija za dalja istraživanja odnosi se na praćenje i na detaljnije ispitivanje razloga koji utiču na privlačnost ove profesije.*

Ključne reči: *profesionalna orijentacija, maturanti, mašinstvo, srednje stručne škole, gimnazija*

1. UVOD

Veliki izbor profesija koji maturanti nakon završenih srednjih škola mogu da odaberu značajno usložnjava njihov proces donošenja odluke o svom budućem zanimanju. Ipak, kako se do sada pokazalo, studije u oblasti mašinstva nisu čest izbor novih generacija. Bez obzira na deklarisani značaj srednjeg stručnog obrazovanja za razvoj privrede i društva u Srbiji, opredeljivanje učenika baš za ona područja rada koja su osnova daljeg razvoja sistema obrazovanja i vaspitanja (posebno koncepcije dualnog obrazovanja) relativno je slabo, a srednje stručno obrazovanje u području rada Mašinstvo i obrada metala, kao deo celokupnog obrazovnog sistema u Republici Srbiji, susreće se sa mnogim teškoćama i izazovima savremenih društvenih tokova [1].

Ovaj rad ima za cilj da utvrdi koliko su maturanti zainteresovani za studije mašinstva i koji su glavni razlozi za odabir tih studija.

2. MAŠINSTVO KAO IZBOR UDUĆE PROFESIJE – EMPIRIJSKO ISTRAŽIVANJE

Osnovni predmet ovog istraživanja je profesionalna zainteresovanost maturanata srednjih škola za izbor mašinstva kao buduće profesije. Empirijski deo ovog rada izdvojen je iz obuhvatnijeg istraživanja profesionalnog opredeljivanja, izbora budućih studija i preduzetničke orijentacije maturanata, koje su sprovele autorke rada i studenti integrisanih akademskih studija Tehnike i informatike Fakulteta tehničkih nauka u Čačku [2, 3, 4, 5].

2.1 Instrument i uzorak

U navedenom istraživanju, sprovedenom školske 2017/18 i 2018/19. godine korišćen je instrument *Upitnik o profesionalnom opredeljivanju.* Ispitanici – maturanti su navodili tri mogućnosti – tri studijska programa koja su im privlačna za dalje školovanje (uz naziv studijskog programa, navodili su i fakultet/visoku školu i univerzitet). Upitnik obuhvata i petospepene skale procene važnosti razloga za odabir određenih studija (od 1 – potpuno beznačajno za mene do 5 – veoma mnogo značajno za mene).

Uzorak je obuhvatao 997 učenika četvrtog razreda srednjih škola. Ispitane su dve generacije maturanata – učenika gimnazija i srednjih stručnih škola u Čačku i Gornjem Milanovcu: 765 učenika četvrtog razreda u toku školske 2017/2018. godine i 232 učenika četvrtog razreda u toku školske 2018/2019. godine.

2.2 Rezultati i diskusija

Od ukupno 997 maturanata, njih 289 se opredelilo da ne nastavi svoje školovanje. Od onih koji su izjavili da će da nastave studije nakon srednje škole, samo 56 maturanata je biralo mašinstvo kao jednu od opcija za buduće studije, što je u proseku 7,9%. U sledećoj tabeli (Tabela 1) prikazana je raspodela učestalosti odabira studija mašinstva kao jedne od opcija u zavisnosti koji su tip srednje škole maturanti pohađali (gimnaziju ili srednje stručne škole). Rezultati ukazuju na to da se 40,3% maturanata iz srednjih stučnih škola opredelilo da ne nastavi studije, dok je taj procenat za gimnazijalce znatno manji (5,6%), što je i očekivano. U obe grupe učenika relativno je mali procenat onih koji su mašinstvo imali kao opciju za buduće studije. Ipak, taj procenat je značajno veći u grupi gimnazijalaca (10,8%) u odnosu na maturante stručnih škola (3,1%). U mnoštvu mogućnosti za odabir buduće profesije, kada postoji 11% onih koji biraju mašinstvo od ukupnog broja gimnazijalaca, može se reći da je to zadovoljavajuć broj. Za razliku od ove umerene „popularnosti“ mašinstva među gimnazijalcima, u srednjim stručnim školama je drugačije stanje i na osnovu našeg istraživanja može se reći da su maturanti srednjih stručnih škola vrlo malo zainteresovani za studije u oblasti mašinstva.

Tabela 1. Odabir studija mašinstva u zavisnosti od tipa srednje škole

Izbor studija	Tip škole				Ukupno	
	Gim	%	SSŠ	%	Broj	%
Bez odabira	18	5,6	271	40,3	289	29
Studije mašinstva	35	10,8	21	3,1	56	5,6
Druge studije	271	83,6	381	56,6	652	65,4
Ukupno	324	100	673	100	997	100

Ovo je zanimljiv nalaz kome se mogu pripisati različiti razlozi. Sa jedne strane, očekivano bi bilo da učenici srednjih stručnih škola pokazuju veće interesovanje za studije mašinstva. Međutim, imajući u vidu podatak da oko 40% ove grupe maturanata ne želi da studira, moguće je da sebe već vide kao zaposlene u svojoj struci nakon završenog srednjeg obrazovanja. Shodno tome, potrebno je detaljnije ispitati zbog čega ne žele da svoje znanje i veštine usavršavaju tokom studija. Rezultati istraživanja koje je imalo za cilj utvrđivanje stavova učenika mašinskih škola prema školi i nastavi pokazalo je da su učenici pretežno negativno procenjivali zadovoljstvo školom i nastavom [1], što se može dovesti u vezu sa ovakvim nalazom. Takođe, u prethodnim istraživanjima preduzetničke orijentacije maturanata dobijen je rezultat da učenici mašinskog područja procenjuju sebe spremnijim na rizik nego gimnazijalci, kao i da maturanti mašinske struke imaju izraženiju preduzetničku orijentaciju nego gimnazijalci [2]. Ta veća usmeravanja učenika ka svetu rada u srednjim stručnim školama, koji na kraju školovanja imaju određeno profesionalno zvanje i zanimanje [2], može delimično da objasni veliki broj odabira da se ne nastavi dalje univerzitetsko školovanje među učenicima srednjih stručnih škola. Druga istraživanja koja su se bavila profesionalnom orijentacijom maturanata dolaze do sličnog nalaza da se gimnazijalci pretežno opredeljuju za nauke u društveno-humanističkom i medicinsko-biološkom polju, dok je interesovanje za prirodne i tehničke nauke niže [6].

Istraživanje o profesionalnoj orijentaciji maturanata iz 2007. godine ukazalo je na tenedenciju učenika tehničkih škola da biraju zanimanja koja im nisu srodna [7] što govori o nezadovoljstvu odabirom srednje stručne škole. Rezultati istog istraživanja pokazuju i da najveći procenat učenika tehničke škole ne želi da nastavi školovanje na fakultetima u odnosu na ostale, što je u u skladu sa nalazima ovog istraživanja.

U cilju ispitivanja razlika u uspešnosti maturanata različitih opredeljenja, sprovedena je ANOVA i analize deskriptivne statistike.

Tabela 2. Prosečne ocene učenika

	Uzorak	Prosečna ocena	Standardna devijacija
Bez izbora	265	2,66	0,758
Studije mašinstva	54	3,28	0,738
Druge studije	625	3,33	0,678
Ukupno	944	3,14	0,767

Iz tabele 2 se može uočiti da maturanti koji ne žele da studiraju imaju najlošiju prosečnu ocenu (M = 2,66), dok maturanti koji se opredeljuju za druge studije imaju viši prosek (M = 3,33) u odnosu na one kojima je mašinstvo jedna od opcija (M = 3,28).

ANOVA analiza pokazuje da postoje statistički značajne razlike u uspehu maturanata na kraju 3. godine u zavisnosti od opredeljenja za buduće studije $F(2,941) = 87,08$; $p=0,000$. Međutim, te razlike su statistički značajne samo između grupe maturanata koji su se opredelili da ne nastave školovanje i dve grupe maturanata koji žele da nastave školovanje (u oblasti mašinstva ili drugih oblasti). Razlika u srednjim vrednostima između maturanata koji ne žele da studiraju i onih koji žele da studiraju mašinstvo je -0,621 (p=0,000), dok je ta razlika između maturanata koji ne žele da nastave školovanje i onih koji su se opredelili za druge studije -0,678 (p=0,000). Sa druge strane, ne postoje statistički značajne razlike u uspehu između grupa maturanata koji žele da studiraju mašinstvo i studije u drugim oblastima.

Radi dobijanja detaljnijeg uvida u značajnost određenih razloga za odabir budućih studija maturanata koji su mašinstvo izabrali kao opciju, u tabeli 3 prikazana je procentualna učestalost procene značajnosti određenih razloga.

Tabela 3. Frekvencija procena značajnosti razloga za odabir studija mašinstva

	Razlozi odabira studija	S.V.	S.D.	Učestalost značajnosti razloga [%]				
				1	2	3	4	5
1.	Nazivi i sadržaji predmeta na budućim studijama.	4,02	1,008	1,8	7,1	17,9	42,6	32,1
2.	Status profesije u našoj zemlji.	4,08	1,118	7,1	5,4	21,4	19,6	46,4
3.	Mogućnost da se steknu specijalizovana znanja i veštine.	4,53	0,790	0	3,6	7,1	23,2	66,1
4.	Mogućnost da se steknu široko primenljiva znanja i veštine.	4,53	0,779	0	1,8	10,7	26,8	60,7
5.	Mogućnost da se sa diplomom fakulteta radi u različitim poslovnim okruženjima.	4,39	0,919	0	1,8	16,1	10,7	71,4
6.	Mogućnost da se sa diplomom, znanjima i veštinama koje steknete zaposlite u Srbiji i drugim državama.	4,60	0,808	0	1,8	12,5	16,1	69,6
7.	Izazov i zanimljivost profesije za koju ćete se na studijama pripremati.	4,32	0,888	0	1,8	23,2	25	48,2

Rezultati iz tabele 3 ukazuju na to da učenici u visokom procentu vrednuju navedene razloge za odabir profesije ocenama iznad 3. Najniže procene su date za stavke koje se odnose na privlačnost nastavnih predmeta i sadržaja (M=4,02) i status profesije (M = 4,08), a najviše za stavku kojom procenjuju mogućnost zaposlenja u zemlji ili inostranstvu (M = 4,6). Nešto niže su procene za razloge u vezi sa sticanjem specijalizovanih i široko primenljivih znanja i veština (M = 4,53).

ANOVA je sprovedena i u cilju utvrđivanja da li postoje razlike u proceni navedenih faktora između maturanata koji su se opredelili za mašinstvo i onih koji su se opredelili za studije u drugim oblastima.

Tabela 4. Razlike u proceni razloga odabira studija između onih koji su odabrali mašinstvo i onih koji su odabrali studije u drugoj oblasti

		Iskazi o razlozima odabira studija						
		1.	2.	3.	4.	5.	6.	7.
Studije mašinstva	Srednja vrednost	3,95	3,93	4,52	4,46	4,52	4,54	4,22
	Uzorak	56	56	56	56	56	56	55
	Std. Devijacija	0,980	1,248	0,786	0,762	0,831	0,785	0,875
Druge studije	Srednja vrednost	4,03	4,10	4,53	4,53	4,37	4,61	4,32
	Uzorak	639	641	640	640	639	638	638
	Std. Devijacija	1,011	1,105	0,791	0,780	0,926	0,810	0,889
Statistička značajnost	F	0,351	1,166	0,009	0,417	1,261	0,396	0,725
	p	0,554	0,281	0,926	0,519	0,262	0,530	0,395

Rezultati iz tabele 4 ukazuju na to da obe grupe maturanata visoko vrednuju značaj navedenih razloga za upis studija (skoro sve procene su iznad 4). Međutim, ne postoje statistički značajne razlike u procenama ovih razloga između ove dve grupe maturanata (sve p vredosti su veće od 0,05). To ukazuje da svi učenici slično vrednuju svoje buduće studije bez obzira na njihovu oblast.

3. ZAKLJUČAK

Ovo istraživanje je pokazalo da maturanti srednjih stručnih škola pretežno nisu zainteresovani za studije mašinstva, dok su maturanti gimnazija umereno zainteresovani da nastave studije u oblasti mašinstva.

U narednom periodu može biti korisno periodično pratiti interesovanje maturanata za buduće studije mašinstva uzimajući ove vrednosti kao parametre za poređnje (3% učenika srednjih stručnih škola i 11% gimnazijalaca) i pratiti kakav trend se razvija. Drugo značajno pitanje i za istraživanje, a i za aktivno uticanje na promovisanje mašinstva kao poželjne profesije, odnosi se na pravljenje strategija koje bi se više „obraćale“ učenicima srednjih stručnih škola i koje bi pospešivale učenike i srednjih stručnih škola da u većem broju vide studije u oblasti mašinstva kao privlačan i ostvarljiv profesionalni izbor za sebe. Korisne smernice u tom pravcu mogu se naći u razlozima koje učenici kojima je mašinstvo jedna od opcija navode kada pozitivno vrednuju mogućnosti studiranja i zaposlenja u ovoj oblasti.

Na kraju, svi navedeni zaključci imaju ograničenje u pogledu generalizacije van područja moravičkog okruga na kom je izvedeno istraživanje. Svakako je potrebno uraditi istraživanje reprezentativno za odeđenu regiju naše zemlje ili na nacionalnom nivou, da bi se utvrdilo kakav je celokupan položaj mašinstva na mapi profesionalnog opredeljivanja maturanata u Srbiji. Takođe, uzorak je obuhvatao veoma raznolika područja srednjeg stručnog obrazovanja, ne samo ona koja imaju bliske veze sa mašinstvom, ali to nije bio predmet ovog rada i može biti polazna osnova za neka buduća istraživanja. Konačno, istraživanjem su obuhvaćeni odgovori koji se odnose na potencijalne izbore, bez informacija o tome koliko učenika zaista sprovede ta profesionala opredeljenja u delo.

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PROFESSIONAL ORIENTATION OF HIGH SCHOOL GRADUATES - WHAT IS THE POSITION OF MECHANICAL ENGINEERING?

Abstract: *This paper investigates how much high school graduates are interested in mechanical engineering studies and what are the reasons for potential choice of mechanical engineering as a future profession. In addition, the aim of this paper is to determine whether there are significant differences in the school performance of high school graduates and to assess the significance of the reasons for choosing studies between students who chose mechanical engineering and those who planned studies in other fields. A total of 997 fourth-year high school students (grammar high schools and vocational high schools) participated in the research. The main results of this research indicate that vocational high school graduates are mostly not interested in mechanical engineering studies, while grammar school graduates are moderately interested in mechanical engineering studies. Also, students for whom mechanical engineering is one of the options positively evaluate the possibilities of studying and employment in this field. No statistically significant differences were found in the school performance of high school students who opted for mechanical engineering and those who chose other fields of study. Also, no statistically significant differences were found in the assessment of the significance of the reasons for choosing certain studies between these two groups of high school graduates. The implication for further research relates to a more detailed examination of the reasons that affect the perception of this profession among high schoolers.*

Keywords: *professional orientation, high school graduates, mechanical engineering, secondary vocational schools, high school*

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GREY WOLF OPTIMIZATION ALGORITHM FOR SOLVING REAL-WORLD DESIGN OPTIMIZATION PROBLEMS

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Abstract: *In design of mechanical elements, designers usually consider certain objectives that are related with cost, time, quality and reliability of product depending on the requirements. In this paper, parametric optimization of spring design problem, pressure vessel design problem and cantilever beam design problem has been carried out using Grey Wolf Optimization Algorithm (GWO for short). The results obtained using GWO are compared with the results reported by other researchers. The source codes the GWO algorithm are publicly available at https://seyedalimirjalili.com/.*

Keywords: *optimization, grey wolf, spring, pressure vessel, cantilever beam*

1. INTRODUCTION

Metaheuristics are an impressive area of research with extremely important improvements in the solution of intractable optimization problems. Major advances have been made since the first metaheuristic was proposed and numerous new algorithms are still being proposed every day. There is no doubt that the studies in this field will continue to develop in the near future.

The most famous biologically inspired metaheuristic algorithms are: Differential evolution (DE), Ant Colony Optimization (ACO), Grey Wolf Optimizer (GWO), Bat Algorithm (BA), Whale Optimization Algorithm (WOA), Grasshopper Optimization Algorithm (GOA), Salp Swarm Algorithm (SSA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO).

In this paper, we will apply GWO for solving classical problems in engineering (spring, pressure vessel and cantilever beam).

The Grey Wolf Optimization Algorithm (GWO) is a novel metaheuristics algorithm proposed by Mirjalili. [4,5]. Grey wolf belongs to Canidae family. They are considered as apex predators, meaning that they are at the top of the food chain. Grey wolfs mostly prefer to live in a pack. Each group contains 5-12 members on average. The main parts of the GWO consist of siege, hunting and attacking the prey. The hunting behaviour of grey wolves is shown in figure 1.

Figure 1. Hunting behaviour of grey wolves

Description of GWO in detail can be found in [4].

2. GWO ALGORITHM FOR CLASSICAL ENGINEERING PROBLEMS

In this section, for each of the optimization problems we describe the basis of the problem. Every step of this process was done using the MATLAB R2018a software suite.

The first problem [1] consists of minimization of spring weight subject to constrains on minimum deflection, shear stress, surge frequency, limits on the outside diameter and design variables. The design variables are: coil diameter D, wire diameter d and number of active coils N.

In Figure 2 a schematic view of spring is shown.

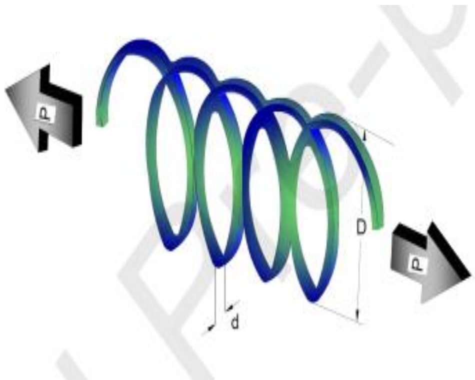

Figure 2. Schematic view of the spring with variable parameters

Goal function to be minimized is defined as:

$$f(x)=(x_3+2)x_2x_1^2 \quad (1)$$

Whilst the conditions to be met are:

$$g_1(x)=1-\frac{x_2^3x_3}{71785x_1^4}\leq 0; \quad (2)$$

$$g_2(x)=\frac{4x_2^2-x_1x_2}{12566\left(x_2x_1^3-x_1^4\right)}+\frac{1}{5108x_1^2}-1\leq 0; \quad (3)$$

$$g_3(x)=1-\frac{140,45x_1}{x_2^2x_3}\leq 0; \quad (4)$$

$$g_4(x)=\frac{x_1+x_2}{1,5}\leq 0; \quad (5)$$

$$0,05\leq x_1\leq 2; \quad (6)$$

$$0,25\leq x_2\leq 1,3; \quad (7)$$

$$2\leq x_3\leq 15; \quad (8)$$

Second problem is optimization of a pressure vessel, which consists of reducing costs of material, montage and welding costs. Four variables are defined for this problem: radius of shell, length of the shell, thickness of the shell and thickness of the dish end [2].

In Figure 3 a schematic view of pressure vessel is shown.

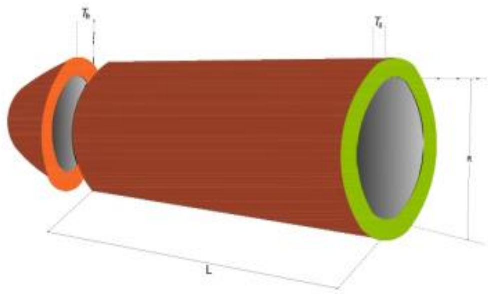

Figure 3. Schematic view of the pressure vessel with variable parameters

The goal function is defined by the equation:

$$f(x)=0,6224x_1x_3x_4+1,7781x_2x_3^2+3,1661x_1^2x_4+19,84x_1^2x_3 \quad (9)$$

Whilst the conditions to be met are:

$$g_1(x)=-x_1+0,0193x_3\leq 0; \quad (10)$$

$$g_2(x)=-x_2+0,00954x_3\leq 0; \quad (11)$$

$$g_3(x)=-\pi x_3^2x_4-\frac{4}{3}\pi x_3^3+1296000\leq 0; \quad (12)$$

$$g_4(x)=x_4-240\leq 0; \quad (13)$$

$$0\leq x_i\leq 100;\quad i=1,2; \quad (14)$$

$$10 \le x_i \le 200; \quad i = 3,4; \qquad (15)$$

Third problem considers the design of cantilever beam (figure 4). The cantilever beam is built using five, hollow, square -section, box girders, and the lengths of those girders are the design parameters for this problem. There is also one constraint for this problem [4].

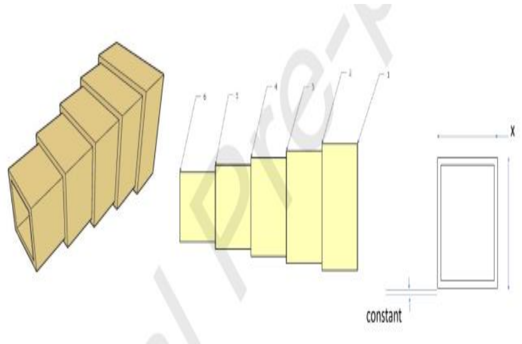

Figure 4. Schematic view of the cantilever beam with variable parameters

Goal function to be minimized is defined as:

$$f(x) = 0,6224(x_1 + x_2 + x_3 + x_4 + x_5), \qquad (16)$$

Whilst the only constraint for this problem being:

$$g(x) = \frac{61}{x_1^3} + \frac{27}{x_2^3} + \frac{19}{x_3^3} + \frac{7}{x_4^3} + \frac{1}{x_5^3} - 1 \le 0, \qquad (17)$$

$$0,01 \le x_1, x_2, x_3, x_4, x_5 \le 100, \qquad (18)$$

3. OPTIMIZATION RESULTS

In this section, the results obtained by using GWO algorithm on previously defined engineering problems is given.

Experimental research was performed for the helical spring problem, and the results of HHO algorithm, along with the results for PSO, GOA, and WCA algorithms, are given in Table 1. The expected value for the goal function in this case is 0.012665.

Table 1. Comparison of results for the spring

Variables	PSO[8]	GOA[5]	WCA[3]	**GWO**
x_1	0.0523	0.05	0.0516	**0.5000**
x_2	0.3722	0.3174	0.3562	**0.3173**
x_3	10.4141	4.4584	11.3004	**10.3038**
f(x)	0.0128	0.0128	0.0126	**0.0127**

In the case of helical spring optimization, GWO gives nearly the same result as WCA, while PSO and GOA giving a slightly worse result.

For the pressure vessel problem, the expected value for the goal function is 5885.3327, with the results shown in Table 2.

Table 2. Comparison of results for the pressure vessel

Variables	PSO[8]	GOA[5]	WCA[3]	**GWO**
x_1	0.822	0.8736	0.7781	**0.779**
x_2	0.406	0.4318	0.3846	**0.385**
x_3	42.602	45.2666	40.3196	**41.225**
x_4	170.484	199.9998	200	**199.116**
f(x)	5964.50	7666.1258	5888.3327	**5888.234**

In this case, the GWO gives the same result as the WCA algorithm, while PSO and GOA gave worse results.

For the cantilever beam design problem, the results shown in Table 3, along with the results obtained by ALO, MMA and GOA methods.

Table 3. Comparison of results for the cantilever beam

Variables	ALO[6]	GOA[5]	MMA[7]	**GWO**
x_1	6.018	6.011	6.010	**6.0298**
x_2	5.311	5.312	5.300	**5.3065**
x_3	4.488	4.483	4.490	**4.4807**
x_4	3.497	3.502	3.490	**3.5166**
x_5	2.158	2.163	2.150	**2.1408**
f(x)	1.339	1.339	1.340	**1.34**

In this case, the GWO gives the same result as the MMA algorithm, while ALO and GOA gave better results.

4. CONCLUSION

This work proposed a metaheuristic optimization algorithm inspired by grey wolves. The proposed method mimicked the social hierarchy and hunting behavior of grey wolves. In order to get further information, three structural engineering (i.e. design of a tension/compression spring, design of a pressure vessel, and design of a cantilever beam) were solved. By using this algorithm, we obtained optimal or near-optimal results, shown in the previous section. The results were shown in table 1,2 and 3. By further development of this algorithm, this method can be modified and improved in order to obtain better results.

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DIGITAL TWIN TECHNOLOGIES AS AN ENABLER OF THE NEXT LEVEL OF PLM EVOLUTION

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Abstract: *As a business paradigm that enables a "product-centric" management perspective, PLM represents a key strategy for achieving company business excellence, also significantly supports growing industry needs for developing technologically superior and market-sustainable product innovations. However, new product development processes have undergone dramatic changes during the last decade, influenced by increasing product complexity, technological progress, and new engineering and market trends. Aimed at supporting today`s changed product development processes more efficiently, PLM systems are facing a higher level of need to adapt by introducing a new type of technology. Many authors agree that Digital Twin technologies bring about a possible means for upgrading PLM's capabilities to respond to current new product development challenges and growing complexities. The paper is aimed at contributing to a comprehensive understanding of how Digital Twin fits into the overall PLM concept, also it discusses how it complements the PLM system capabilities to overcome today's challenges in product-related operations.*

Key words: *product management, PLM, Digital Twin, innovation management, new product development*

1. INTRODUCTION

Product Lifecycle Management (PLM) is a business paradigm enabling a so-called "product-centric" management perspective. This concept is oriented towards the integration of the company's functions by connecting and controlling business processes through collaborative creation, management, and use of product-related information, using a consistent set of integrated IT solutions.

Given the rather heterogeneous conceptualizations of PLM, there is no single perspective on what exactly PLM contains. Namely, it is a multi-layered and multidimensional concept that encompasses different heterogeneous issues such as organization, management, processes, economic issues, techniques, and tools. Despite the pronounced IT dimension, it is not just a technology, but a „comprehensive, systematic and scientific-based approach to enterprise performance management based on a coherent and consistently integrated information system“ [1].

PLM could be understood as an integrated, information-based approach consisting of people, processes, and technologies covering all aspects of the product life cycle, from its design through production, implementation, and maintenance, to final disposal [2].

Today, PLM has the status of "a new paradigm of the 21st century for the realization of products - a new view on the product world" [3] as well as of the most effective responses to the challenges of the modern business environment, such as the increasingly intense process of globalization, shorter product lifecycles and increasing demand for a wide range of complex, sophisticated and customized goods and services.

During the last decade, PLM is becoming a key strategy for achieving business excellence. According to [4], globalization and technological progress are highlighting the need for the PLM concept, to help turn emerging markets into emerging economies, and mature markets into innovator markets.

Moreover, this approach shows great potential to support the modern industrial companies' need to develop technologically superior and market-sustainable product innovations efficiently and economically. Zammit et al. [5] indicate that these PLM effects are manifested through greater efficiency of the entire innovation process, where they can be observed through the operational, organizational and strategic dimensions. Some of these benefits include: reducing new product development costs [6], a higher level of product innovativeness [7], shorter time to market [8], a higher degree of innovation market success [9], achieving economic, sociological and environmental aspects of sustainability of product development processes [10], faster response to customer requests [11].

However, new engineering trends in product development, market demands, rapid technological progress, and increasingly complex technologies embodied in products, have influenced significant changes in product development processes and caused the growing need to raise the level of PLM digitization. On the other side PLM systems, with their standard capabilities are no longer able to reflect the entire digital product with all types of systems and subsystems throughout the product lifecycle. This leads to the inability of providing effective support in the development of technologically superior and market-sustainable product innovations.

In addition, a new approach is required to deal with the rapidly growing complexity of product-related data, also with its complex relationships that can't be managed manually.

Bearing in mind the above-mentioned challenges, it is clear that PLM capabilities need to be built up by introducing a new type of technology. Many authors agree that the Digital Twin (DT) technologies bring about a possible means for upgrading PLM's capabilities to respond to current new product development challenges. These technologies provide realistic virtual models of products to simulate their characteristics, behavior, and performances in operation, enabling generating, tracking, and interpreting an enormous amount of product-related data on time. Thus creating a new environment that supports overcoming today's complexity in product-related operations.

The paper will provide insight into the concept of DT and the business benefits that the introduction of DT technologies brings, as well as contribute to a comprehensive understanding of how DT itself fits into the overall PLM concept. Also, it discusses how DT technologies impact the adaptation of PLM systems to overcome today's complexity in product-related data and its relations.

2. A NEW PRODUCT LIFECYCLE MANAGEMENT CHALLENGES

During the last decade, the new product development processes have undergone dramatic changes influenced by increasing product complexity, technological progress, and new engineering and market trends.

Market demands and technological progress lead to evolution from the concept of „standalone" to the product that includes multiple technologies, components, and systems inside and outside a single product. On the other side, the increase of product complexity is not reflected only in the growing number of assemblies they contain, but in the increasing complexity of embedded technologies.

Due to the transition from purely mechanical to mechatronics systems, electronic, mechanical, and software components are integrated into the same entity, hence cross-disciplinary collaboration at all stages of the product lifecycle becoming the key enabler of product quality. Moreover, new product development technologies are becoming increasingly complex, besides, the fusion of heterogeneous technology becoming regarded as an important factor of successful innovation development.

In addition, today world is increasingly moving towards a new way of looking at the product world, according to which the product is no longer just a mere artifact, but the so-called „ecosystem“ or multiple complementary products that the company offers to its customers to purchase and use in tandem, which besides the tangible product core include intangible assets such as product-related services. Also, the product ecosystem doesn't cover only the scope of the product itself but the environment the product is interacting with. So the scope that needs to be addressed by product design increases from a single product to its complementary products, product-related services, and environment the product is interacting with.

Also, as a result of the complexity that accompanies the digitization of products and manufacturing systems has made the development process even more of a multi-discipline effort. [12]

These changes and complexities caused the rapidly growing complexity of product-related data, as well as its complex relationships and flows. Moreover, their interpretation in the form of knowledge becomes increasingly difficult. On the other side, new engineering trends in product development require enhanced capabilities of product-related data visualization as well as predictive capabilities using "virtual reality".

Due to its inability to support a changed product development process efficiently, PLM systems are facing a higher level of need to adapt. PLM systems must be able to accurately describe and simulate all aspects of the product in a multi-domain environment. Also, PLM systems must continually adapt to and support emerging digital trends, the level of PLM environment digitalization needs to be raised to a higher level, namely, PLM systems must be able to reflect the entire digital product with all types of systems and subsystems, as well as their interaction throughout the product lifecycle.

Moreover, PLM systems need to be adapted to become more comprehensive product innovation platforms and to support product optimization across multiple lifecycle domains from the conception and among the entire lifecycle and to overcome today's complexity in product-related operations.

One of the possible directions of the PLM capabilities evolution is related to the use of DT enabling technology, due to its ability to provide product-related information with increasing level of detail; capability to provide a digital description of components, products, and systems including the information from all product lifecycle phases; and potential to enable reaching a higher maturity level in all PLM processes. In addition, DT technologies are shaping PLM's evolution by expanding the platforms' scope, modify its architectures and enhance software capabilities. [12]

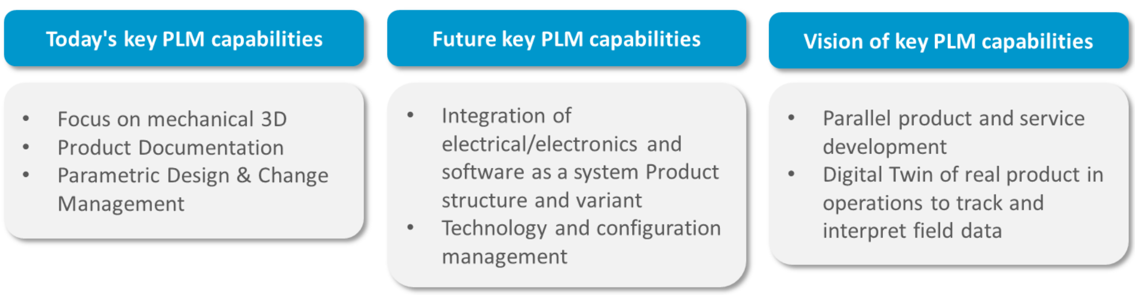

Figure 1. Directions of PLM capability evolution [13]

3. THE CONCEPT OF DIGITAL TWIN

According to Cunbo et al. [14], DT presents a virtual, dynamic model in the virtual world that is fully consistent with its corresponding physical entity in the real world and can simulate its physical counterpart’s characteristics, behavior, life, and performance in a timely fashion. Fei et al. [15] defined DT as an integrated multi-scale and probabilistic simulation of a complex product or system to mirror the life of its corresponding twin. DT composes three elements: physical products in the real world, virtual products in the virtual world, and data transfer between the real and virtual worlds [16]. It is a bi-directional relation between a physical artifact and the set of its virtual models, which enabling the efficient execution of product design, manufacturing, servicing, and various other activities throughout the product life cycle [17]. In addition, Lim et al. [18] indicate that DT technologies enable reflecting interactions between humans, machines, objects, and environments within simulation models in a realistic manner.

DT enabling technology and associated tools link the real and the virtual worlds together, providing a set of realistic virtual models of a product in operations that simulate its physical twin’s characteristics, and behavior. This provides product design optimization, reduction of operational cost, improving productivity, and process efficiency. Also, connection with advanced analytics together with a remote data collection system enables a better understanding of operational data and improving decision-making processes during the product development and operation.

According to CIMdata [19], the business benefits that DT delivering to companies include:

- Early detection of system performance through advanced performance simulation and intended use.
- Assessment of the current and future capabilities of the system during its life cycle.
- Preliminary optimization of the machine settings.
- Determination of the optimal maintenance point.
- Education in a virtual reality environment to help future operators to become familiar with the product-specific operations.
- Optimization of products processes during real-time operation.

4. THE DIGITAL TWIN AND PLM

The company's ability to develop a technology superior and market-sustainable product innovation is limited by the gaps in information flows between the BOL (Beginning of Life) product lifecycle phase, ie product development and production activities; the MOL (Middle of Life) phase, ie product exploitation, and maintenance, and EOL (End of Life) phases involving product recall.

Overcoming these gaps gave rise to the need for closing the product lifecycle information loop. Schuh et al. [11] identified the key elements required to be established for closing the product lifecycle information loop (Figure 2): from integrating product development and process specification, and dynamic requirements management to lifecycle environmental impact analysis and service and maintenance data reuse at product development.

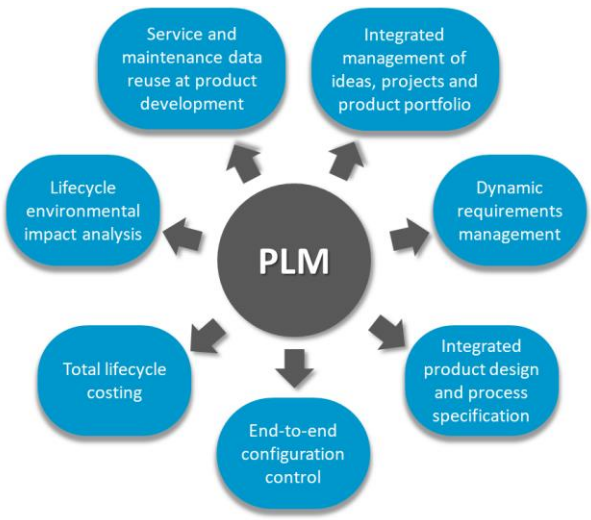

Figure 2. Elements necessary for closing product lifecycle information loop [11]

According to CIMData [20], such a concept can be achieved by implementing a PLM system that must provide:

- universal, secure, managed access and use of product definition information;
- maintaining the integrity of the product definition and related information throughout the entire product lifecycle;
- managing and maintaining business processes that generate, manage, disseminate, share and/or use product information.

In today's conditions of a rapidly growing complexity of product-related data and its complex relationships, this is becoming an increasing challenge. Namely, PLM platforms must strongly support dynamic updates and feedback, as well as deliver the accuracy required to predict behavior and optimize product performance. [12] In such conditions, the concept of the DT gradually becomes vital for closing the product lifecycle information loop, due to its ability to adapt PLM capabilities for meeting the above requirements. Furthermore, DT is capable to connect product development and manufacturing information the real-world product performance information. [12]

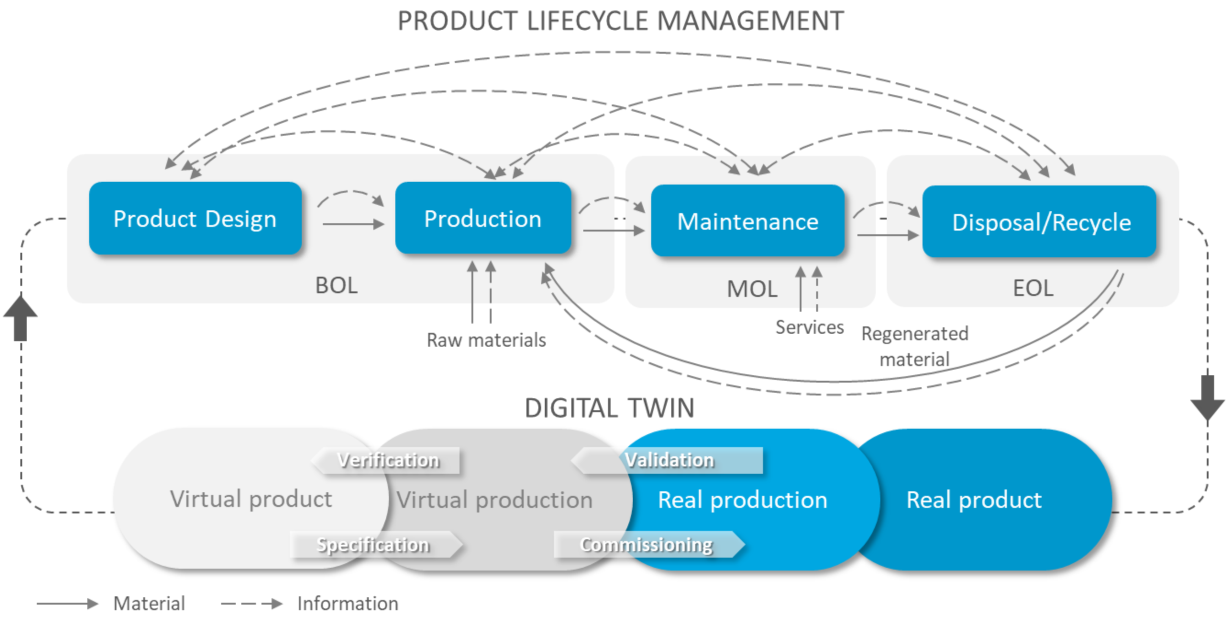

Figure 3. Closing the PLM information loop with Digital Twin

DT concept could be considered as a decentralized approach to managing product-related information in the virtual space along the entire product lifecycle. [16] It is capable to create, modify and use data to support all phases of a product's lifecycle from BOL through MOL to EOL phases.

Namely, DT moves with the physical model of the product during its entire lifecycle and helps to absorb and integrate enormous amounts of data and knowledge about its characteristics and performance by simulation of its physical counterpart's real behavior. DT provides digital product definitions in a managed, secure, and controlled environment that supports effective access and data reuse of all aspects of the product lifecycle, i.e. product development, production, maintenance, and disposal. This also includes all process definitions that create the product such as machining and molding processes and other processes in the value chain.

Besides static data, DT technology feeds PLM systems with dynamic real-time data, generated from the set of DT models, such as system models, functional models, metaphysics models, manufacturing models, usage models, etc.

In addition, DT may be applied to enhance simulation and product traceability during the product lifecycle and to support the offering of value-added services along the lifecycle. [17]

Moreover, DT is becoming a key technology to realize the comprehensive digital description of components, products, and systems including the information from all product lifecycle phases. Namely, DT enables digitally mirroring the lifecycle of a physical product with more comprehensive data and accumulation of knowledge, which leads to raising the PLM digitalization to a higher level.

According to Lim et al. [18] by adopting DT companies can focus on relevant PLM aspects for product enhancement including design and production integration; analysis and validation; production digitalization; production optimization; monitoring production process; supply chain optimization; warehouse management; workflow improvement; shop-floor enhancement; increasing energy and resource efficiency, knowledge reuse and evaluation, etc.

The information obtained from the DT simulation can be used to support the monitoring of all product lifecycle activities and enhancing decision-making outcomes.

DT frameworks and technologies enable the improvement of the design phase and make the production process efficient, reliable, and adaptable. Using real-time monitoring and other solutions, DT facilitates operations during the logistics phase. Using the ability of DT during the exploitation phase, the prediction and design of next-generation products, product upgrades, and support for the maintenance of production assets are enabled. [18]

PLM systems are also considered as a product innovation platform that provides a comprehensive set of heterogeneous applications that are integrated and configured to support product optimization across multiple lifecycle domains from the concentration and among the entire lifecycle.

Modern product innovation platforms must be built in a way to overcome complexity in today’s new product development processes. In the other words, today`s PLM systems need to be adapted to become more comprehensive product innovation platforms and to overcome today’s complexity in product-related operations. In that context, DTs play a significant role.

As a set of "realistic product and production process models DT links enormous amounts of data to fast simulation, which allows the early and efficient assessment of the consequences, performance, quality of the design decisions on products and production line." [21]

„These capabilities allow the enterprise to focus on innovating to create value, leveraging higher level or more advanced product innovation platform capabilities to assess product and business scenarios to optimize the business.“ [22]

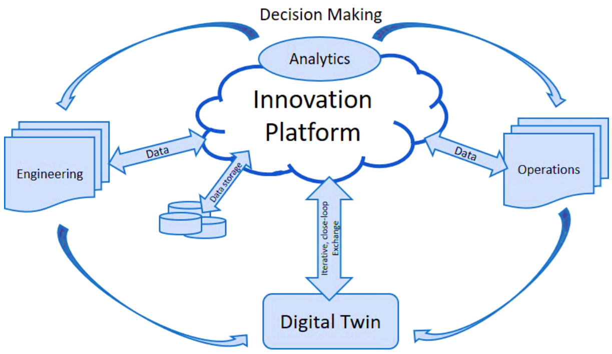

Figure 4. PLM innovation platform and DT [19]

Moreover, a new approach is required to deal with the rapidly growing complexity of product-related data, also with its complex relationships that can’t be managed manually. One of the most effective approaches for managing today’s complexity of product-related data and processes is Model-Based Engineering (MBE).

Namely, “MBE is an approach that uses mathematical multi-dimensional models as an integral part of the technical product definition that includes the requirements, analysis, design, implementation, and verification of a product throughout its lifecycle beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.” [22]

Its application must be efficiently supported by the PLM system, in other words, "PLM platforms are expected to leverage engineering approaches to embed modeling methodologies and put simulation of mechatronics structures together with associated materials and software management at the core of the engineering-manufacturing cross-loops." [23] In addition PLM „platforms must be agile enough to accommodate a broader range of data types and formats and powerful enough to support MBE". [12] Also, a fundamental tenant of the MBE approach is that development teams must be able to build a holistic system model to ensure the collaboration of all contributing disciplines. [12]

However, the full-scale alignment between PLM and MBE approaches requires the implementation of DT enabling technologies. Namely, critical elements of MBE are Digital Twin models of products and processes used as the virtual representation of the complete product definition including mechanical, electronic, and software items that describe the product, from concept through its lifecycle. DT has the potential to monitor processes, create a virtual reality of actual operations in real-time. In addition, it is not just a descriptive model of related digital information, but the digital description including all the behaviors of physical equivalent.

The integration of PLM features and DT enabling technologies brings optimization of change management processes too, reduction of their complexity and uncertainty, as well as minimization of changes impact on later product lifecycle phases.

By digital prototyping, a numberless of modifications can be modeled without spatial and temporal constraints; also it could be used to validate product functionality and behavior after a change implementation, in a virtual space.

Furthermore, users can test for different "what if" scenarios for changes in the design, materials, manufacturing parameters, logistics, and operational conditions, etc., also, the effects of the modifications to the other phases of the life cycle could be assessed. [24]

5. CONCLUSION

DT technologies bring about a possible means for adapting PLM's capabilities to respond to current challenges in new product development processes, the rapidly growing complexity of product-related data, and its complex relationships. Some of the key aspects of the PLM evolution driven by Digital Technologies include the following:

- Enhancing simulation and product traceability during the product lifecycle
- Enabling companies to focuses on relevant PLM aspects for product enhancement
- Contribution to closing product lifecycle information loop in conditions of the rapidly growing complexity of product-related data and its complex relationships
- Raising the PLM digitalization to a higher level by providing a comprehensive digital description of components, products, and systems, including the information from all product lifecycle phases
- Enabling monitoring of all product lifecycle activities and enhancing decision-making outcomes
- Extending of PLM platforms to become more comprehensive product innovation platforms and to overcome complexity in today's new product development processes
- Adapting PLM platforms for leveraging engineering approaches that use multi-dimensional models as an integrated part of the technical product definition such as the MBE approach
- Optimization of change management, and minimization of their impact on later product lifecycle phases

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ANALYSIS OF THE IMPLEMENTATION OF WIELAND FACTORY SUITE INFORMATION SYSTEM IN THE PRODUCTION AREA OF WIELAND THERMAL SOLUTIONS AND ITS INTEGRATION WITH SAP

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Abstract: *This paper summarizes the main results obtained from a master thesis developed in a company. The aim of the project was to analyse since the beginning the implementation of a Manufacturing Execution System (Wieland Factory Suite) and an Enterprise Resource Planning (SAP) in a company from HVAC industry, Wieland Thermal Solutions. Prior to the implementation, the information system architecture of the company was only based in paper files, excel files, and two main databases, what means that the information was not integrated.*
The main results with the implementation of these two new systems are the hig level of digitalization, reduction up to 95% of paper use in the shopfloor, a solid integration between systems and all departments, a high user satisfaction (about 60% of total respondents) and all these achievements were reached by using just 80% of the previously defined budget.
As suggestion for improvements and future work were identified two main topics, the need to have the changes made in SAP and MES reflected in MES after releasing production orders from SAP to MES and the reengineering of business processes in what concerns to quality checks.

Keywords: *Manufacturing Execution System, Enterprise Resource Planning, Integrated Management Systems, Wieland Factory Suite, SAP.*

1. INTRODUCTION

The company, Wieland Thermal Solutions, integrates the German group named Wieland and it's a market leader in the industry of HVAC producing technical tubes.

Due to the fact that their old systems (excel files, paper files, databases) were not integrated it were identified problems dealing with all the information/data that comes out of day-to-day work. It was very difficult to keep a trace or even search for some specific information. And one of the worst cases was the situation that the production manager only knew the productivity of the day afterwards in next morning.

Based on that was decided internally to implement an integrated management system.

In order to analyse the results of the whole implementation process, prior to the implementation was necessary to have a closer look on how the production worked and analyse the reasons that lead to decision of implementing an integrated management system.

After the systems Go Live, surveys were distributed to all three organizational levels (strategic, tactical, and operational levels) in order to identify the positive and negative or constraints of the implementation and most importantly to evaluate the user satisfaction towards these new systems use.

2. STATE OF THE ART

2.1 Information Systems and Information Technologies

Information systems can be defined as a group of components (books, drawings, records) which collect and organize data and information [1][2].

Information technologies are directly related with the computer invention, mostly with the software part that deals with all the data and turns it into more valuable information [2][3].

2.2 Enterprise Resource Planning

The use of computers in industrial environment started in 1960/1970. Back to that time the organizations started developing their own software in order to have a clear look of their stock levels, to facilitate the order process from their suppliers, and also to have records during production to support production planning [4].

Over the years these systems were being developed and improved, and this evolution can be organized as shown in Figure 1.

2021 and Future	Intelligent ERP (iERP)
2010	ERP cloud computing based (ERP III)
2000	Extended Enterprise Resource Planning (EERP)
1990	Enterprise Resource Planning (ERP)
1980	Manufacturing Requirements Planning (MRP II)
1970	Manufacturing Requirements Planning (MRP)

Figure 1. Chronological organization of ERP systems evolution.

Nowadays, we are experiencing the growth of IERP. These new generation of ERP uses technologies such as artificial intelligence, machine learning, augmented reality, big data, cloud, mobile and business intelligence in order to reach a high predictive capacity based on historical data [5].

2.3 Manufacturing Execution System

Manufacturing Execution Systems (MES) are considered the bridge between ERP and the the shopfloor, these systems guarantee the execution of production processes [6].

MES receive input from ERP first, then the operators insert data in MES during production process, and this data is uploaded to the ERP almost in real time as these two systems are in constant communication. These systems can also be seen as a way to control and optimize production processes [7].

3. IMPLEMENTATION PROCESS

The ERP and MES implementation process had 4 main phases in order to be concluded with success.

Scoping lasted two months and during this period of time were defined the risks, deadlines, goals, processes, requirements and also an estimation of how much hours were needed to each task. This step was closed with a declaration of agreement between Wieland Thermal Solutions and the implementation team (members of Wieland from Germany).

During the second phase, templating, the systems were parametrized based on the requirements previously defined. Also during this time, almost 9 months, there was provided training for all types of users, it was prepared and assembled the whole infrastructure on the shopfloor in order to have there the computers and also WiFi, and finally one of the most critical steps occured when implementing the new system, with the migration of data from the old system to the new one.

The third phase was the Go-Live and it was when the company abandoned all the old information systems and started using just the new system, integrating ERP and MES.

After Go-Live there was the phase of 'hypercare'. At this stage, Go-Live, the systems were not 100% well maintained and also it was when the users experienced the systems live for the first time and thus many errors did occur with further corrections and implementation cycles. Therefore, the so called 'hypercare' phase was considered to be of upmost importance, and which did not imply the stoppage of the production at the company do to the occurrence of problems in the information systems and data handling.

4. CONCLUSION

As mentioned before, the company Wieland Thermal Solutions had a very difficult time when using their old information systems.

Based on survey results it's possible to affirm that the major difficulties were the manual data insertion, the high level of disintegration of files (and consequently between departments) and the amount of time spent when looking for some specific information/data.

The base, or the main motivator to the implementation of an integrated ERP and MES solution (specially the decision of which software should be used) were the decisions of high level at the Wieland Group to have all the entities using the same systems in order to standardize and facilitate the management process. It was also identified the possibility to have access to reliable data in real time and the implementation came as an opportunity to re-engineer some of the business processes.

The identified benefits of using these new information systems were the reduction of paper use on shopfloor (at almost 95%) and the high level of integration and digitalization that lead to more valuable and safe information in real time.

As any other project it also had some disadvantages and the respondents listed the complexity of the ERP system, the cost of all implementation project and the productivity decrease in the first weeks after the Go Live.

In what concerns to the general user satisfaction level, and also to the budget usage in this project it is possible to affirm that this implementation was a true success. Almost 60% of the respondents are satisfied with the introduction of a new system in their day-do-day work and in regarding the budget is was only used 80% of the total amount previously defined, which is a very rare case in ERP implementations.

As limitations or future work for this project there are two main topics, the possibility to be reflected in MES all changes made in SAP after the production order has been released to MES (mainly changes in quantities to produce, changes in delivery dates, etc.) and the re-engineering of business processes regarding to quality checks during the production (there are too many quality inspections and this cause the MES system to get slower).

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ANALYSIS OF CONTRIBUTORY FACTORS ON THE TECHNOLOGICAL CYCLE TIME

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Abstract: *The paper problematizes the relationship of the duration of technological cycle time concerning the duration of technological operations, sizes of the production batch and the mode of workpiece move. Recent literature sources only confirm that the technological duration of a cycle, based on a parallel movement of the item is the shortest one, whereas the consecutive is the longest, and the combined duration has values that fall somewhere in between of these two extremes. So far, neither the impact of the production-transport batch onto the duration of the cycle has been researched in detail, nor its impact on the intra-operational losses.*

Keywords: *technological cycle time, mode of workpiece move, production batch, intra-operational losses.*

1. INTRODUCTION

In terms of theoretical considerations, industrial practice and duration, three types of cycle time length can be distinguished: technological cycle time or ideal manufacturing cycle ($T_t \equiv T_{ci}$, $t_t \equiv t_{ci}$), manufacturing (real) cycle (T_{cs}, t_{cs}) and projected manufacturing cycle (T_{cp}, t_{cp}), Fig. 1.

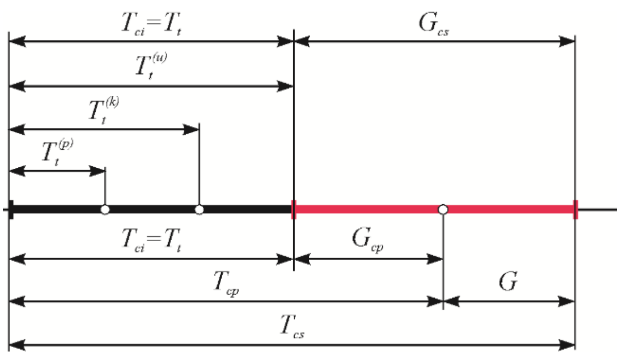

Figure 1. Types of cycles as determined by duration

Time dimension of the technological cycle includes the projected times necessary for performing all technological operations, of the production phase (t_t) or complex item (T_t), on the items of a single lot. The benchmark points of the technological cycle (TC) of any production phase were defined at the start of manufacturing the first item in a lot, on the first operation, and at the end of manufacturing the last item in a lot, on the final technological operation. The production phase (PPh) implies a segment of the manufacturing and technological process characterized by a sub-set of technological operations by means of which the workpiece is transformed from one to another qualitative condition.

The TC length (t_t) of PPh is affected by the total number (n) of operations, time of technological operations $\theta_n = (t_i, i = \overline{1,n})$, lot size ($q$) and batch ($p$), as well as by the workpiece move (WM) that can be consecutive

(U), parallel (P) and combined (K), relation (1). In the current Russian literature other parameters are also used, e.g. number of workplaces, [1-7]. Given that this is an organizational element, influential in cycle projection, its impact on TC is eliminated, assuming that each technological operation is executed in a single workplace.

$$A = \{n, \theta_n, q, p, WM\} =$$
$$= \left\{n, (t_i, i = \overline{1,n}), q, p, \{U, P, K\}\right\} \Rightarrow$$
$$t_t = \left\{t_t^{(u)}, t_t^{(p)}, t_t^{(k)}\right\}. \quad (1)$$
$$t_t^{(p)} < t_t^{(k)} < t_t^{(u)}. \quad (2)$$
$$t_t^{(p)} \le t_t^{(k)} < t_t^{(u)}. \quad (3)$$

Depending on the duration of technological operations (t_i), sizes of production batch (p) and mode of workpiece move (WM) there are three dilemmas related to the technological cycle of the operation and the production phases:

1. Ratio between the technological cycles (TC) production phase (PPh) based on consecutive (U), combined (K) and parallel (P) methods are defined by relation (2) which has its stand in the majority of relevant literature resources [8-15]. This implies that the duration of TC based on the parallel method WM is the shortest, based on the consecutive the longest, and based on the combined method falls somewhere in between of these two extremes. However, the duration of TC based on the parallel and the combined methods can be identical in certain circumstances, relation (3) [16, 17]. The first dilemma stems from this first premise.
2. The impact of the production-transport batch onto the duration of TC PPh emerges as the second dilemma, a problem that has been under-researched so far.
3. A causal connection between the production-transport batch (p) and intra-operational losses τ_{uo_i}, based on the parallel method WM, emerges as the third dilemma that needs to be explored in further research.

2. CONDITIONS WHICH DEFINE THE RELATIONSHIPS BETWEEN TC

If the formulae for calculation of TC PPh are equated based on the combined, relations (4) and (5,) and the parallel, relation (6), method WM, new conditions which allow identical cycle duration will be created if we assume that the lot size of the production-transport batch in both formulae is the same. The conditions (7) - (11) refer to the duration of the operations $(t_i, i = \overline{1,n})$ in the technological procedure.

The ratio between TC PPh based on the consecutive and parallel method WM is conditioned by the relation (12), based on the consecutive and parallel (13) and summative, by relation (14).

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_k t_k - \sum_j t_j\right), \left(\forall x_j \middle| j = \overline{1,m}\right) \in PF \wedge A = \{n, \theta_n, q, p = 1, K\},$$
$$t_k \in (t_i | i = \overline{1,n}) \;\wedge k = \left\{\{k = 1 | t_1 \ge t_2\}, \{k = \overline{2, n-1} | t_{k-1} < t_k \ge t_{k+1}\}, \{k = n | t_n > t_{n-1}\}\right\} \wedge$$
$$t_j \in (t_i | i = \overline{2, n-1}) \;\wedge \left\{j = \overline{2, n-1} \middle| t_{j-1} \ge t_j < t_{j+1}\right\} \quad (4)$$

$$t_t^{(k)} = \sum_{\alpha=1}^{n} t_\alpha + (q-1) \cdot \left(t_1 + \sum_{\alpha=2}^{n} (t_\alpha - t_{\alpha-1}) \cdot F_\alpha\right), \left(\forall x_j \middle| j = \overline{1,m}\right) \in PF,$$
$$(\forall \alpha | t_\alpha > t_{\alpha-1}) \Rightarrow F_\alpha = 1 \wedge (\forall \alpha | t_\alpha \le t_{\alpha-1}) \Rightarrow F_\alpha = 0, A = \{n, \theta_n, q, p = 1, K\} \quad (5)$$

$$t_t^{(p)} = \sum_{i=1}^{n} t_i + (q-1) \cdot t_{max}, t_{max} = max\{t_i | i = \overline{1,n}\} \wedge A = \{n, \theta_n, q, p = 1, P\} \quad (6)$$

$$(6) \wedge (4) \wedge t_t^{(p)} \equiv t_t^{(k)} \Longrightarrow \sum_{i=1}^{n} t_i + (q-1) \cdot t_{max} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_k t_k - \sum_j t_j\right) \vee$$
$$(6) \wedge (5) \Rightarrow \sum_{i=1}^{n} t_i + (q-1) \cdot t_{max} = \sum_{\alpha=1}^{n} t_\alpha + (q-1) \cdot \left(t_1 + \sum_{\alpha=2}^{n} (t_\alpha - t_{\alpha-1}) \cdot F_\alpha\right) \Rightarrow$$
$$t_{max} = \left(\sum_k t_k - \sum_j t_j\right) = \left(t_1 + \sum_{\alpha=2}^{n} (t_\alpha - t_{\alpha-1}) \cdot F_\alpha\right) \forall k, j, \alpha \in (i, i = \overline{1,n}) \quad (7)$$
$$(7) \wedge j = \{\quad\} \Rightarrow \sum_j t_j = 0 \Rightarrow t_{max} = \sum_k t_k,$$
$$k = \left\{\{k = 1 | t_1 \ge t_2\}, \{k = \overline{2, n-1} | t_{k-1} < t_k \ge t_{k+1}\}, \{k = n | t_n > t_{n-1}\}\right\} \Rightarrow$$

$$i = k = 1 \wedge t_1 = t_{max} \Rightarrow \{\{t_i\}: t_i \geq t_{i+1} \vee \{t_i\}: t_i > t_{i+1} \vee \{t_i\}: t_i = t_{i+1} = c\} | i = \overline{1, n-1} \quad (8)$$

$$i = k = n \wedge t_n = t_{max} \Rightarrow \{t_i\}: t_{i-1} < t_i | i = \overline{2, n} \quad (9)$$

$$\exists i \in (\overline{1, n}) \Rightarrow i = k | t_{k-1} < t_k = t_{k+1} \Rightarrow \{t_i\}: t_{i-1} \leq t_i | i = \overline{2, n} \quad (10)$$

$$(8) \wedge (10) \Rightarrow \exists i \in (\overline{1, n}) \wedge i = k | t_{k-1} < t_k \geq t_{k+1} \Rightarrow$$
$$\{t_i\}: t_{i-1} \leq t_i | i = \overline{2, j} \cup t_i \geq t_{i+1} | i = \overline{j, n-1} \quad (11)$$

$$t_t^{(u)} > t_t^{(p)} \Rightarrow q \cdot \sum_{i=1}^{n} t_i > \sum_{i=1}^{n} t_i + (q-1) \cdot t_{max} = \sum_{i=1}^{n} t_i + q \cdot t_{max} - t_{max} \Rightarrow$$
$$q \cdot (\sum_{i=1}^{n} t_i - t_{max}) > \sum_{i=1}^{n} t_i - t_{max} \Rightarrow q > 1 \Rightarrow t_t^{(u)} > t_t^{(p)} | q > 1 \wedge t_t^{(u)} = t_t^{(p)} | q = 1 \quad (12)$$

$$t_t^{(u)} > t_t^{(k)} \Rightarrow q \cdot \sum_{i=1}^{n} t_i > \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_k t_k - \sum_j t_j\right) =$$
$$= \sum_{i=1}^{n} t_i + q \cdot \left(\sum_k t_k - \sum_j t_j\right) - \left(\sum_k t_k - \sum_j t_j\right) \Rightarrow$$
$$q \cdot \left(\sum_{i=1}^{n} t_i - \left(\sum_k t_k - \sum_j t_j\right)\right) > \sum_{i=1}^{n} t_i - \left(\sum_k t_k - \sum_j t_j\right) \Rightarrow q > 1 \Rightarrow$$
$$t_t^{(u)} > t_t^{(k)} | q > 1 \wedge t_t^{(u)} = t_t^{(k)} | q = 1 \quad (13)$$

$$(7) - (13) \Rightarrow t_t^{(p)} = t_t^{(k)} = t_t^{(u)} | q = 1 \wedge t_t^{(p)} \leq t_t^{(k)} < t_t^{(u)} | q > 1 \forall i = \overline{1, n} \quad (14)$$

Table 1. Equation validation of TC $t_t^{(p)}$ and $t_t^{(k)}$ based on the relations (8) - (11)

No	Relation – condition	$\theta_6 = (t_i, i = \overline{1,6})$ q=9, p=3	Technological cycles				
			$t_t^{(p)}$	$t_t^{(k)}$	$t_t^{(u)}$	t_t	$\tau_{uo}^{(pf)}$
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	(8) ⇒ $t_i \geq t_{i+1}$, $i = \overline{1,5}$	(6, 6, 5, 4, 4, 2)	117	117	243	$t_t^{(p)} \leq t_t^{(k)} < t_t^{(u)}$	54
2	(8) ⇒ $t_i > t_{i+1}$, $i = \overline{1,5}$	(6, 5, 4, 3, 2, 1)	99	99	189		90
3	(8) ⇒ $t_i = t_{i+1}$, $i = \overline{1,5}$	(4, 4, 4, 4, 4, 4)	96	96	216		0
4	(9) ⇒ $t_{i-1} < t_i$, $i = \overline{2,6}$	(2, 3, 4, 6, 7, 9)	147	147	279		0
5	(10) ⇒ $t_{i-1} \leq t_i$, $i = \overline{2,6}$	(2, 2, 3, 4, 5, 5)	93	93	189		0
6	(11) ⇒ $t_{i-1} \leq t_i$, $i = \overline{2,4}$ ∪ $t_i \geq t_{i+1}$, $i = \overline{4,5}$	(2, 3, 3, 5, 4, 1)	84	84	162		30

As given in Table 1 we can confirm the hypothesis on equality of technological cycles based on the parallel and combined methods WM if the conditions predefined by the relations are met (8) - (11). However, the identical duration of TC does not, as a consequence, provide identical values of the overall technological losses at the level PPh, column 8. This idea is of vital importance and should be taken into account when the technological production process is designed, as well as within the projection of the production cycles PPh.

3. THE IMPACT OF THE PRODUCTION BATCH ONTO THE DURATION OF THE TC

The second dilemma which refers to the duration of TC, depending on the method WM and the lot size of the production-transport batch (*p*), will be explored in detail in the example PPh which comprises *n* = 5 operations, Table 2. Table 2 shows results of TC for the constant value of the production series (q = 6 pieces) that is realized with a different number of pieces in a production batch ($p = \overline{1,6}$).

Table 2. Values of TC depending on the method of WM and size of the lot size of the batch *p*

TC min/lot	$q = 6, p = \overline{1,6}$						t_i min/piece
	p=1	*p*=2	*p*=3	*p*=4	*p*=5	*p*=6	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
$t_t^{(u)}$	48	48	48	48	48	48	t_1=2 t_2=1
$t_t^{(k)}$	23	28	33	38	43	48	t_3=1
$t_t^{(p)}$	18	24	30	36	42	48	t_4=1 t_5=1

Under the condition that the production series q is constant, with the increase of the production batch the duration of TC increases based on the combined $t_t^{(k)}$ and parallel $t_t^{(p)}$ method WM. With the consecutive model WM the production batch does not affect the duration of the cycle $t_t^{(u)}$ due to the fact that the production series q is treated as one batch. Minimum values of TC based on the combined $t_t^{(k)}$ and parallel $t_t^{(p)}$ method WM will be calculated for the values of the production batch p=1 (Table 2, column 2) whereas maximum values will be calculated for p=q (Table 2, column 7), relation (15).

$$p = 1 \Rightarrow mint_t^{(p)} \equiv mint_t^{(k)},$$
$$p = q \Rightarrow maxt_t^{(p)} \equiv maxt_t^{(k)} = t_t^{(u)} \quad (15)$$

4. THE IMPACT OF THE PRODUCTION BATCH ONTO THE INTRA-OPERATIONAL LOSSES

The third dilemma is related to the investigation of the causal connection between the production-transportation batch (p) and intra-operational technological losses τ_{uo_i} , based on the parallel method WM, Table 3. The technological process PPh is analyzed which comprises of n = 10 operations with the allotted times, given in column 2. The process of the production is simulated for the constant value of the series of q = 12 pieces and production batches (p) which use the values of 1 up to 12 pieces ($p = \overline{1,q} \wedge q = \overline{1,12}$). The values of TC operations (i) $t_{t_i}^{(o,p)}$ and intra-operational losses τ_{uo_i} are calculated using formulas (16) and (17) depending on the lot size of the production-transport batch. Intra-operational losses equal 0 with the first and the sixth operations, as given in relation (18).).

Overall technological intra-operational losses at level PPh $\tau_{uo}^{(pf)}$ will be calculated by adding technological losses in all operations (19). The sum of technological cycles of all operations of the PPh $t_{t_{pf}}^{(o)}$ will be calculated using relations (19) and (20) depending on the method WM. Using formula (21) percentage is calculated.

For example, if the production process is performed in batches of 3 pieces, the following results will be calculated (Table 3, columns 7 and 8), relation (22).

Based on the results presented in Table 3 it can be concluded that the duration of TC and the intra-operational losses, at the level of the technological operation and PPh, is inversely proportional to the size of the production batch. The lesser the production batch, the bigger the values, and vice versa.

$$q\colon \left(t_{t_i}^{(o,p)} \Rightarrow \tau_{uo_i} \geq 0 | i = \overline{1,n}\right) \Rightarrow t_{t_i}^{(o,p)} = q \cdot t_i + \tau_{uo_i} = t_{t_i}^{(o,k)} + \tau_{uo_i} = t_{t_i}^{(o,u)} + \tau_{uo_i} \quad (16)$$

$$\tau_{uo_i} = \left(\max_j\{t_j, j = \overline{1,\iota}\} - t_i\right) \cdot (q - p), \forall i = \overline{1,n} \quad (17)$$

$$\tau_{uo_i} = 0 \Rightarrow t_i = \max_j\{t_j, j = \overline{1,\iota}\} \forall i, j \in \{1,2,3,\ldots,n\} \quad (18)$$

$$\tau_{uo}^{(pf)} = \textstyle\sum_{i=1}^n \tau_{uo_i}, t_{t_{pf}}^{(o)} = \left\{t_{t_{pf}}^{(o,p)}, t_{t_{pf}}^{(o,k)}, t_{t_{pf}}^{(o,u)}\right\},$$
$$t_{t_{pf}}^{(o,k)} = t_{t_{pf}}^{(o,u)} = \textstyle\sum_{i=1}^n t_{t_i}^{(o,k)} = \sum_{i=1}^n t_{t_i}^{(o,u)} = t_t^{(u)} \quad (19)$$

$$t_{t_{pf}}^{(o,p)} = \textstyle\sum_{i=1}^n t_{t_i}^{(o,p)} = \sum_{i=1}^n \left(q \cdot t_i + \tau_{uo_i}\right) = t_t^{(u)} + \tau_{uo}^{(pf)} \Rightarrow t_t^{(u)} = t_{t_{pf}}^{(o,p)} - \tau_{uo}^{(pf)} \quad (20)$$

$$P_{\tau_{uo}}^{(p)} = \frac{\tau_{uo}^{(pf)}}{t_t^{(p)}} \cdot 100,\ P_{\tau_{uo}}^{(o,p)} = \frac{\tau_{uo}^{(pf)}}{t_{t_{pf}}^{(o,p)}} \cdot 100,\ P_{\tau_{uo}}^{(u)} = \frac{\tau_{uo}^{(pf)}}{t_t^{(u)}} \cdot 100 \quad (21)$$

$$p = 3 \Rightarrow t_{t_i}^{(o,p)} = \{48,42,42,45,42,60,48,57,54,57\}, \forall i = \overline{1,10} \wedge t_{t_{pf}}^{(o,p)} = \textstyle\sum_{i=1}^{10} t_{t_i}^{(o,p)} = 495,$$

$$\tau_{uo_i} = (0,18,18,9,18,0,36,9,18,9) \forall i = \overline{1,10} \wedge \tau_{uo}^{(pf)} = \textstyle\sum_{i=1}^{10} \tau_{uo_i} = 135,$$

$$t_t^{(p)} = 135 \wedge t_t^{(k)} = 198 \wedge t_t^{(u)} = 360,\ P_{\tau_{uo}}^{(o,p)} = \frac{\tau_{uo}^{(pf)}}{t_{t_{pf}}^{(o,p)}} \cdot 100 = \frac{135}{495} \cdot 100 = 27{,}3\%$$

$$P_{\tau_{uo}}^{(p)} = \frac{\tau_{uo}^{(pf)}}{t_t^{(p)}} \cdot 100 = \frac{135}{135} \cdot 100 = 100\%,\ P_{\tau_{uo}}^{(u)} = \frac{\tau_{uo}^{(pf)}}{t_t^{(u)}} \cdot 100 = \frac{135}{360} \cdot 100 = 37{,}5\% \qquad (22)$$

Table 3. Values of TC operations, TC PPh and intra-operational losses for *q* = 12 *pcs* and $p = \overline{1{,}12}$

i	t_i min/pcs	*p* = 1		*p* = 2		*p* = 3		*p* = 4		*p* = 5		*p* = 6		*p* = 7		*p* = 8		*p* = 9		*p* = 10		*p* = 11		*p* = 12	
		$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}	$t_{t_i}^{(o,p)}$	τ_{uo_i}
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*
1	**4**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	**0**	48	0
2	2	46	22	44	20	42	18	40	16	38	14	36	12	34	10	32	8	30	6	28	4	26	2	24	0
3	2	46	22	44	20	42	18	40	16	38	14	36	12	34	10	32	8	30	6	28	4	26	2	24	0
4	3	47	11	46	10	45	9	44	8	43	7	42	6	41	5	40	4	39	3	38	2	37	1	36	0
5	2	46	22	44	20	42	18	40	16	38	14	36	12	34	10	32	8	30	6	28	4	26	2	24	0
6	**5**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	**0**	60	0
7	1	56	44	52	40	48	36	44	32	40	28	36	24	32	20	28	16	24	12	20	8	16	4	12	0
8	4	59	11	58	10	57	9	56	8	55	7	54	6	53	5	52	4	51	3	50	2	49	1	48	0
9	3	58	22	56	20	54	18	52	16	50	14	48	12	46	10	44	8	42	6	40	4	38	2	36	0
10	4	59	11	58	10	57	9	56	8	55	7	54	6	53	5	52	4	51	3	50	2	49	1	48	0
Σ	30	525	165	510	150	495	135	480	120	465	105	450	90	435	75	420	60	405	45	390	30	375	15	360	0
$t_t^{(p)}$ min/lot		85		110		135		160		185		210		235		260		285		310		335		360	
$P_{\tau_{uo}}^{(p)}$ %		194,1		136,4		100,0		75,0		56,8		42,9		31,9		23,1		15,8		9,7		4,5		0	
$t_t^{(k)}$ min/lot		162		180		198		216		234		252		270		288		306		324		342		360	
$t_t^{(u)}$ min/lot		360		360		360		360		360		360		360		360		360		360		360		360	
$P_{\tau_{uo}}^{(o,p)}$ %		31,4		29,4		27,3		25,0		22,6		20,0		17,2		14,3		11,1		7,7		4,0		0,0	
$P_{\tau_{uo}}^{(u)}$ %		45,8		41,7		37,5		33,3		29,2		25,0		20,8		16,7		12,5		8,3		4,2		0,0	

Where

$P_{\tau_{uo}}^{(p)}$ - Percentage of the sum of tech. intra-operational losses $\tau_{uo}^{(pf)}$ based on the duration of TC PPh, based on parallel method WM $t_t^{(p)}$.

$P_{\tau_{uo}}^{(o,p)}$ - Percentage of the sum of tech. intra-operational losses $\tau_{uo}^{(pf)}$ in relation to the sum of TC of operations, based on parallel method WM $t_{t_{pf}}^{(o,p)}$.

$P_{\tau_{uo}}^{(u)}$ - Percentage of the sum of tech. intra-operational losses $\tau_{uo}^{(pf)}$ related to the duration of TC PPh based on consecutive method WM $t_t^{(u)}$.

5. CONCLUSION

By analyzing the impact of time cycles of technological operations, lot size of the production-transport batch and the mode of workpiece move in the production onto duration and relationship within TC, the following can be concluded:

1. In the phase of technological process PF design, we should make sure that the overall number of operations (*n*) is as smaller as possible, whereas the duration of the technological operations is identical or almost the same so that each operation is longer or the same when compared to the previous one, relation (23). In this way, the technological intra-operational losses are eliminated τ_{uo_i}, as they occur due to unequal duration of operations, when the duration of TC PPh based on the parallel and combined methods WM is identical.

$$PF: (n \rightarrow min \wedge t_i = c | i = \overline{1,n}) \vee$$

$$(n, t_{i-1} \leq t_i | i = \overline{2,n} \wedge t_i - t_{i-1} \rightarrow 0) \Rightarrow$$
$$\tau_{uo_i} = 0 \wedge t_t^{(p)} \equiv t_t^{(k)} \quad (23)$$

2. If the condition (23) is not realized by the technological procedure, the levelling of the technological operations should be secured by the organizational factors during the project phase of the cycle (number of workplace, shifts).

3. The least TC PPh is calculated for the value of the batch $p = 1$ which is practically acceptable when the process of production is realized in bigger series and in mass production. If the small quantity production and middle quantity production is concerned, as mentioned above, the lot size of the production-transport batch should be optimized. Onto the optimal values (p_o) the lot size of the production-transport batch (q_o), has a dominant effect, then the scope of the unfinished production $q_i^{(rn)}$ and safety inventory which secures the continuity in production, relation (24).

$$p = 1 \Rightarrow min t_t^{(p)},$$
$$\left(q \longrightarrow q_o \wedge q_i^{(rn)} \rightarrow opt q_i^{(rn)}\right) \Longrightarrow$$
$$p \longrightarrow p_o \Longrightarrow opt t_t^{(p)} \quad (24)$$

4. The results presented in Tables (1) - (3) are calculated using the programs created within the software tool *Mathematica* and are presented in relevant literature [18]. The program for calculation of technological cycles of operations and phases *PPTCOPF3* is based on the comparison of time cycles of 3 subordinate operations, whereas program *PPTCOPF2* is based on the comparison of time cycles of 2 subordinate operations, when we take into account calculation of TC PPh based on combined model WM. Both programs provide identical results, they are easy to use and give all the results which deal with technological operations and production phases.

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IMPLEMENTACIJA LEAN KONCEPTA PROIZVODNJE U MALIM I SREDNJIM PREDUZEĆIMA

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Apstrakt: *Kako je značaj primene Lean principa direktno povezan sa poboljšanjem poslovnih aktivnosti u malim i srednjim preduzećima, tako je kroz ovaj rad prikazano kako Lean koncept proizvodnje utiče na napredak u procesu proizvodnje u jednom od malih i srednjih preduzeća. Studija pokazuje da mala preduzeća u većini slučajeva nemaju sistem koji obezbeđuje da kupac dobija kvalitetan proizvod na vreme, da se ne optimiziraju procesi proizvodnje zbog ograničenja u resursima i nedovoljno se sprovode standardne procedure u kojima se prevazilaze razlike između zahteva posla i veština zaposlenih, tačnije ne primenjuje se Lean koncept proizvodnje. Shodno tome rad takođe daje preporuke za poboljšanje procesa proizvodnje proizvoda u jednom od malih preduzeća koje uključuju: uvođenje Ćeliske proizvodnje, Supermarket i Kanban proizvodnje, što ce biti predstavljeno preko mape toka vrednosti (VSM) i samim tim uticati na poboljšanje u procesu proizvodnje u smislu smanjenja glavnog vremena proizvodnje proizvoda, eleiminisanja svih proizvodnih gubitaka i dobijanju kvalitetnog proizvoda.*

Ključne reči: *Lean alati i tehnike, Mapa toka vrednosti, Čelijska proizvodnja, Supermarket sistem, Kanban sistem, mala i srednja preduzeća.*

1. UVOD

Različita preduzeća raznih delatnosti širom sveta su prepoznala teorijske i praktične aspekte Lean koncepta proizvodnje, sa ciljem sistematskog unapređenja poslovnih procesa. Primena ovog koncepta nije moguća samo u velikim preduzećima nego i u mikro, malim i srednjim preduzećima, pri čemu je moguće postići kontinualna dugoročna poboljšanja. Takođe, Lean koncept je sa proizvodnje prebačen na ostale delatnosti kao što su priprema proizvodnje, razvoj, transport, logistika, a primena ovog koncepta počela je u oslatim oblastima poslovanja gde pokazuje veliki potencijal [1].

Danas, u korporativnom poslovnom svetu izraz "Lean" se koristi da označi savremenu, uspešnu poslovnu filozofiju, tj. proizvodnju svetske klase kvaliteta. Cilj ove filozofije je da omogući preduzećima da u uslovima rastuće konkurencije, opadanja lojalnosti kupaca, konstantnih tehnoloških inovacija, drastičnog skraćivanja životnog veka proizvoda, ostvari zadovoljavajuću, ako ne i vodeću, tržišnu poziciju. Tajna ili ključ uspeha Lean koncepta upravljanja proizvodnim operacijama leži u težnji za eliminisanjem svih vrsta gubitka i rasipanja proizvodnih resursa. Lean koncept, takođe, insistira i na prvobitnom pravilnom izvođenju svake aktivnosti. Naime, nema ponavljanja, nema popravljanja delova, nema grešaka, sve mora da funkcioniše besprekorno onda kada treba i u meri u kojoj treba. Zato je vrlo bitno prepoznati, ne samo problem u procesu poslovanja, nego i njegovu pozadinu, tj. uzrok problema [1].

Kao najbolji način za predstavljanje Lean koncepta proizvodnje u malim i srednjim preduzecima kao i njen doprinos u poslovanju prikazan je procesom implemenatacije Lean alata i tehnika u jednom od malih preduzeca, gde ce uočavanje grešaka i rasipanja proizvodnih resursa koji se javljaju u toku procesa proizvodnje biti najbolje prikazani izradom trenutne mape toka vrednosti proizvodnog pogona. U ovom slučaju, objekat posmatranja je pogon za proizvodnju sobnih vrata. Cilj primene Lean implementacije je da se smanji vreme izrade proizvoda, koje je ujedno i glavni resurs ovog pogona, putem eliminacije proizvodnih gubitaka koji se javljaju u toku procesa proizvodnje, što samim tim doprinosi kvalitetu proizvoda.

Nakon kreiranja trenutne mape toka vrednosti moguće je postići detaljan uvid u trenutno stanje preduzeća i lako se mogu uočiti gubici koji prouzrokuju zastoje i kašnjenje u toku proizvodnog procesa. Ovi gubici se mogu otkloniti primenom Lean alata i tehnika u procesu proizvodnje.

Posle primene Lean alata i tehnika u proces proizvodnje i smanjenja gubitaka, čime se ostvaruje viši novo kvaliteta proizvoda, ponovo se pristupa crtanju nove mape toka vrednosti koja predstavlja buduće stanje koje će biti primenjeno nakon primene određenih Lean alata i koje će u velikoj meri unaprediditi sam proces proizvodnje proizvoda kao i njen kvalitet i samim tim dokazati da Lean koncept proizvodnje ima doprinos ne samo u velikim preduzećima, nego i u mikro, malim i srednjim preduzećima.

2. ISKUSTVO U PRIMENI KONCEPTA LEAN PROIZVODNJE

2.1 Lean

Teorijska osnova Lean sistema datira iz ranih 50 -ih godina 20. veka, a njegov začetnik je Toyotin proizvodni sistem (TPS - Toyota Production System) gde su Lean metode i korisni alati stvoreni na osnovu prakse. Njihov pravi potencijal primećen je tek krajem 80 -ih, kada je počelo sa sve većim interesovanjem za Lean konceptom kao i njegovom primenom u kompanijama [1].

Lean znači sistem koji postiže dodavanje vrednosti aktivnostima različitih procesa i smanjenje gubitaka, smanjenjem i uklanjanjem onih aktivnosti koje nemaju vrednost. Lean sistem uključuje skup metode i alate koji skraćuju vreme proizvodnje i eliminišu gubitke. Kroz takav sistem kompanija koristi manje ljudskog rada za obavljanje posla, koristi manje materijala za kreiranje proizvoda i usluga, a sve to postiže kroz manje vremena, prostora i energije. Takva preduzeća su orijentisana prema kupcima, njihovim zahtevima i potraživanjima, a proizvode i usluge koje proizvode objedinjuje kvalitet i ekonomska isplativost. Pa je stoga i osnovno načelo Lean proizvodnje da se proizvodi tačno ono što kupac želi, drugim rečima kvalitet i količinu proizvoda diktira tržište [1].

Na samom početku se Lean terminologija odnosila isključivo na proizvodnju. Danas je, zbog povezanosti svih sektora kompanije i kompatibilnosti poslovanja, koncept Lean proširen na celu kompaniju sve do administrativnih delatnosti gde posluje pod imenom Lean administracije [1].

Da bi Lean imao potpuni efekat, potreban je sistem stalnog poboljšanja procesa i eliminisanje nepotrebnih troškova prilagoditi celoj kompaniji. Sistem stalnog poboljšanja uključuje sve vrste aktivnosti: interne funkcije, mreže dobavljača i kupaca, transport. Takođe, uz sve Lean metode i tehnike, najvažniji aspekt u implementaciji Lean-a su zaposleni koji čine kompaniju efikasnom u težnji ka savršenstvu

kroz sistematsko sprovođenje obuka. To zapravo govori da su svi zaposleni, počev od najvišeg menadžmenta do radnika u pogonima kreatori Lean sistema i njegove implementacije. U ovom slučaju postoji upotpunjeno Lean preduzeće, a ne samo proizvodnja sa Lean elementima [2].
Lean je pre svega proizvodna filozofija koja, kada se implementira, skraćuje vreme od narudžbine do isporuke gotovog proizvoda, eliminišući sve izvore rasipanja, odnosno gubitke u proizvodnom procesu [2].

2.2 Trenutno stanje primene Lean koncepta

U poslednjih nekoliko godina, mala i srednja preduzeća postala su predmet pažnje mnogih autora u njihovim naučnim radovima. Razlog za ovaj trend bazira se na činjenici da su mikro, mala i srednja preduzeća brojna i da su kičma privrede [3]. MSP su preduzeća sa manje od 250 zasposlenih i čine 99.8 % svih preduzeća u EU, što predstavlja oko 20 miliona preduzeća koja zapošljavalju skoro 65% od ukupnog broja zaposlenih. Detaljniji pregled otkriva da 91,8% sačinjavaju mikro preduzeća (zapošljavaju manje od 10 osoba), dok 6,9% od ukupnog broja čine mala preduzeća (10-49 zaposlenih lica), 1,1% srednja preduzeća (50 – 249 zaposlenih lica) a preostalih 0,2% su velika preduzeća (sa 250 i više zaposlenih lica) [4].
U literaturi se može pronaći mnogo primera implementacije Lean koncepta proizvodnje u velikim i srednjim preduzećima. Razmatrajući kategorije preduzeća, primećeno je da su Lean koncepti proizvodnje u osnovi uspešno primenljivi u velikim i srednjim preduzećima, dok implementacija koncepta Lean proizvodnje, u malim i mikro preduzećima sa manje od 10 zaposlenih ne bi trebalo da bude efikasna. Međutim, za mnoga mala preduzeća između 10 i 49 zaposlenih, primena Lean koncepta proizvodnje može biti jedan važan korak u povećanju produktivnosti i konkurentnosti na tržištu. U osnovi, MSP, a posebno mala preduzeća nisu samo prilagodiva i inovativna u pogledu proizvoda, već i u njihovim proizvodnim praksama [5].
Uvažavajući stalan pritisak konkurencije, male organizacije postaju sve aktivnije u poboljšanju poslovanja, što je dobra polazna tačka za uvođenje Lean metoda. Razni autori veruju da Lean proizvodnja i metode poboljšanja proizvodnje generalno skrivaju ogromne teškoće. Hayes [6] je ukazao da uspešna implementacija programa Lean proizvodnje u MSP zahteva strogo planiranje pre realizacije kako bi se izbegli problemi i ostali vidovi poteškoća. O Lean proizvodnji je diskutovano intenzivno u prošloj deceniji [7]. Samo nekoliko autora poput White-a, Conner-a ili Achanga-e vršilo je diskusiju o implementaciji Lean proizvodnje u MSP, a posebno u malim preduzećima. MSP još nisu sigurna o troškovima implementacije, izvesnosti rezultata i koristi koje mogu da ostvare. Većina ovih preduzeća strahuju da primene ovaj vid proizvodnje zbog visokih troškova i dugotrajnosti samog procesa implementacije. U poređenju sa većim firmama, male firme imaju manje resursa i ograničen pristup kapitalu što rezultuje nižim nivoima usvajanja skupih paketa.[10]
Smatra se da MSP koja usvoje Lean koncept proizvodnje mogu ostvariti korist povećanjem konkurentnosti na tržištu kroz bržu inovaciju i produktivnost, povećavajući fleksibilnost. Vrlo često mala preduzeća su vođena od strane jednog vlasnika (preduzetnika) ili su u pitanju porodične firme. U ovom slučaju, poslovni vlasnici moraju da budu ubeđeni u prednosti Lean filozofije zato što su učešće i posvećenost menadžmenta identifikovani kao možda najbitniji preduslovi da se sprovede sistem Lean proizvodnje u malim preduzećima [8].
Menadžeri u malim preduzećima često ne veruju eksternim stručnjacima i savetnicima koji bi mogli da im pomognu u fazi implementacije. Mala preduzeća imaju prednost da budu fleksibilnija u odnosu na veća preduzeća. Kada odluče da se sprovede metoda Lean koncepta proizvodnje, poslovni menadžeri nižeg nivoa često mogu uvesti promene brže u manjim preduzećima nego što je to slučaj u većim, iz razloga što oni imaju niži stepen birokratije, kraće kanale komunikacije i manje

su vezana za tradiciju. Neformalna priroda malih preduzeća i liderstvo vlasnika/menadžera mogu učiniti implementaciju programa Lean proizvodnje efikasnijom u malim u odnosu na veća preduzeća [9].

3. PRIMENA LEAN TEHNIKA U PROCESU PROIZVODNJE SOBNIH VRATA

3.1 Proces proizvodnje sobnih vrata

Sobna vrata se izrađuju od medijapana (skraćeni komercijalni naziv - MDF) i mogu biti presvučena PVC,CPL ili melamin soft folijom u raznim dezenima. Sobna vrata, koja su prikazana na slici 1, se satoje od tri glavna elementa: rama vrata, opšivnih lajsni i vratnog krila.

Slika 1. Izgled sobnih vrata u preseku

3.2 Tehnološki proces izrade rama vrata

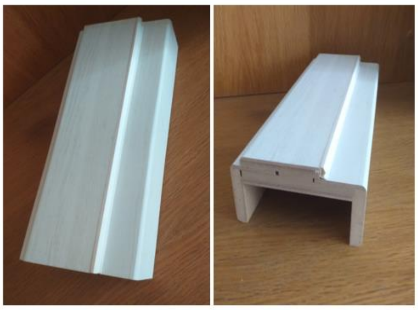
Tehnološki proces izrade rama vrata sastoji se od sledećih tehnoloških operacija: sečenje medijapana iz tabli; obrada žljeba; presvlačenje folije; sečenje ugla, bušenje i kraćenje na meru; spajanje rama vrata i predhodno izrađenih opšavnih lajsni; pakovanje, otpremanje. Kao krajnji proizvod svih tehnoloških operacije dobija se finalni proizvod prikazan na slici 2.

3.3 Tehnološki proces izrade opšavne lajsne

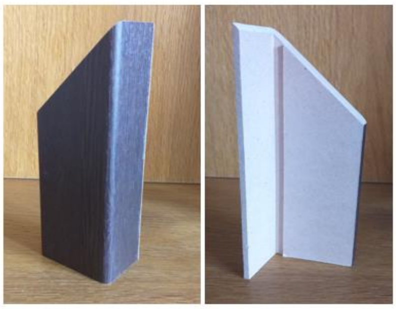
Tehnološki proces izrade opšavne lajsne se sastoji od sledećih tehnoloških operacija: sečenje pera i tela opšava iz tabli medijapana; lepljenje lajsne; presvlačenje folije; sečenje ugla i kraćenje na meru. Kao krajnji proizvod svih tehnoloških operacije dobija se finalni proizvod prikazan na slici 3.

3.4 Tehnološki proces izrade vratnog krila

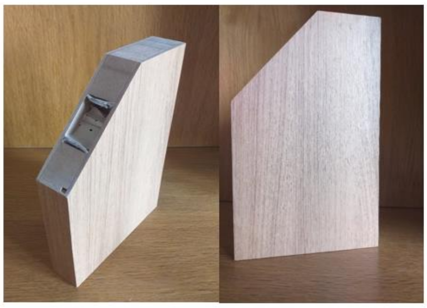
Tehnološki proces izrade vratnog krila se sastoji od sledecih tehnoloških operacija: sečenje gredica unutrašnjeg rama iz tabli medijapana; ručno sklapanje duplog unutrašnjeg rama, uporedno sa tim se izvodi sečenje obloga iz tabli medijapana, lepljenje folije na oblogu; lepljenje obloge na unutrašnji ram; sečenje na meru; lepljenje zaštitne trake na bočnim stranicama; busenje; pakovanje; otprema. Kao krajnji proizvod svih tehnoloških operacije dobija se finalni proizvod prikazan na slici 4.



Slika 2. Izgled rama vrata

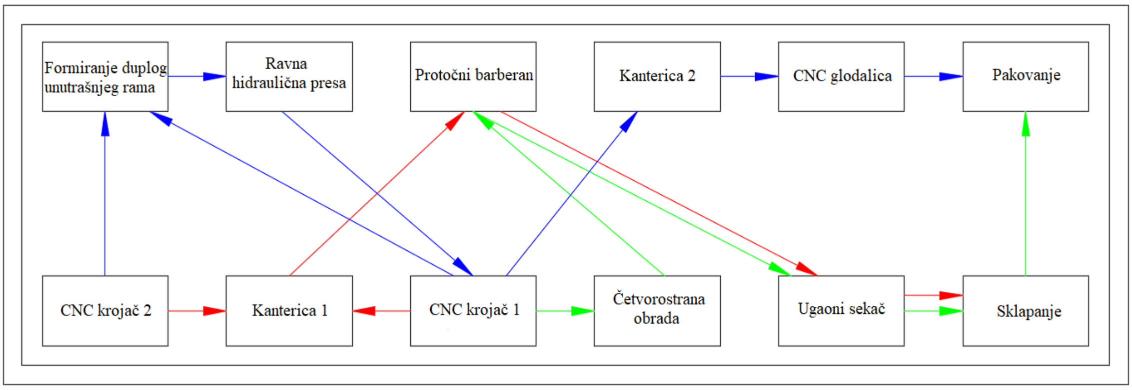


Slika 3. Izgled lajsni



Slika 4. Izgled vratnog krila

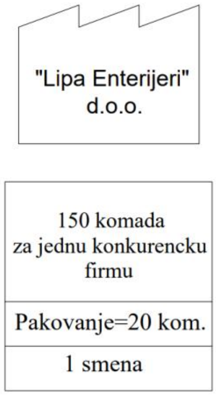
Dispozicioni crtež pogona proizvodnje, na kome je pokazan detaljni raspored mašinskog dela opreme koji se koristi u navedenim tehnološkim procesima potrebnim za izradu proizvoda, prikazan je na slici 5.
Različitim bojama su prikazane putanje proizvoda, tj. put kojim sirovi matreijal prolazi kroz tehnološke operacije da bi se došlo do gotvog proizvoda. Zelenom bojom je prikazana putanja kojom se izrađuje ram vrata. Crvenom bojom je prikazana putanja kojom se izrađuje opšavna lajsna, a plavom bojom je prikazana pokazati putanja kojom se izrađuje vratno krilo.



Slika 5. Dispozicija pogona proizvodnje sobnih vrata

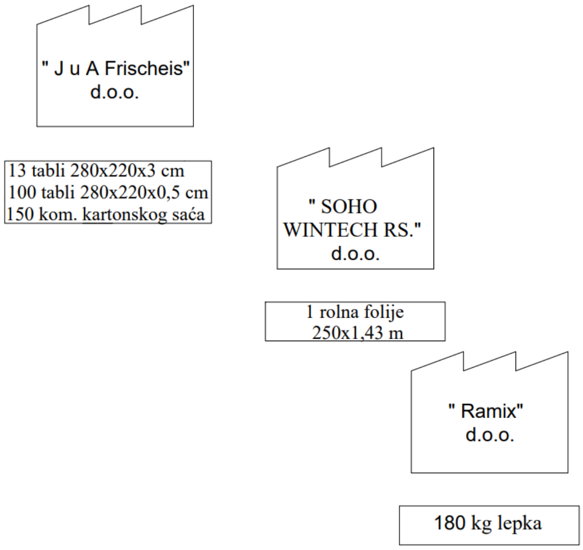
3.5 Kreiranje trenutne mape toka vrednosti

Mapa toka vrednosti je prvi korak koji preduzeće treba da preduzme u kreiranju sveobuhvatnog plana za primenu Lean inicijative. Lean inicijativa započinje sa konsenzusom zaposlenih o trenutnom stanju odvijanja poslova u preduzeću, nakon čega se pristupa crtanju trenutne mape toka vrednosti koja koristi jedinstvene grafičke simbole ili ikone za prikazivanje redosleda aktivnosti i kretanja informacija i materijala u obavljanju poslova u preduzeću. Trenutna mapa toka vrednosti takođe obezbeđuje način da se lako identifikuju i eliminišu oblasti u kojima se pojavljuju proizvodni gubici, koji utiču na povećanje glavnog vremena izrade proizvoda.
Kreiranje trenutne mape toka vrednosti za izradu vratnog krila počinje od kraja proizvodnog lanca, dakle od kupca. Prva "kućica" koja se na mapi toka vrednosti nalazi u desnom gornjem uglu je "kućica kupca" tj. organizacije koja naručuje proizvod. Ispod "kućice kupca" nalazi se "kućica podataka" gde se upisuju podaci o zahtevima kupca: mesečna količina, način pakovanja proizvoda, broj smena proizvodnje, što je grafički pokazano na slici 6.



Slika 6. "Kućica kupca" i "kućica podataka"

Druga "kućica" koja se nalazi na mapi toka vrednosti je "kućica dobavljača", tj. organizacije od koje se naručuje sirovi material koji se koristi za izradu vratnog krtila. Ispod "kućice dobavljača" nalazi se "kućica podataka" gde se upisuju podaci o potrebama materijala koji se poručuje: količina proizvoda, što je grafički prikazano na slici 7.

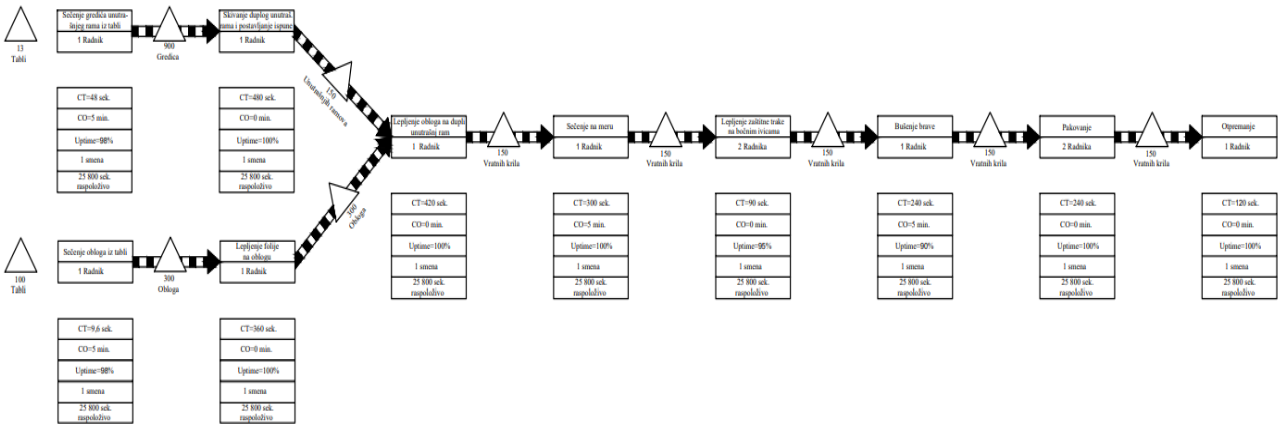


Slika 7. "Kućica dobavljača" i "kućica podataka"

Drugi korak u crtanju trenutne mape toka vrednosti je crtaje "procesne kucice", gde se unose procesi (operacije) koji se obavljaju pri izradi vratnog krila, kao što su: sečenje gredica unutrašnjeg rama iz tabli medijapana; ručno formiranje duplog unutrašnjeg rama, uporedno sa tim se izvodi sečenje obloga medijapana iz tabli, lepljenje folije na oblogu; lepljenje obloge na unutrašnji ram; sečenje na meru; lepljenje zaštitne trake na bočnim stranicama; busenje; pakovanje; otprema.

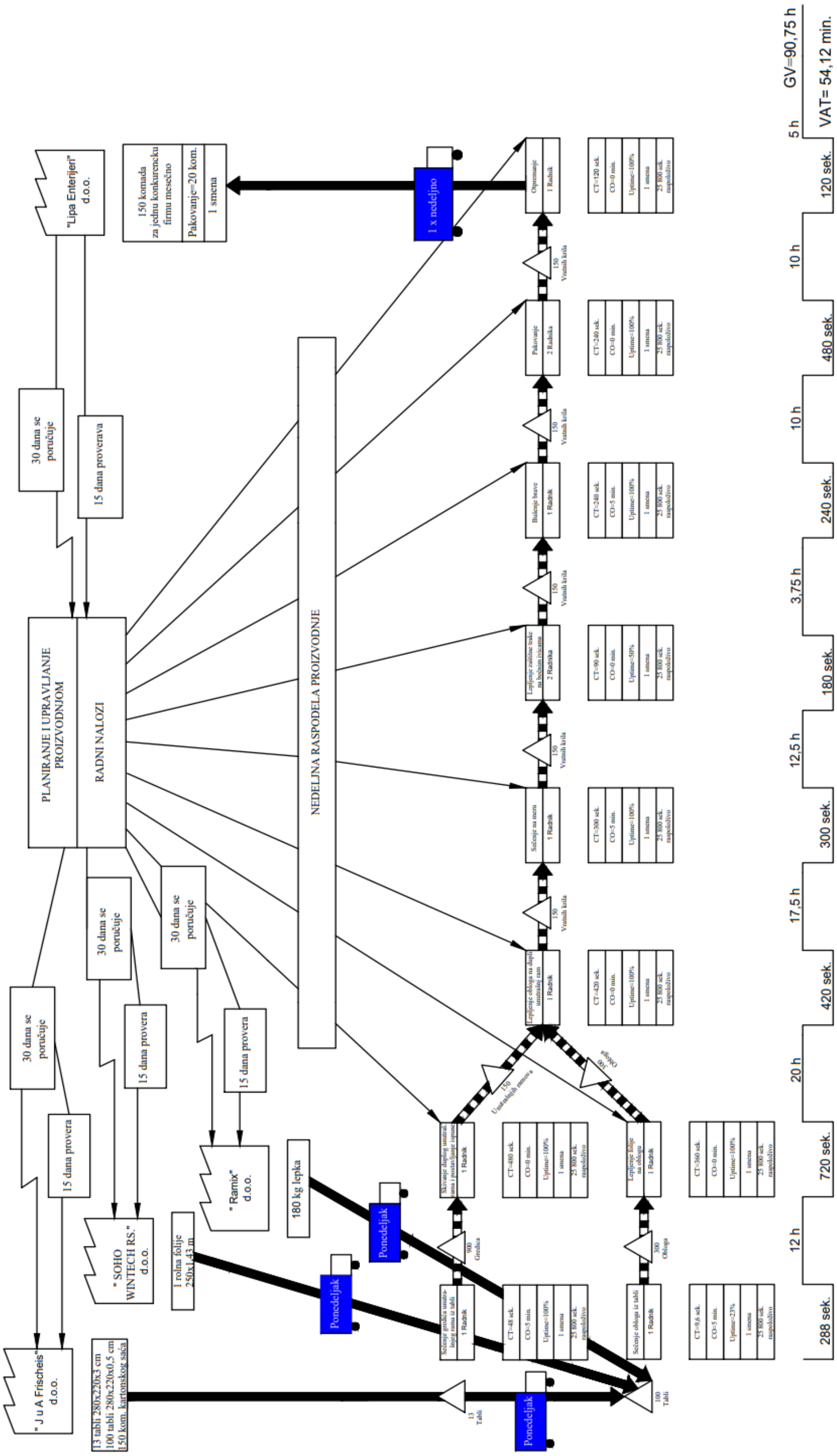
Između "procesnih kućica" se nalaze ikone koje pokazuju kako se pomera materijal između procesa. Na ikone za pomeranje materijala nanose se ikone koje pokazuju zalihe (broj komada komponenti koji je proizvden na prethodnoj tehnološkoj operaciji). Ispod "procesne kućice" nalaze se "kucića podataka", gde se upisuju podaci o zahtevima procesa: ciklusno vreme, vreme promene sistema, iskorišćenost mašine i raspoloživo vreme (slika 8).

Treći korak u crtanju je prikazivanje toka materijala od dobavljača do proizvođača i od proizvođača do kupca, gde je tačno pokazana količina materijla i gotovih proizvoda koji se transportuju kao i vremenski period transporta. Trenutni tok vrednosti informacija najčešce se sastoji od: razmena informacija između kupca i preduzeća i razmena informacija između dobavljača i preduzeća. Tok informacije izgleda ovako: kupac šalje mesečnu prognozu svojih potreba za proizvodom koji preduzeće isporučuje, a koja se svakih 15 dana proverava. Takođe, preduzeće šalje mesečnu prognozu potrebe svojih zaliha dobavljaču sirovog materijala, a svakih 15 dana tu informaciju proverava. Na kraju se crta vremenska linija pomoću koje se izračunava glavno vreme proizvodnje (GV) i vreme aktivnosti koje dodaje vrednost (VAT). Ovako predstavljena karta toka vrednosti predstavlja kartu (slika 9) koja pokazuje trenutno stanje u pogonu za proizvodnju vratnog krila.



Slika 8. "Procesne kućice" i "kućice podataka"

Na sličan način se izvodi kreiranje trenutne mape toka vrednosti i u pogonima za proizvodnju rama vrata i opšavne lajsne.



Slika 9. Karta trenutnog stanja toka vrednosti za proizvodnju vratnog krila

3.6 Primena Lean tehnika u procesu proizvodnje i nova dispozicija pogona

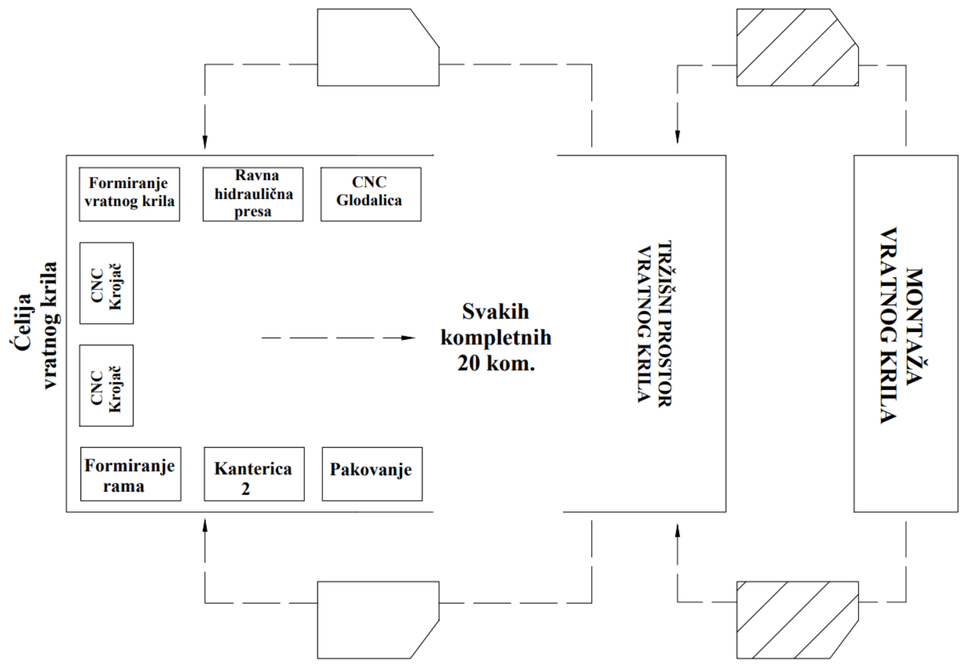
Nakon crtanja trenutne mape toka vrednosti, pristupa se traženju najboljeg rešenja za unapređenje proizvodnog pogona za proizvodnju sobnih vrata, tačnije pogona za proizvodnju vratnog krila. To rešenje se ogleda u smanjenju proizvodnih gubitaka i skraćenju dužine proizvodnog ciklusa, kao i doprinosu u kvalitetu samog proizvoda. Zahvaljujuci "procesnim kućicama" gde se unose važni podaci o zahtevima zadatog procesa (operacija) i uz pomoć vremenske linije uočeno je da se unapređenje može postići:

- Uvođenjem Ćelijske proizvodnje,
- Uvodjenjem Supermarket sistema ili Tržišnog prostora u proizvodnju
- Korišcenjem Kanban sistema,
- Promenom kombinovanog redosleda izvođenja operacija.

3.6.1 Ćelijska proizvodnja

Ćelijska proizvodnja je jedan od osnovnih Lean alata. Ćelijska proizvodnja se odnosi na proizvodni sistem u kome se oprema i radne staniceraspoređuju uefikasnom redosledu, koji omogućava kontinualno i nesmetano kretanje zaliha i materijala za izradu proizvoda, od početka do kraja procesa proizvodnje proizvoda pri čemu nastaje minimalni transport ili vreme čekanja, ili bilo kakva kašnjenja po tom pitanju. Ćelijska proizvodnja daje fleksibilnost kupcima pri izboru željenog proizvoda. Pretvaranje fabrike/laboratorije u ćelijsku proizvodnju znači eliminaciju rasipanja (gubitaka) iz procesa i operacija i skrećenje vremena proizvodnje.

Nakon primene ćelijske proizvodnje, Supermarket sistema i Kanban Sistema, dispozicija pogona proizvodnje vratnog krila ima novi oblik, kao što je prikazano na slici 10.



Slika 10. Dispozicioni crtež pogona za proizvodnju vratnog krila nakon primene lean tehnika

3.6.2 Supermarket sistem ili tržišni prostor

Lean preduzeća koriste supermarket sistem ili tržišni prostor da bi ostvarili Just-In-Time (upravo na vreme) nivo zaliha.

3.6.3 Kanban sistem

Kanban sistem je metoda korišćenja karti (metalnih pločica) kao vizuelnog znaka (simbola) koji se koristi za aktiviranje i upravljanje toka materijala ili delova, koji se odvija tokom procesa proizvodnje. Kroz ovaj sistem sinhronizuju se tehnološki procesi kao i procesi nabavke materijala i komponenti koje se poručuje od spoljnih dobavljača, takođe i isporuka finalno obrađenog proizvoda kupcu. Kanban metalna pločica se kreće zajedno sa i/ili materijalom između tehnoloških procesa. Tačnije, kada nekom procesu nedostaje materijal ili delovi, on šalje odgovarajući Kanban dobavljaču tako da Kanban tada ima funkciju porudžbenice. U realnoj poslovnoj praksi moguće je identifikovati tri tipa Kanbana za "povlačenje" koji imaju istu svrhu, a to je povlačenje materijala.

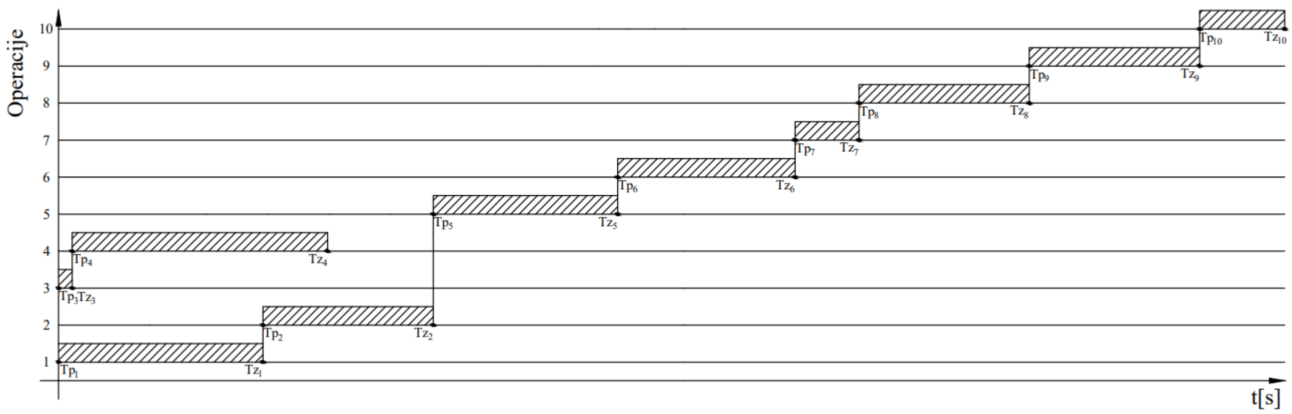
- Kanban kupca: Kanban se koristi za pomeranje materijala od skladišta gotovih proizvoda do lokacije kupca.
- Kanban pomeranja materijala: Kanban se koristi za pomeranje materijala od magacina sirovih proizvoda do tehnoloških operacija, i/ili od jedne tehnološke operacije na drugu.
- Kanban dobavljača: Koristi se za pomeranje materijala od spoljnjeg dobavljača do skladišta sirovog materijala proizvođača.

3.6.4 Primena kombinovanog redosleda operacija

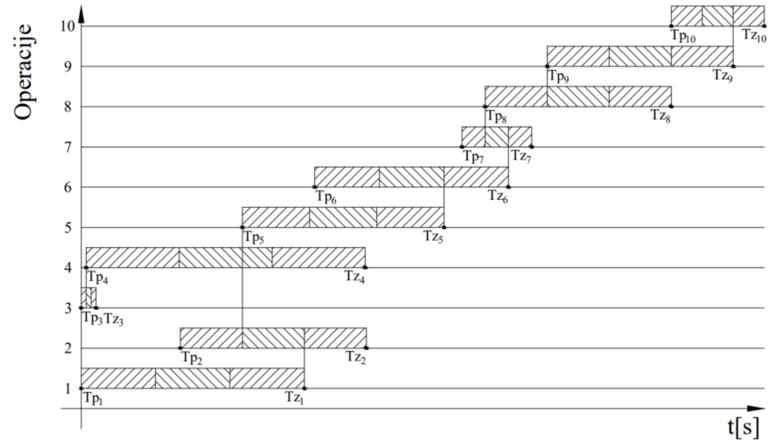
Budući da proizvodni ciklus obuhvata vremenski period od početka izrade jedne količine proizvoda pa do njenog potpunog završetka to se vremensko trajanje proizvodnog ciklusa sastoji od proizvodnog i neproizvodnog vremena. *Neproizvodno vreme* se odnosi na međusmenske i međuoperacione zastoje i ovde neće biti razmatrano. *Proizvodno vreme* obuhvata tehnološko i netehnološko vreme. *Netehnološko vreme* se odnosi na vreme potrebno za transport sa mašine na mašinu i vreme potrebno za međuoperacijsku kontrolu. Primenom ćelijske proizvodnje ovi gubici su svedeni na minimum. Skraćenje *tehnološkog vremena* je ostvareno primenom kombinovanog tipa redosleda izvođenja operacija i podelom serije na više manjih lotova (serija).

Tekuća proizvodnja je organizovana po uzastopnom tipu redosleda operacija u serijama od po 150 komada vrata (slika 11). Ukupna dužina proizvodnog ciklusa iznosi Tc=90,75(h).

Podelom serije na tri manja lota (serije) od po 50 komada i primenom kombinovanog redosleda operacija (slika 12) skraćena je dužina proizvodnog ciklusa za vratno krilo na Tc=36,72(h).



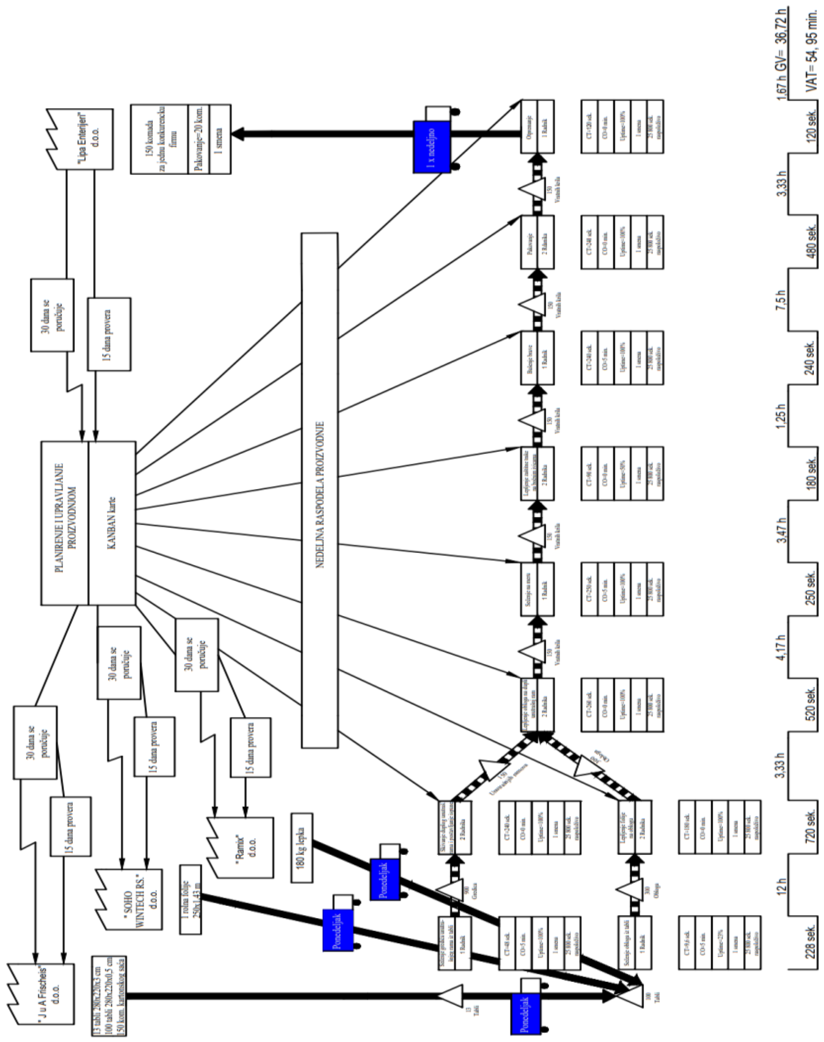
Slika 11. Uzastopni redosled izvođenja operacija za vratno krilo



Slika 12. Kombinovani redosled izvođenja operacija za vratno krilo

3.7 Buduca mapa toka vrednosti

Kao krajnji proces primene Lean koncepta proizvodnje kreirana je nova mapa toka vrednosti za vratno krilo, koja je prikazana na slici 13, a koja predstavlja buduće stanje proizvodnog pogona. Kreiranje mape toka vrednosti budućeg stanja se odvija po istom principu kao i kod kreiranja trenutne mape toka vrednosti, samo što su ovde primenjeni Lean alati koji u velikoj meri doprinose smanjenju vrememena izvršavanja operacija procesa i eliminaciji proizvodih gubitaka.



Slika 13. Karta budućeg toka stanja za vratno krilo

4. ZAKLJUČAK

Uvođenjem ćelijske proizvodnje u proizvodni pogon za proizvodnju sobnih vrata omogućava se da jedan radnik može da opsluži vise mašina u toku jednog radnog dana, to zapravo omogućava veću iskorišćenost i opreme i radnika, a takođe olakšava i transport materijala između tehnoloških operacija, shodno tome da je mašinski deo opreme raspoređen u najefikasnijem mogućem smislu. Samim tim se olakšava i razmena informacija između radnika na mašinama.

Primenom Supermarket sistema kod proizvodnog pogona za proizvodnju sobnih vrata omogućena je vizuelna kontrola zaliha. Jednim pogledom na Supermarket ima se uvid u količine zaliha koje se nalaze u Supermarketu. Kada se Supermarket napuni sa potrebnim zalihama traženog dela proizvoda - proizvodnja tog dela se zaustavlja, što može sprečiti prekomernu proizvodnju čime se rešava problem hiperprodukcije u toku proizvodnje.

Korišćenje Kanban sistema u pogonu za proizvodnju sobnih vrata doprinosi sigurnijem i efikasnijem transportu:

- sirovog materijala od dobavljača do kupca,
- gotovih proizvoda u skladište
- delova proizvoda sa jedne na drugu tehnološku operaciju.

Kanban sistem predstavlja istovremeno i sredstvo kontrole, koje omogućava sprečavanje prekomerne proizvodnje.

Primenom kombinovanog redosleda operacija omogućena je podela serije na tri manja lota (serije) od po 50 komada, čime je postignuto skraćena dužine proizvodnog ciklusa za vratno krilo.

Implementacija Lean koncepta proizvodnje je najvise zastupljena u velikim i srednjim preduzećima gde pokazuje veliki doprininos, dok implementacija u malim i mikro preduzećima još uvek nije toliko efikasna. Međutim mala preduzeca poput proizvodnog pogona za proizvodnju sobnih vrata koji je predstavljen u okviru ovog radu pokazuju da je implementacija Lean koncepta proizvodnje moguća. Efikasnost procesa proizvodnje se u ovom primeru ogleda u sledećem:

- proces proizvodnje je efikasniji u smislu da je smanjeno vreme proizvodnje serije proizvoda od 150 komada vratnih krila sa 90,75h na 36,72h,
- eliminisani su proizvodni gubici koji su se do sad javljali i
- dobijen je kvalitetan proizvod kojih je konkurentan tržištu.

Prednost malih preduzeća je i u njihovoj fleksibilnosti pa se u budućnosti može očekivati da implementacija Lean koncepta bude efikasnija u malim preduzećima u odnosu na velika preduzeća.

ZAHVALNICA

Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Republike Srbije za podršku u realizaciji i finansiranju naučnoistraživačkog rada u 2021. godini na osnovu Ugovora br. 451-03-9/2021-14/200108.

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IMPLEMENTATION OF LEAN CONCEPT OF PRODUCTION IN SMALL AND MEDIUM ENTERPRISES

Abstract: *As the importance of the appropriate Lean principle is directly related to the improvement of business activities in small and medium enterprises, so this paper shows how the Lean concept of production affects the progress of the production process in one of the small and medium enterprises. The study shows that small businesses in most cases do not have a system that ensures that the customer receives a quality product on time, does not optimize the production process due to resource constraints and insufficient implementation of standard procedures that overcome differences between job requirements and employees, more precisely the Lean concept of production does not apply. Consequently, the paper also provides recommendations for improving the product production process in one of the small enterprises, which include: introduction of Cellular Production, Supermarket and Kanban Production, which will be presented through the Value Flow Map (VSM) and thus influence the improvement in the production process. Reduction of the main production time of the product, elimination of all production losses and obtaining a quality product.*

Keywords: *Lean tools and techniques, Value flow map, Cellular Production, Supermarket system, Kanban system, small and medium enterprises.*

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THE INFLUENCE OF LEAN TOOL APPLICATION ON THE EFFICIENCY OF THE PRODUCTION PROCESS

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Abstract: *The paper presents the application of Takt Time, as one of the many Lean tools, which increases the efficiency of the production process. The production process was analyzed on the example of products for special purposes, which is part of the production program of the company AD "Sloboda" Čačak. This is a product whose production process consists of several production positions, each item is analyzed separately, based on technological procedures obtained in the company. The planned realization time of each position was calculated using a parallel type of organization of production operations. By applying the Takt Time tool, a reduction in the duration for each position was achieved concerning the previously planned times defined by certain deadlines. The influence of this tool on the daily regulation of production processes under customer requirements is also emphasized. As a result, in this case, a significant reduction in the newly planned production time compared to the previously planned time was shown.*

Keywords: *Lean concept, Takt Time, production process, production efficiency*

1. INTRODUCTION

The main goal of every manufacturing company is to make a profit. However, increasing competition requires continuous work to improve production processes, for industrial companies to become competitive in the market. The market is becoming more and more unstable day by day, so understanding the dynamics of the market is a crucial factor if we want to better design production systems [1]. Market instability and frequent introduction of innovations in production processes and technologies requires the production system manager to constantly adjust the system architecture and operating parameters to meet profitable business conditions and remain competitive in the global market [2]. Customers become quite indecisive when buying and show much less loyalty to long-standing inherited business relationships. Modern business conditions and the complexity of production processes impose the need to use different techniques to optimize production processes as a function of time as an important factor of efficiency. There is no single model or concept whose application would guarantee success in achieving greater profitability or competitiveness in the market. The Lean concept stands out as one of the most applicable organizational strategies in the last few years. Many companies have just adopted Lean manufacturing to survive in today's competitive markets. Lean production believes in the simple fact that customers will pay for the quality of the products they buy, but will not pay for mistakes [3]. These differences include shorter delivery times, higher quality, and lower prices.

A Lean concept is a systematic approach to the management and organization of industrial and manufacturing companies, ie the way of interaction between human resources, production resources, means of work, organization, and technologies within the production system. It is a systematic method for removing waste within the production system [4]. The application of the Lean concept is caused by customer requirements and requires constant improvement of work and production processes following the given circumstances.

One of the most important goals in Lean business transformation is to shorten the length of the production cycle, which has a direct impact on product delivery times, an important factor in the fight for competitive dominance in the market. The Lean concept also offers other benefits that can be attractive to manufacturers based on their specific production capabilities. In trying to answer a specific question such as reducing production time, very little attention is paid to other improvements that result from the transformation of the company into a Lean system. When these improvements stand out over time, they are a great pleasure and surprise for the manufacturer. An increasing number of industrial companies have applied the Lean concept to improve their business, innovate or create their products and services of better quality with less labor, using less space, less capital, and time. It also successfully eliminated various losses such as overproduction, unnecessary inventory, waiting, overprocessing, scrap, excessive transport, unnecessary movements, and underutilization of employee potential.

This paper aims to explain the concept and use of the Takt Time tool and to explain its direct connection with the production process, to achieve a shorter duration compared to the planned time before implementation.

The paper presents the impact of the implementation of the Takt Time Lean tool for the efficiency of the production process, a product for special purposes A1, which is part of the production program of the company AD "Sloboda" Čačak. By applying this tool, for a production volume of 150,000 pieces per month, efficiency is achieved in the form of reducing the total required duration of the production process.

2. THE IMPORTANCE OF USING LEAN TOOLS IN CONDITIONS OF INDUSTRIAL PRODUCTION

In industrial systems, the Lean concept is mainly based on designing a work process that is applicable, flexible, consistent, and sustainable in space and time [5]. By applying the Lean concept, various tools and other production management mechanisms have been developed over the years, given the numerous specifics of different production processes. The Lean concept may seem simple and easy at first glance, but its application is not an easy task. Introducing the Lean concept into an organization tends to change the work culture. Such changes are considered obstacles in the process of applying the Lean concept. The changes that happen in the organization tend to change the workers in the organization as well. As the application of Lean tools leads to the improvement of production processes, so many point them out as the only visible results of Lean production, which is not true in practice. Lean production methods and tools are very important, but they cannot achieve complete success if the leading people, as well as all employees in the company, do not know and feel about Lean production. In addition to the implementation of Lean tools in production processes, the biggest challenge is to change the current way of thinking, behavior, and mentality, both managers and all employees. The biggest difference in the approach of Lean production concerning the previous method of production is precisely the role of human resources.

2.1 Application of Lean tools in manufacturing companies

The value that is nurtured and sought by the customer has a special role in the implementation of Lean tools in companies. It is the customer who determines whether or not an activity has any added value. However, in a broader sense, it is the customer who pays for the correctness, quality, shape, and design of the product, and he is not interested in the organizational activities of the manufacturer or what the production facilities of the manufacturer look like. Taking into account this fact, the way of managing a company cannot create added value for the customer, but the value of the product is given by the workers, and the managers are only the creators of the optimal working environment. To achieve a better work and organizational culture, it is the directors, managers, and managers who need to show the desired situation by their example [6].

Many studies and research show that the expected production time can be reduced by up to 90%. By applying various Lean tools, companies are trying to achieve significant results in eliminating losses. Several authors emphasize the advantages of implementing Lean tools in manufacturing companies. The application of Lean tools can reduce cycle times and increase production in production lines [7]. By reducing waste, the process flow rate can be increased [8]. With the introduction of a new Lean tool called Project Time Deployment (PTD) whose goals are to classify, analyze and eliminate losses, it is possible to reduce production time in Engineer-to-Order (ETO) environments [9]. Development of a tool called the Leanness Assessment Tool (LAT) that measures the assessment of the use of the Lean concept using eight quantitative dimensions of performance: time efficiency, quality, process, price, human resources, delivery, customers, and inventory [10]. Modifying the existing Lean tool into the so-called Project Cost Deployment (PCD), which has the task of identifying hidden losses and quantifying waste from an economic point of view [11]. A practical example shows how the Lean tool can be useful in the analysis of losses, ie. waste in the production process [12]. Presentation of a classification scheme that systematically organized 101 Lean tools for achieving economical production [13].

3. IMPLEMENTATION OF TAKT TIME AS A LEAN TOOL ON THE EFFICIENCY OF THE PRODUCTION PROCESS

In previous years, many theoretical and even practical studies have shown that the growing need of companies to increase production efficiency. Therefore, numerous methods and techniques have been developed to solve this problem. However, as we have previously pointed out, one of the most effective methods has been the Lean concept, ie the use of various Lean tools. One of the main tools of Lean production is Takt Time. It is one of the first Lean tools developed at Toyota, where, among other things, the Lean concept originated. The basic task of the Lean Takt tool is thus to connect customer demand with the available production time and is used to increase production efficiency.

3.1. Takt Time

Using this Lean tool, the rhythm of production is monitored and determined, which harmonizes production with customer requirements. Represents the quotient of the planned production time and the time required by the customer. It provides a simple, consistent, and intuitive method for determining the rhythm of production. It can be very easily applied in the workshops themselves (actual number of products/target number of products).

The Takt Time Lean tool is used in companies that apply the Lean concept to determine a steady pace at which the process must achieve deliverable results to keep up with customer demand. In most cases, it is expressed in minutes or as a percentage of minutes. One work unit (Takt Time value) is performed by a person and/or a machine. The partially completed unit is then forwarded to the next resource down the line, where another "Takt" work task is performed. The work unit continuously progresses through all production processes until all required works are completed (Figure 1).

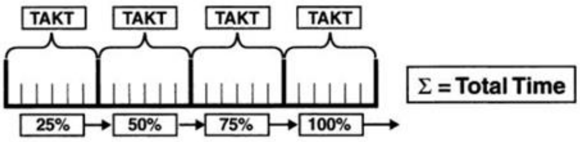

Figure 1. Sequential Work in Takt Time Increments

Takt Time affects the organization of the production process through all hierarchical levels, ie the overall layout of production plants, machine capacity, and work tasks. In a sequential manufacturing process, all processes operate following the clock time to ensure a continuous flow from process to process. Within each production process, the capacity of the machine is set to the operating time of the process clock. The work task of the operator is set so that the worker can complete the process within the time clock. In the operational phase, the clock is thus one parameter that determines the production sequence.

3.2. Application of Takt Time Lean tools on the production process

The first part of the paper presents an analysis of recording the duration of the production process of the complex product A1 for special purposes, which is part of the production program of the company AD "Sloboda" Čačak. The product consists of 5 assemblies and 34 positions (Figure 2). The necessary analyzes and research were conducted in the company, in a period of one month, during which, from detailed analyzed technological procedures, the following data were obtained: number of work shifts during one day, number of working minutes per shift, as well as production time in cmh for one piece (Table 1).

Based on these data, the production time per piece for serial production of 150,000 pieces per month is precisely determined for each position. As it is a question of serial production, the possibilities for achieving a more efficient production process are great. At different intervals, it is possible to change the duration of individual operations, as well as the waiting time, the way objects flow through production operations, as well as the planning and modification of these operations.

Table 1 shows the results of the calculation of the duration of the production cycle for position P24, which is part of the observed assembly. The data obtained by the performed recording were applied to each assembly and subassembly, as well as to the position of product A1.

Table 1. Necessary analyzes and measurements performed for the position a Laboration of missle

ASSEMBLY		**S3**									
POSITION	**Name**	**P24**									
	Drawing number:	**D27**									
OPERATION		Required no. of workers	Capacity for a shift (7,5h)	Number of shifts	Daily capacity	Number of machines	Total capacity	Making time per piece in cmh	Total Time machine for every day in norma time	No. of product	Total Time for a month in norma time
No.	**NAME**										
1.	Transport between workshops	1	10000	2	20000	1	20000	75	15,00	150000	112,50
2.	Weighing explosively flammable mixtures	2	800	2	1600	1	1600	187,4	3,00	150000	281,10
3.	Assembly, removal tools and filling mixture	1	800	2	1600	1	1600	187,4	3,00	150000	281,10
4.	1st i 2nd pressing explosively combustible mixture in the jacket shell	1	800	2	1600	1	1600	187,4	3,00	150000	281,10
5.	Clean the coils on the tee and depth control	1	800	2	1600	1	1600	187,4	3,00	150000	281,10
6.	Preventive control	**OVERHEAD OPERATIONS**									
7.	Transport between operation	0,5	1500	2	3000	1	3000	500	15,00	150000	750,00
8.	Application pressurizers the thread lighter and partially winding	2	1500	2	3000	1	3000	500	15,00	150000	750,00
9.	Finally winding lighter	1	1500	2	3000	1	3000	500	15,00	150000	750,00
10.	Clean excess pressurizers and workshop control	1	1500	2	3000	1	3000	500	15,00	150000	750,00
11.	Degreasing of lighter and shell granate	1	1500	2	3000	1	3000	500	15,00	150000	750,00
12.	Lacquir the lighter	2	1500	2	3000	1	3000	166,67	5,00	150000	250,00
13.	Repair lacquir peak lighter - manually	1	1500	2	3000	1	3000	500	15,00	150000	750,00
14.	Workshop control	1	1500	2	3000	1	3000	500	15,00	150000	750,00
15.	Technical control	**OVERHEAD OPERATIONS**									
16.	Transport btw operation	1	3000	2	6000	1	6000	250	15,00	150000	375,00

Based on the data obtained from the technological procedures, Table 2 shows the duration of the production process (expressed in days) for each assembly calculated using a parallel type of organization of production operations, using the following expression [14]:

$$T_{cp} = \sum_{i=1}^{m} t_i + (q-1)t_{i,max} \quad (1)$$

The second part of the paper shows the application of the Takt Time Lean tool that defines the rate of progress of the product cycle time [15], [16]. Determining the Takt Time of a product is expressed in such a way that the complete tasks are grouped into production units and then balanced to the calculated and pre-formulated time, which is expressed in minutes.

Table 2. The duration of each assembly of the product A1

Name of assembly	Time from the technological process [days]	Duration of the assembly after applying Takt Time Lean tool [days]
S1	85	81
S2	150	138
S3	242	221
S4	35	32
S5	28	27

Table 2 also shows the calculated Clock Time Time for each assembly, using the following expression [15]:

$$\text{Takt} = \frac{\text{WMS} \cdot \text{NSD}}{\text{TVD}} \quad (2)$$

where is:

WMS - Work Minutes per Shift

NSD - Number of Shifts per Day
TVD - Throughput Volume per Day

The TVD value is calculated using the expression [15]:

$$\mathrm{TVD} = \frac{\text{Total Throughput}}{\text{Makespan}} \tag{3}$$

When calculating the duration of the production process, using the Takt Time tool, it must be harmonized with all technological processes and work tasks. During the manufacturing process, the product progresses sequentially until all operations are completed. Each partially completed product is forwarded to the next technological process by a line on which the next "Tact" of work tasks is performed. This paper presents the production process of product A1, which takes place in two shifts, while the production time per shift is taken from technological procedures. Using Takt Time Lean tools, the company has the ability to regulate the production process daily by customer requirements. The total available time for each job daily was obtained from the technological procedures.

Based on the obtained results using equation (2), for each position and each product assembly A1, new durations were obtained, shown in Table 2. It can be concluded that the use of this tool increases the efficiency of the production process in the range of 5% to 10% with each assembly and position. As we mentioned earlier, within each production process, employees are focused on their managers. As this A1 product consists of 34 positions, one manager must manage the same number of Takt Times. This Lean tool provides an opportunity for managers to change the output data during the management of the production process, to better match the requirements of the customer.

The third part of the paper in Figure 2 shows a comparative analysis of the duration of all assemblies and the position of the production process before and after the use of the Takt Time Lean tool. The view is represented by a Gantt chart using the MS Project application.

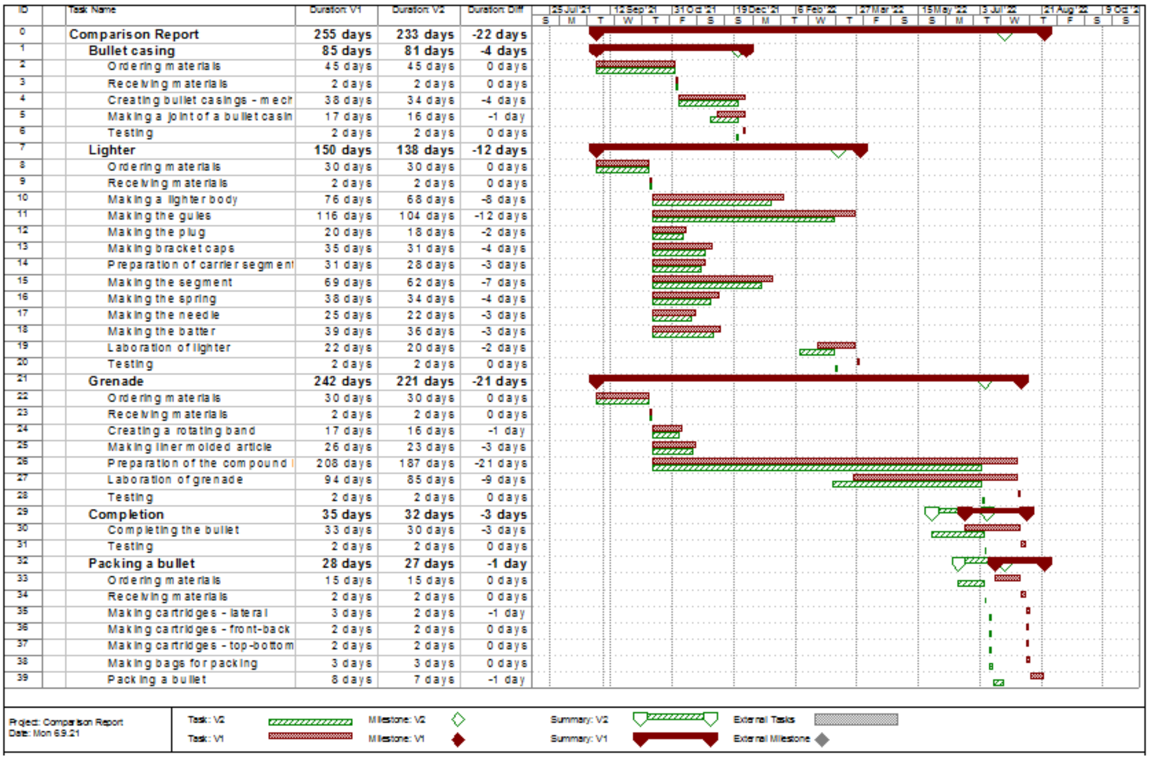

Figure 2. Comparative Gantt chart of the duration of production operations before and after the use of the Takt Time Lean tool

The planned durations were calculated using a parallel type of organization of the order of production operations, using equation (1). The new times obtained were calculated using the Takt Time tool, using equation (2). The date 01.09.2021. was chosen as the beginning of the production process. For a production volume of 150,000 pieces per month, following the agreed delivery times, it was calculated that the total required duration of the production process of product A1 is 357 days. We must mention that when defining the production processes, Saturdays and Sundays were treated as non-working days. After the application of the Takt Time Lean tool, visible results were achieved in the increased efficiency of the production process. The end date of the production process is 22.06.2022. that is, the new total required duration of the production process of product A1 is 325 days. We can conclude that more efficient production was achieved by 9%.

4. CONCLUSION

For years, Lean production technology has been the subject of dialogue among manufacturers. The introduction of Lean production in any type of industry has a direct impact on production processes. Lean organizations focus on customer demand and thus produce high-quality products and services most efficiently and economically. Achieving success by applying the Lean system in production ultimately encourages change throughout the company. Due to the great influence of the company, the implementation of the Lean system should never start as a short-term project with a clearly defined start and end date. The implementation of Lean causes the company to always be in transition and to constantly improve. If the implementation of the Lean system is implemented appropriately, it can lead to various positive improvements in the organization.

This paper presents the use of Takt Time Lean tools and their impact on achieving a more efficient production process. A reduction in the duration of the production process of product A1 by a total of 32 days was achieved. This feature of the Takt Time tool, by which managers achieve a change in the progress of the production cycle time daily, according to customer requirements, has proven to be a powerful tool in managing production processes. Results show that the efficiency of the overall production performance will be improved, by continuous work on adjusting the duration of the production process to Takt Time.

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EKOLOŠKI ZNAČAJ UKLANJANJA ŠTETNIH SASTOJAKA IZDUVNIH GASOVA MOTORA SA UNUTRAŠNJIM SAGOREVANJEM MIKROLEGIRANIM, MULTIFUNKCIONALNIM I NANOSTRUKTURNIM ČVRSTIM MATERIJALIMA

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Apstrakt: *Pored vode i zemlje, vazduh je jedan od najvažnijih resursa na Zemlji. Ovom inovacijom, na sveobuhvatan način, rešava se jedan važan ekološki problem gradskog i drugog smoga, koji udišu sva živa bića. Smog je toksičan jer nastaje hemisorpcijom štetnih gasova na partikularnim mikro i nano česticama prašine različitog porekla. Monodisperzne i mikro čestice se nalaze u suspendovanom stanju i bez dodatne agregacije vrlo teško se talože. One partikule smoga koje su taložne, kvašenjem padavinama se ponovo vraćaju na tlo, usled mraza se dezintegrišu u mikro čestice i ponovo vraćaju u atmosferu. Smog, vrlo čvrsto vezuje adsorbovane materije i pri dezintegraciji dolazi do formiranja ogromnog broja klastera sa poreklom iz štetnih gasova. Veliki uticaj na smog imaju izduvni gasovi motora sa unutrašnjim sagorevanjem, sa kojima smog postaje opasnost po život ljudi i drugih bića. Živa bića koja udišu takav smog, posle interakcije partikula sa tečnom fazom iz pluća i drugih organa u metabolizmu, vezuju štetne i toksične materije i monodisperzne čestice silicijum dioksida, čađi i oksida kalcijuma (koji čine najmasovnije partikule u vazdušnom smogu) i tako nastaje hronična bolest silikoze pluća, koja potom podstiče anginu pektoris i opštu slabost srca. Eto, ukratko, zašto je od presudne važnosti prečišćavati diskretno sve gasove tamo gde nastaju, korišćenjem predložene inovacije, čiji su uređaji prilagođeni veličini konstrukcije vozila i mašina.*

Ključne reči: *smog, izduvni gasovi motora, kasetna ispuna, mikrolegirani i nanostrukturni materijali*

1. UVOD

1.1 Naučno-stručni aspekti procesa sagorevanja i stvaranja izduvnih gasova i partikularnih čestica

Glavno aerozagađenje u gradovima i naseljenim mestima čini smog različitog porekla, koji ima i svoju toksičnost koju ispoljava zbog adsorpcije toksičnih gasovitih materijala, različitog porekla na aktivnu površinu partikularnih mikro/nano čestica. Glavni zagađivači u gradovima i naseljenim mestima su izduvni gasovi motora sa unutrašnjim sagorevanjem i gasovi nastali sagorevanjem različitih goriva za grejanje i kućne potrebe. Na partikularnim česticama smoga; nema preferentne adsorpcije, već se na istoj površini mogu naći klasterske oblasti sačinjene od nekoliko molekula ili adatoma različitih materija. Pošto smog nastaje agregacijom brojnih materija u atmosferi, pod uticajem sinergizma brojnih materija i čvrstih čestica, na česticama smoga se vrši hidroksilacija uz stvaranje kiselinsko-baznih centara i adsorbcija. Zbog znatnog prisustva vodene pare u dimnim gasovima motora sa unutrašnjim sagorevanjem, ona se preferentno adsorbuju na partikularnim česticama SiO_2, koje su najzastupljenije u vazdušnoj atmosferi, adsorpcijom molekula vode preko kiseoničnih mostova. Ovakvo stanje partikularnih čestica smoga je nestabilno i veoma aktivno, zbog toga što mikročestice imaju nestehiometrijski sastav, jer su nastale destrukcijom raznih čvrstih silikata, što potvrđuje dodatnu aktivnost uz promenu naelektrisanja. Sagorevanjem pogonskih goriva dizela i benzina, u uslovima već postojećeg smoga u gradskoj atmosferi, postojeće filtriranje vazduha pre ulaska u usisnu granu motora, obezbeđuje da se filtriraju samo krupnije i taložive čestice prašine u vazduhu. Međutim, mikro i nano čestice, koje su lebdeće zajedno sa adorbovanim smogom ulaze u usisnu granu i učestvuju u procesu sagorevanja. Proces sagorevanja u motoru zavisi od čitavog niza parametara i faktora, koji su redovni pratilac heterogenih i mikro heterogenih procesa u sistemu tečno-čvrsto-vazduh, odnosno od odnosa tečno-gas. Ukoliko ovaj odnos nije znatno veći nego što to zahteva stehiometrijski odnos prema sledećoj jednačini (1):

$$C_8H_{18}(l) + 12{,}5O_2(g) + N_2(g) \rightarrow 6CO_2(g) + 2CO(g) + 2NO(g) + 9H_2O(g) + Q \qquad (1)$$

Najosnovniji materijalni bilans izduvnih gasova dizel motora po svakom molu reaktanata prikazan je jednačinom (2)

$$114grC_8H_{18}(l) + 400grO_2(g) + 28grN_2(g) \rightarrow 264grCO_2(g) + 56grCO(g) + 60grNO(g) + 162grH_2O(g) + Q \qquad (2)$$

Dakle, kao što pokazuje jednačina (2), iz 114 gr oktana, sagorevanjem dobija se 562 gr gasova. Ako se proprati bilans sagorevanja 1000 gr C_3H_8, onda se dobija 4754 gr štetnog izduvnog gasa.

Pri stehiometrijskom odnosu prema jednačini (1), proces se odigrava u ravnotežnim uslovima kada dolazi do nepotpunog sagorevanja, tako da se stvaraju čestice čađi (C) ugljenika u vidu nano, mikro i makro čestica. Naravno, dolazi do sinteze CO, CO_2, SO_2 i NOx gasova i sublimacije nesagorelog goriva. Međutim, čak i pri dobro izvedenoj smeši gorivo-vazduh, zbog prisustva partikularnih čestica u vazduhu, znatno su složeniji mikroheterogeni sistemi čvrsto-tečno-gas. U procesu sagorevanja dominantnu ulogu i najveći je prinos $CO_2(g)$ i $H_2O(g)$, a paralelno se sintetizuju (ili stvaraju) SO_2 i NOx gasovi i čvrste čestice čađi, kao rezultat nepotpunog sagorevanja. Ovi gasovi su nestehiometrijskog sastava i veoma aktivni, pa se adsorbuju na partikularnim česticama različitih dimenzija. Pošto je temperature gasa u izduvnom gasu između 300 i 500°C, postoje uslovi da se vodena para razloži na vodonik i kiseonik i da pri strujanju kroz auspuh ponovo dođe do praskavog gasa. Dakle, u prvom postojećem filtru za čestice evro3, evro4 i evro5 motora, sa aktuelnom aktivnom ispunom na bazi alumosilikata i plemenitih metala, u mirnim stacionarnim uslovima, dolazi do stvaranja i akumulacije čađi na alumosilikatima, a na katalizatoru dolazi izduvni gas sa nano/mikro partikularnim materijama, koje neće moći da nesmetano reaguju, jer su to naelektrisane čestice istog naelektrisanja kao i čađ koji ih blokira. Tako, za volatilne molekule i gasove je mala verovatnoća njihovog učešća u odgovarajućim procesima razlaganja, zato što čađ inhibira stacionaran nepokretni sloj. Relativno male koncentracije uslovno slobodnih gasova i partikularne čestice sa adsrbovanim gasovima, **bez razlaganja prolaze kao smog u izduvnim gasovima,** zajedno sa onim česticama koje vode poreklo iz nečistog vazduha. Ovako složeni izduvni gas, bez obzira na motore evro3, evro4 i evro5, prolazi neočišćen kroz prvi i drugi lonac u atmosferu. Naravno, u ovom slučaju dolazi; ne samo do inhibiranja procesa na postojećem filtru i postojećem katalizatoru, nego i do otežanog funkcionisanja izduvnog sistema, uz promenu zvuka motora. Dakle, za uspešno funkcionisanje izduvnog sistema potrebno je izvršiti regeneraciju-čišćenje filtra spaljivanjem čađi sa filtra i katalizatora. **Zaključak je da bez obzira na kvalitet i starost automobila, ovakav sistem, nije zadovoljavajući i ne može da ispuni sve norme WHO standarda, što se dešava posle određenog broja desetina hiljada pređenih kilometara. Polazište je da je bolje nešto nego ništa. Drugo, kada se isključi rad motora usled kondenzacije H_2O gasa u celom sistemu filtera i katalizatora, dolazi do stvaranja ugljene kiseline koja će se izduvati u okolinu pri sledećem nastavku rada motora**. Nesporno je da je mikro/nano heterogeni sistem čvrsto-tečno-gas veoma složen, jer gotovo ništa ne učestvuje u procesima u homogenoj fazi. Zato se **naglašava nestehiometrijski sastav svih gasova sintetizovanih sagorevanjem goriva,** koji prolaze kroz filtracioni sistem i katalizatore kao izduvni gasovi. Poznato je da se NO stvara na veoma visokim temperaturama između 800 i 900°C direktno u motoru, a kada dospe u filter, pošto se izduvni gas ohladi na 300 - 500°C (300°C pri ler gasu, a 500°C pri povećanju broja obrtaja motora), NO gas se spontano pretvara u NO±x, CO±y dok se ne sintetizuje CO_2 gas. Na katalitički aktivnim materijalima, ako isti postoje u filter i katalizatoru, H_2O(g)-para se hemisorbuje na kiselinsko-baznim centrima kao H ads+OH ads, naročito na temperaturama 500±x°C, kada može doći do molekulizacije u vodonik, uz praskav gas, što se često dešava u svim benzinskim i dizel motorima, posebno kada je veća turaža motora i kada temperature izduvnih gasova poraste iznad 500°C. Bilo da su nestehiometrijskog sastava ili degradirani na katalizatoru, molekuli i molekulski ostaci (radikali) su veoma aktivni i odmah se hemisorbuju na mikro i nano partikularnim česticama, pa ako ove čestice ostanu u fluidu izduvnog gasa, kao takvi izlaze sa izduvnim gasovima i zagađuju atmosferu. Imajući u vidu da je spoljašnja atmosfera mikro i makro heterogeni sistem čvrsto-gas, kada se ovoj atmosferi pridruže izduvni gasovi sa mikro/nano partikularnim česticama, agregacijom i brojnim interakcijama sa vazdušnom atmosferom, **posebno sa česticama prašine SiO_2, CaO i drugih minerala, nagrađuje se složena i opasna atmosfera pod nazivom smog**.

Dakle, bez nano/mikro partikularnih čestica sa adsorbovanim sintetizovanim i destrukcijom narušenih gasova u vidu radikala nema smoga. Partikularne čestice u izduvnim gasovima, sa adsorbovanim gasovima, pretvaraju ove čestice u smog u izduvnim gasovima,. Jer one **vode poreklo iz zagađenog vazduha u usisnoj grani motora** i pri sporom sagorevanju uslovljava prolaz kroz postojeći filter, katalizator, kao i prednji i zadnji lonac auspuha.

1.2 Inovaciono sveobuhvatno rešenje procesa uklanjanja nano/mikro partikularnih čestica i štetnih izduvnih gasova

Polazeći od gore izvedenog materijalnog bilansa, dolazi se do zaključka da adsorbcija i sorbcija gasa nije u stanju i ne može da prečisti izduvne gasove, čak i pri 10000 m^2/gr specifične površine aktivnog materijala. Dakle, štetni gasovi se moraju katalitički razlagati, što se naziva ireverzibilan adsorbcija. Do adsorbcije i razlaganja dolazi kod NO gasa, CO gasa i SO_2 i SO_3 gasa, a da se pritom aktivni ugljenik C elementarni sumpor S i drugi volatilni gasovi vezuju za aktivne metale u različita jedinjenja. **Inovacija koju predlažemo, daje sveobuhvatno rešenje na sve navedene nedostatke u postojećim tehničko-tehnološkim rešenjima, a odnose se, pre svega, na proces uklanjanja nano/mikro partikularnih čestica i štetnih gasova. Za ovaj poduhvat u tehnologiji prečišćavanja izduvnih gasova, umesto postojećih filtera kod motora automobila, predložena je inovaciona tehnologija koja se bazira na originalnim, jedinstvenim, mikrolegiranim, multifunkcionalnim i nanostrukturnim materijalima koji imaju odlično kontaktiranje i multifunkcionalna svojstva sa izduvnim gasovima (inovator, akademik prof. dr Milovan Purenović).** Treba istaći da ovi materijali u kompozitima sa zrnastom matricom imaju specifičnu površinu 100 -500 m^2/g, tako da se sa 4-5 kg takve mase smeštene u kompaktni modul sa najmanje dva protočna kolektora "MILPUR" u kolonama sa kesetnom ispunom, a uz prethodno četvorostadijumsko filtriranje u kaskadnom samočišćećem filtru "MILPUR", primoravaju izduvni gas da pređe preko razvijene površine preko million m^2 aktivne površine. **Svaka komponenta izduvnog gasa mora da prođe kroz makro i mezo pore,da ih kapilarni prisak uvuče u mikro pore, da dođe do masovne destrukcije i epitaksijalnog pretvaranja materije u tanke filmove i do manifestacije nepovratne–ireverzibilne adsorbcije i pasivizacije na aktivnoj i pokretnoj ispuni multifunkcionalnih materijala.**

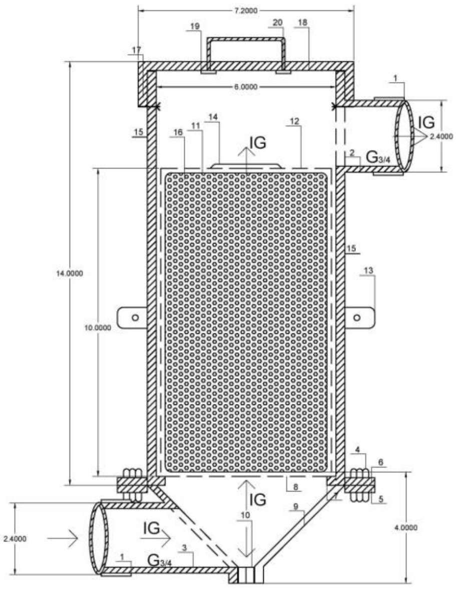
Dakle, umesto postojećeg filtra koji se nalazi u primeni, ovom inovacijom projektovani su; samočišćeći kaskadni filter "MILPUR" bez ispune i eko protočni kolektor "MILPUR", sa elektrohemijskim, fizičkim i katalitičkim multifunkcionalnim svojstvima, u kolonama sa kasetnom ispunom na bazi mikrolegiranih i nanostrukturnih materijala. U ovim novim multifunkcionalnim materijalima nalaze se veoma veliki brojevi nano/mikro galvanskih spregova i klastera sa velikom gustinom statičkog elektriciteta, potrebne energije za razlaganje gasova, pasivizaciju i agregaciju partikularnih čestica, njihovim vezivanjem u mikro heterogene sisteme čvrsto(1)-čvrsto(2)-gas. Pored ovih navedenih glavnih svojstava, koje nemaju postojeći nemikrolegirani materijali, multifunkcionalni materijali imaju i ostala kiselinsko-bazna, električna i tribo električna svojstva, koja su od presudnog značaja, ne samo za proces prečišćavanja, nego i za izvođenje merno regulacionih procesa u tehnologiji izduvnih gasova.

Jedan kompaktni modul za automobil ima za ispunu masu oko 5kg što daje ukupnu specifičnu površinu daleko veću od pet miliona m^2 (površinu ravnu oko 150 fudbalskih igrališta). sitne granule, određenih dimenzija, su smeštene u kasete, koje su potpuno zatvorene, da ne mogu da napuste to punjenje, a ostavljen je nepopunjen prostor da granule mogu da se pomeraju pod dejstvom struje gasova. Lagano pokretanje granula obezbeđuje da svaka čestica granule bude oblivena izduvnim gasom, uz sveobuhvatno kontaktiranje sa nano/mikro galvanskim spregovima, klasterima i kiselinsko-baznim aktivnim centrima.

2. NAUČNO-STRUČNA ANALIZA KOMPAKTNE MODULARNE, ORIGINALNE, UNIVERZALNE I JEDINSTVENE INOVACIONE TEHNOLOGIJE UKLANJANJA PARTIKULARNIH ČVRSTIH ČESTICA, ŠTETNIH GASOVA NOx, SOx i COx I DRUGIH ŠTETNIH GASOVITIH SASTOJAKA

Kompaktnu modularnu tehnologiju čini kaskadni četvorostadijumski samočišćeći filter "MILPUR", postavljen na samom kraju izduvne grane motora i komplet od dva eko-protočnih kolektora "MILPUR"; od kojih je jedan postavljen pre prednjeg lonca auspuha, a drugi pre zadnjeg lonca auspuha. Svaki eko-protočni kolektor "MILPUR" sadrži po šest kontaktnih kolona koje su međusobno kaskadno povezane, s tim što je drugi eko-protočnih kolektor "MILPUR" postavljen nekoliko metara od prvog. Konstruisan je ceo auspuh sa gasovodima, priključcima sa novim uređajima i priključcima za noseće konstrukcije celog sistema sa podnom prednjom i zadnjom konstrukcijom, kako bi se obezbedila stabilnost i kvalitetno prigušivanje efekata zvučnih talasa njihovom konačnom atenuacijom u zadnjem loncu. Zavisno od tipa automobila i vozila, gasovod auspuha će uvek biti nešto većeg preseka, a iste dužine. Sva pričvršćivanja treba da budu fleksibilna sa šrafovima i sa spojnicama za međusobno povezivanje i vezivanje za podnu konstrukciju. Vodiće se računa da ceo auspuh ima približno pravolinijski tok sa veoma malim kaskadama. Ovom inovacijom projektovana je primarna filtracija, filtracijom na četiri kaskadno postavljena samočišćeća filtra, filterskom tkaninom cilindričnog oblika sa gradacijom propustljivosti 30, 20, 10 i 5 µm. Filterska tkanina je izrađena od nerđajućeg čelika, a ista je zaštićena sa perforisanim cilindrom. Filter je vezan za izduvnu granu sa odgovarajućom dvodelnom spojnicom, kao i sve četiri kaskadne veze u filtru. Eko-protočni kolektor "MILPUR" je projektovan sa šest kontaktnih kolona sa kasetno ispunom multifunkcionalnom, fizičko-hemijskom i fizičkom i hemijskom aktivnošću. Projektovani kompaktni modularni **sistem eko-protočni kolektor "MILPUR" je mali katalitički reaktor**, jer ima dimenzije prilagođene dimenzijama vozila i motora sa unutrašnjim sagorevanjem tečnih i gasovitih goriva u putničkim automobilima, autobusima, kamionima i drugim vozilima.

Projektovani su kaskadni samočišćeći filter i eko protočni kolektor izduvnih gasova motora "MILPUR", prikazan na Slici 1.



Slika 1. Eko protočni kolektor izduvnih gasova motora „MILPUR"

3. ZAKLJUČAK

◆ Ovaj rad predstavlja jedan mali uvod u naučni poduhvat jednog od autora inovacije, kojeg odlikuju brojna originalna otkrića, kako bi se dobila aktivna čvrsta masa za prečišćavanje izduvnih gasova motora sa unutrašnjim sagorevanjem, takve aktivnosti da što duže traje.

◆ Veoma je važno da se znatno produži vreme do početka saturacije – zasićenja aktivnog materijala, što se postiže uključivanjem novog stvojstva aktivnog kompozita, koji ima sposobnost razlaganja pojedinih izduvnih gasova, njihove redukcije i transformacije štetnih materijala iz izduvnih gasova, kao i njihovo zarobljavanje u makro, mezo i mikroporama aktivnog materijala. Ovaj fenomen na novim nanostrukturnim mikrolegiranim materijalima je potpuno nov i originalan i pripada fenomenu ireverzibilne adsorpcije, koja je potvrđena otkrićima autora ove tehnologije.

◆ Kada se napravi materijalni bilans procesa sagorevanja dizela ili bezina, odmah se može zaključiti da su količine nastalog gasa nastalog sagorevanjem toliko velike da njihovom adsorpcijom ne bi mogle da budu uklonjene više nego delimično, što znači da je vrlo teško postići WHO standarde za prečišćavanje izduvnih gasova motora. Prema tome, ova inovacija je sigurno prva u svetu koja ima potpuno novi pristup u rešavanju ovog problema putem ireverzibilne adsorpcije.

◆ Da su u svetu naučnici imali dobro polazište u materijalnom bilansu sagorevanja goriva u motorima sa unutrašnjim sagorevanjem, izraženo kroz urađeni materijalni i energetski bilans, onda ne bi predložili tako loše sisteme katalitičkog prečišćavanja štetnih gasova pomoću nekoliko žica od legure platine, paladijuma i rodijuma i sa pdf filterom i izrazili kroz evro 1 do evro 6. Njihovi sistemi na novim vozilima ne mogu da izdrže više od 50 pređenih km. Dakle, sva vozila sa evro sistemima, se jednog dana izjednačavaju sa vozilima koja uopšte nemaju nikakav tretman.

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ECOLOGICAL SIGNIFICANCE OF HARMFUL COMPONENTS REMOVAL OF ENGINES WITH INTERNAL COMBUSTION EXHAUST GASES BY MICROALLOYED, MULTIFUNCTIONAL AND NANOSTRUCTURAL SOLID MATERIALS

Abstract: *In addition to water and land, air is one of the most important resources on Earth. This innovation, in a comprehensive way, solves an important environmental problem of urban and other smog, which is inhaled by all living beings. Smog is toxic because it is formed by hemisorption of harmful gases on particular micro and nano dust particles of different origin. Monodisperse and micro particles are in a suspended state and are very difficult to precipitate without additional aggregation. Those smog particles that are sedimentary return to the ground by wetting with precipitation, due to frost they disintegrate into micro particles and return to the atmosphere. Smog binds adsorbed substances very tightly and during disintegration, a huge number of clusters with the origin of harmful gases is formed. Exhaust gases of internal combustion engines have a great influence on smog, with which smog becomes a danger to the lives of people and other beings. Living beings that inhale such smog, after the interaction of particles with the liquid phase from the lungs and other organs in metabolism, bind harmful and toxic substances and monodisperse particles of silicon dioxide, soot and calcium oxide (which make up the most massive particles in air smog) and thus chronic disease pulmonary silicosis, which then promotes angina pectoris and general heart failure appears. In short, this is why it is crucial to discreetly purify all gases where they are generated, using the proposed innovation, whose devices are adapted to the size of vehicle and machine construction.*

Keywords: *smog, engine exhaust gases, cassette filling, microalloyed and nanostructured materials*

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APPLICATION OF DIGITAL TOOLS IN CIRCULAR PRODUCTION OF CASTINGS

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Apstract: *An implementation of digital tools for the production of castings, particularly for the simulation of casting processes as well as for the design and virtual development of the casting itself as aided by digital technology, has proven to significantly affect the energy consumption and reduce the greenhouse gas emissions. Foundries are known to be enormous consumers of energy since the production of only a ton of castings requires an average of 2,000 kilowatt hours of energy. Foundries in Serbia nowadays produce castings with a technology that does not assures the "healthy" casting while also simultaneously wasting a great amount of time and resources including used energy, materials, and money without preventing very harmful gas emissions. An adequate implementation and usage of modern software tools for the design and simulation of the casting processes enables engineers in foundries to conduct precise and optimum technology-based projections of the casting system prior to starting the casting process. Another valuable benefit driven through the usage of digital tools and in regard to achieving better energy efficiency includes the reduction of CO2 emissions due to the reduction of time needed to perform the entire casting process. Castings produced in such way also require a shorter time for machining which reduces the consumption of energy. Energy efficiency and closely correlated environmental protection benefits, as complemented by described potential savings of energy and materials that are unquestionably achievable through the use of digital tools, make the acquisition and inclusion of these tools in foundries mandatory. Unfortunately, foundries in Serbia still to this day do not use the advantages of digital applications in the production of castings even while recognizing that casting is a complex process that releases a highly detrimental amount of gases and waste this particular approach will enable the application of the circular economy principles in Serbian foundries in the true sense.*

Keywords: *Digital tools, Casting, Energy consumption, Greenhouse gas emissions*

1. INTRODUCTION

The European Commission has adopted an Eco-Design Directive that sets several limits, for example - limiting energy consumption for EU products that are large energy consumers - which is a measure to combat climate change by reducing greenhouse gas emissions, but also a measure to reduce pressure to the environment. In respect of the current circumstances related to energy efficiency and environmental protection, the presented potential savings of energy and materials, which can be achieved by using computers, make the use of digital tools in foundries mandatory. The application of information technologies and virtual production of castings, in addition to shortening the time of product acquisition and reducing production costs, enables the production of higher quality castings in the first attempt, which can significantly contribute to increasing technical competence and economic competitiveness of foundries. Adapting to the requirements of the global market, increasing technical capabilities and economic efficiency requires foundries to rationalize and optimize the production of castings. To explain this more precisely, the entire projection process takes place in the virtual digital application, which generates energy savings in the following two ways: first by significantly reducing the requirements for materials and second, by reducing the energy consumption necessary for the metal melting process. Another valuable benefit driven through the usage of digital tools and in regard to achieving better energy efficiency includes the reduction of CO_2 emissions due to the reduction of time needed to perform the entire casting process. Castings produced in such way also require a shorter time for machining which reduces the consumption of energy.

Unfortunately, foundries in Serbia still to this day do not use the advantages of digital applications in the production of castings even while recognizing that casting is a complex process that releases a highly detrimental amount of gases and waste. Despite of the aforementioned obvious system deficiencies that still remain unresolved, the Serbian law also inconsistently requires these same foundries to align with the predefined maximum levels of emissions in order to obtain approvals for their Integrated Permits on emissions.

With your kind help and support in regard to the above examined initiative, we look forward to your response in hope of enabling foundries in Serbia to soon commence producing "healthy" castings driven by the implementation of innovative digital tools that are designed to inspect and provide a virtual display of conditions on every material before proceeding with the casting process.

This particular approach will enable the application of the circular economy principles in foundry in the true sense.

2. STATE OF TECHNOLOGY IN THE FIELD OF METAL CASTING

In all countries of the region, due to the pandemic caused by the Covid 19 virus, the presence of employees in the workplace is limited. Limiting the presence of workers in foundries, related to casting technology, does not necessarily lead to a decline in production and a reduction in product quality. How?

The proposed solution of virtual production and optimization of casting technology in a computer environment enables optimal technology to be obtained anywhere. This is achieved if the real conditions are duly transferred from the plant to the world of digital tools and computers. There we perform virtual production, through casting design and casting technology optimization. Through multiple iterations, we can illuminate all observed product defects and optimize product design as well as casting technology design. This significantly reduces the presence of experts in foundries. They can do their creative work anywhere and deliver the results of their virtual casting to the physical casting plant. We will show the above solution on the example of a modern one foundry, which can be a guide for other foundries in region.

The mentioned solution will be presented on the example of cooperation with the modern Cranfield foundry, which can be a signpost for other foundries in region. Cranfield (www.cfoundry.com) foundry is a new modern plant with an automatic molding line produced by DISA. Such production equipment provides the possibility of digitization of castings and the process of casting. In these plants, there is a small percentage of human factor that can negatively affect the process. After the virtual casting, the Cranfield foundry will perform physical casting in its plant in order to demonstrate that the results of the virtual castings are equivalent to the results obtained in the plant.

On a specific family of castings, which today are produced with a range of accessories for machining and with a large amount of scrap, using digitalization and computer simulation of the casting process, we will enable production in the first attempt without error

Therefore, the end customer benefits, because they receive the casting on time, with less energy consumption and quality casting in the first attempt. The foundry benefits because it does not have to perform test castings with an uncertain outcome, and it does not have to spend time on test castings which negatively affect the time of delivery of castings.

3. PROPOSED SOLUTION

Naturally, foundries have long, for economic reasons, focused on the use and other developиing energy-saving casting processes through the reuse of sand, waste cast iron and water. Energy consumption is a considerable part of production costs in foundries and significantly impacts profits and competitiveness.

The main focus of campaigns to reduce energy consumption revolves around the optimization of energy processes, i.e. melting and starting operations of foundry equipment: more efficient furnaces with higher efficiency, furnace linings with better insulation capacity, use of energy recovery or optimized distribution of compressed air, are part of current research programs.

Less energy and raw material input through digitization of metal casting designs and processes. How to achieve this?

Digitization of the casting process can make a significant contribution to the energy efficiency of the foundry. It supports the reduction of the required amount of raw materials in many ways and thus the consumption of energy needed for melting metals. A considerable amount of energy used to produce the final casting, if it is possible to reduce the amount of liquid metal and increase the net weight of the casting / total weight of the casting system. Can save a large amount of energy can be saved. Improving the casting extract from 60% to 70% can save up to 300,000 kWh of electricity per year for a foundry that produces 2,000 metric tons of castings using an induction furnace.

“Energy hotspots” leads to a reduction in CO2 emissions throughout production and provides foundries with an advantage in cost and competitiveness.

With the introduction of digital tools in the design of castings and simulation of the casting process, for the first time, it was possible to look into the mould “Black Box” and, based on this data to optimize the function and design of the casting system. The primary goal of the casting process simulation is to develop economic, cost-optimized casting processes to produce a higher quality casting—all to achieve better use of raw materials, energy savings and costs.

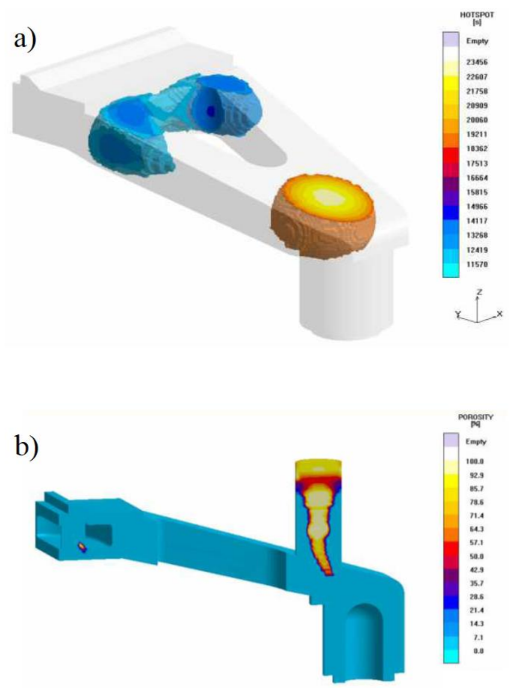

Figure 1. Casting simulation in software MAGMASoft a) Hotspot criteria and b) Porosity criteria

The systematic use of digital tools from design to a simulation of the casting process leads to economic production with the highest utilization of scrap metal and sand. In addition, it can achieve energy savings by improving productivity by improving the temperature distribution in permanent moulds and tools and the heat treatment process.

Therefore, the predictive process description used as a “virtual testing foundry”, where the casting technology is not checked only once to confirm the initial assumptions but used iteratively to perform parameter studies and optimizations to detect the impact of essential processes parameters process. This iterative procedure leads to optimal technology and optimal use of equipment, thus eliminating one phase in the process known as trial casting. Classic technology requires trial casting with each new product.

The designer of the casting system determines the dimensions and places of casting, defines the size and feeding places of the casting, makes the model of the casting and other parts of the casting system. Then makes a sand mould around the prepared geometry of the model, opening the mould, removing the model, closing the mould. Thus, the preparation for casting a trial series of castings was achieving. The result terms of quality and health of the casting are uncertain. In case of specific errors, the model of the casting system is changing, and the procedure is repeated. Using modern digital tools is possible to achieve all the potential of cast parts and their production processes in a computer. Computer tools for design and simulation today can accurately predict the impact of process parameters on the casting quality. They can be used very early in the product development process to reduce casting weight. Provide outputs support the designer in finding a design that can is released and the weight to be optimized and the engineers in the foundry to establish a stable and cost-effective production.

Initially, the designer creates a model that meets the load requirements. Knowledge related to the casting process is often introduced into the design when a potential supplier is involved. At this point, the plan is often already frozen, and any necessary changes required by the casting process cause a lot of work and lead to expensive communication loops between the designer and the supplier. What found that 80% of all production costs define by the design of castings. Primarily for parts that require special attention to the requirements related to the use of a limited casting mass, the early inclusion of the casting process simulation provides enormous benefits. Design characteristics can be problematic for the casting process. Thus potential quality loss can be detected early when a simulation is used and discussed between the designer and the supplier. It is especially true for multi-step production processes where the casting process, the heat treatment process, and the following processing processes define the final properties of the casting.

Without simulating the casting process, many expensive cycles of the casting process must be performed after the design of the work is completed. The simulation almost eliminates this process of approaching the optimal process configuration through physical test casting. Foundry experts use a simulation service to establish all process parameters for optimal production before production begins. By eliminating the need for trial batches, the initial savings of raw materials and energy was realized immediately.

The introduction of new casting technology in any foundry is associated with challenges and risks. How to introduce new technologies in foundries? Given the scarce professional potential, digital illiteracy, the cost of software for design and process simulation, this project solves the problems of foundries from one place while respecting their specific production constraints. The proposed can report on implementing "circular casting" from design to final casting.

In competition with other production processes, casting is the most direct path to the product. By using closed-loop strategies, the casting process has energy advantages over machining or welding processes. Each ton of casting uses only two-thirds of the primary energy required for the machined parts. Current simulation technology can convert manufactured parts into complex castings of almost "mesh" shape.

In many world foundries, simulation of the casting process has been established as a standard technology to reduce costs and ensure process stability. Unfortunately, this is not the case in the Western Balkans region. Customers in the automotive and equipment manufacturing industries increasingly require their suppliers to provide castings that have been verified through the application of simulation. The European Union's energy and climate goals need an energy efficiency improvement of more than 20%.

Once robust foundries in the region no longer exist, which has disappeared a vast intellectual capital, systematically developed for decades (Econometer 134 (2016) 14/15). The scale of this situation is most directly illustrated by the need to re-conquer the technology of casting capital castings. Many types of castings are of great strategic importance. The problem is even more significant if we consider the fact that new casting technologies have appeared in the world. Modern technological equipment, which is the basis for rapid product development in developed economies, is available only in the foundry, which leads to the possibility of product development with the help of digital tools, application of innovation and increased competitiveness.

4. INNOVATION OF THE PROPOSAL

What is innovative in our proposal?

The proposal is innovative and designed to improve the production process in foundries and gives results in several directions: melting management of the optimal amount of metal, design and optimization of casting systems. All these directions are of great importance for improving production processes in foundries by Industry 4.0. Our vision is summarized through the following:

• Creation of new knowledge, development of new and improvement of existing technologies in foundries.

• Support for technological progress of foundries through the transfer of innovation and technology into operation

• Application of innovative technologies in foundries to raise competitiveness and competence to produce quality castings in the first attempt.

• Application of virtual production of castings to avoid expensive prototyping, reduce energy consumption per kilogram of castings and positively affect climate change by reducing gas emissions.

The proposed innovative technology of design and optimization of casting systems includes the synchronized application of digital tools. The application of the proposed innovative technology is reflected in the elimination of the need for trial casting (which is the practice in many foundries today), and thus the optimization of the process by virtual casting in a computer before physical realization in foundries. This approach contributes to the growth of efficiency, economy and quality of the production process and will achieve energy savings and reduce greenhouse gas emissions.

5. CONCLUSION

Virtual reality and virtual business are options to overcome space-time constraints. This is possible by combining two new technologies that facilitate computer-aided engineering.

The proposal is innovative as a whole and designed to improve the production process in foundries and gives results in several directions: melting management of the optimal amount of metal, design and optimization of casting systems. Further application of 3D printers for making sand and core molds. All these directions are of great importance for the improvement of production processes in foundries in accordance with the requirements imposed by Industry 4.0. Our vision is summarized through the following:

• Creation of new knowledge, development of new and improvement of existing technologies in foundries.

• Support for technological progress of foundries through the transfer of innovation and technology into operation

• Application of innovative technologies in foundries with the aim of raising competitiveness and competence for the production of quality castings in the first attempt.

• Application of virtual production of castings in order to avoid expensive prototyping, reduce energy consumption per kilogram of castings and positively affect climate change by reducing gas emissions.

The proposed innovative technology of design and optimization of casting systems includes synchronized application of digital tools. The result of the application of the proposed innovative technology is reflected in the elimination of the need for trial casting (which is the practice in many foundries today), and thus the optimization of the process by virtual casting in a computer before physical realization in foundries. This approach will contribute to the growth of efficiency, economy and quality of the production process, and will achieve energy savings and contribute to the reduction of greenhouse gas emissions.

The final product is homogeneous, and the technology applied in the production process essentially determines the amount of costs. Low costs mean a comparative advantage over competitors. This further implies that market entry is directly dependent on investment in technology and low costs on that basis. These are favorable conditions for the penetration of innovative technologies. The advantages are reflected in the fact that the innovator is the first in the industry to implement the solution and takes a superior position on that basis, standing out from other competitors. Foundries on the territory of region still do not implement modern technological solutions, so the competition on this basis is weak, which speaks in favor of the feasibility and cost-effectiveness of our endeavor.

The proposal enables the application of virtual engineering in all foundries and tool shops in region. By applying the proposal results in all phases of the casting production, savings are realized, which we will show through the project activities and the effects that will be achieved in the foundry.

The project ensures that expert knowledge is transferred into practice, with the aim of technology transfer, implementation of new casting technologies, optimization of existing casting technologies, application of "new" casting materials, reduction of greenhouse gas emissions, education, etc. The project is based on several key objectives, which in the future must be achieved by foundries:

• Manufactured castings must meet customer requirements, especially in the field of quality,

• Foundries must pass the cost criterion in relation to other production technologies,

• The image of castings and casting technology must be positive for the customer,

• Working conditions in foundries and environmental compatibility must comply with world standards and regulations.

• Energy efficiency and related environmental protection, shown potential energy and material savings, which can be achieved by using digital tools, make the use of these tools in foundries mandatory

Prerequisite for the application of knowledge and new technologies are not only computer programs, good machines and simulation tools, but above all the will and readiness for real teamwork. It is necessary to establish partnerships with buyers of castings, both in the development of new castings and in optimization of the production of castings. The concept of virtual casting enables the foundry to cooperate more directly with the casting buyer in terms of optimizing the design and functionality of the casting. The proposed concept significantly reduces the time and costs of developing new types of castings for serial and individual production, which certainly contributes to increasing the competitiveness of foundries. Lastly, we must not forget the most important link in the chain, and that is the human factor. Without well-educated professionals, all of the above equipment is a dead letter on paper. The implementation of the results of this project will achieve effects in management, engineering, production and sales through:

- Reduction of costs;
- Increasing of quality;
- Expanding the boundaries of the casting process beyond our experiences;
- Enabling foundries to produce a large number of highly profitable castings;
- Faster market presence;
- Improving the organization.

These improvements are visible, measurable and easy to track and monitor. The also addresses the common challenges that the foundry is facing as a whole. Namely, the departure of young people abroad, declining interest in professional advancement and weakened capacities can be solved by knowledge transfer, networking and cooperation envisaged within the project. Furthermore, automation of the mold filling process leads to improved safety at work. This social dimension of influence is also of particular importance.

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ENERGETSKI POTENCIJALI BIOMASE I KORIŠĆENJE VISOKO ENERGETSKIH BILJAKA KAO OBNOVLJIVOG IZVORA ENERGIJE NA TERITORIJI OPŠTINE ČAČAK

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Rezime*: Korišćenje biomase šumskih i poljoprivrednih ekosistema kao obnovljivih izvora energije, poslednjih godina predstavlja praktičan i pouzdan način za dobijanje energije u većini zemalja EU. Brojna naučna i praktična istraživanja usmerena su upravo na mogućnosti upotrebe različitih oblika drvnih i biljnih biomasa kao potencijalnih energenata. U ovom radu dati su rasoploživi energetski potencijali biomase, kao i mogućnosti korišćenja visoko energetskih biljaka na teritoriji grada Čačka.*

Ključne reči: *drvna i biljna biomasa, energetski potencijal, teritorija opštine Čačak.*

1. UVOD

Korišćenje raspoložive poljoprivredne drvne i biljne biomase u energetske ili druge svrhe, je značajno zbog siromašnih energetskih potencijala uopšte, kao i zbog smanjenja uvozne zavisnosti, obezbeđenja snabdevanja energijom, smanjenja zagađenja okoline, zadovoljenja međunarodnih obaveza za smanjenje emisije CO_2 [1]. Takođe, racionalno korišćenje raspoložive poljoprivredne otpadne drvne i biljne biomase u energetske i druge svrhe, značajno bi imalo uticaj na podizanje tehnološkog nivoa energetike, mašinogradnje, prehrambene industrije i dr., bržeg razvoja slabo razvijenih regiona koji su bogati sa drvnom i poljoprivrednom biomasom koji mogu da se ostvaruje kroz: realizaciju investicija, angažovanjem lokalne radne snage, otvaranjem novih radnih mesta, poboljšanjem lokalne infrastrukture i ostvarivanjem prihoda kroz razne vrste proizvodnje.

Racionalno korišćenje raspoloživih sirovina drvne i poljoprivredne biomase ima generalno tri međusobno povezana aspekta: (1) ekonomsku (ili možda tehnoekonomsku) održivost, (2) ekološku održivost i (3) socijalnu održivost. Tako održivi sistemi za razvoj zavise od praktične primene odgovarajućih tehnologija koje obezbeđuju najbolju “spregu” između tehnoekonomske izvodljivosti, društvene prihvatljivosti i ekološki održivog korišćenja raspoloživih resursa.

Neki od aspekata za zaštitu životne sredine su zbirni ekološki uticaji od ostataka poljoprivredne proizvodnje na emisije u: vazduh, vodotokove i zemljište na promenu ili degradaciju staništa (ljudi, flore i faune).

Predmet ovog rada je sagledavanje potencijala raspoložive biomase koja se može koristiti u energetske svrhe na teritoriji opštine Čačak. Sadašnje raspoložive količine biomase će se definisati detaljnim pregledom zvaničnih statističkih podataka na republičkom i lokalnom nivou i njihovim usaglašavanjem sa sadašnjom stvarnom situacijom na terenu. Navedena istraživanja su realizovana uz svesrdnu pomoć lokalnih institucija iz sektora: privrede, urbanizma, zaštite životne sredine, razvoja, šumarstva, poljoprivrede, elektrodistribucije i energetike uopšte. U prikazu sadašnjeg stanja i potencijala u proizvodnji i korišćenju biomase posebna pažnja je usmerena na definisanju prirodnih činilaca sredine, kao primarnog faktora u proizvodnji i eksploataciji biomase.

2. RASPOLOŽIVI ENERGETSKI POTENCIJALI OD DRVNE I BILJNE BIOMASE SA TERITORIJE OPŠTINE ČAČAK KOJI MOGU DA SE KORISTE U ENERGETSKE SVRHE

Raspoloživi energetski potencijali od drvne i biljne biomase na teritoriji lokalne samouprave grada Čačka nastaju od:

- ogrevnih drva namenjenih za grejanje,
- drvnih ostataka koji nastaju, na prvom mestu, krčenjem drvnih zasada: neiskorišćeno drvo, ostaci klada, panjevi, granje, i dr.,
- poljoprivrednih ostataka: slama, lišće, delovi voćaka, otpadi pri proizvodnji maline i kupine, vinove loze, stabljike kukuruza i dr.
- otpadne drvne i biljne biomase iz: fragmenata šuma, međa, uvala, klizišta, održavanja: elektrovodova, puteva i sl.,
- komunalnog drvnog i biljnog otpada iz domaćinstava, od prehrambene industrije i sl.

2.1 Energetski potencijali od ogrevnog drevta iz redovnog gazdovanja šumama

Sa teritorije opštine Čačak, ze energetsko korišćenje mogu se koristiti biomase iz šumskih ekosistema (ona ima i drvo i niže biljke), biomasa travne vegetacije (livade, pašnjaci), biomasa voćnjaka, vinograda, biomasa ratarskih kultura i sl.

Na teritoriji opštine Čačak velike površine su pod poljoprivrednim zemljištem (440,25 km^2) i šumom (148,25 km^2), što predstavlja veliki potencijal za racionalno energetsko korišćenje [2,3]. Šumsko zemljište: 14 825 ha (9 907 ha privatnih šuma i 4 918 ha šuma u državnom vlasništvu) – Privatne šume su izdanačke očuvane šume, a u državnom vlasništvu 153 ha su visoke šume (100% bukova šuma), 3 227 ha su izdanačke šume – lišćari (55% bukova šuma, 45% hrastova mešovita šuma), 958 ha su veštački posađene šume (crni bor) i 598 ha su šikare i šibljaci – devastirane šume lošeg kvaliteta. Takođe, na teritoriji opštine Čačak postoje velike mogućnosti za namensku proizvodnju biomase koja neće konkurisati proizvodnji hrane jer su sela u velikoj meri napuštena i velike poljoprivredne površine koje stoje neobrađene, a mogle bi se iskoristiti u svrhu proizvodnje drvne biomase. Godišnje se u privatnim i državnim šumama poseče oko 20.000 m^3. Šumski otpad je oko 1.200 m^3. Organski otpad iz privatnih firmi u Čačku iznosi 196,44 t/god. Otpad biljnog porekla iznosi oko 115 t/god., ostaci hrane su oko7,5 t/god., otpad životinjskog porekla je oko 8.200 m^3. Od ukupno posečene zapremine drveta, dve glavne vrste proizvoda su: tehničko oblo drvo i prostorno drvo. Takođe, postoji i drvni ostatak (kora, tanke grane i panjevi) koji po sadašnjim tehnologijama rada obično ostaje u šumi, a mogli bi da se svrsishodno koriste.

Prema [4] u tabeli 1., date su gornje toplotne moći i zapreminska masa, za drveća koja su zastupljena, za teritoriju opštine Čačak.

Tabela 1. Gornje toplotne moći i zapremiska masa, za drveća koja su zastupljena, za teritoriju opštine Čačak [5].

Vrsta drveća	Gornja toplotna moć (MJ/kg)		Zapreminska masa (kg/m^3)	
	Drvo	Kora	Drvo	Kora
Bukva	18,82	18,00	680	580
Hrast	18,36	19,70	650	425
Crna topola	17,26	18,00	410	412
Smrča	19,66	21,20	430	340
Jela	19,46	21,00	410	460
Bor	21,21	20,62	580	300

U tabeli 2. prema [4], date su toplotne moći za različite vrednosti vlažnosti drveća, kao i zapreminske mase za različite vrednosti vlažnosti drveća, za opštinu Čačak.

Tabela 2. Toplotne moći za različite vrednosti vlažnosti drveća, kao i zapreminske mase za različite vrednosti vlažnosti drveća, za opštinu Čačak [5]

Vrsta drveta	Toplotne moći (MJ/kg)				Zapreminska masa (kg/m^3)			
	Vlažnost			Kora sa 0% vlage	Vlažnost			Kora sa 0% vlage
	0%	30%	50%		0%	30%	50%	
Bukva	18,82	11,87	7,7	17,00	680	798	1117	580
Hrast	18,36	11,80	11,50	19	650	750	980	425
Bor	21,21	12,87	9,50	20,62	750	980		300
Jela	19,46	11,90	8,30	21,00	410	730	880	460
Smrča	19,66	12,57	8,28	21,20	430	542	759	340
Ostalo drveće	oko 15	oko 10	oko 5	17,00	250	300	400	300

Prema tabeli 2. usvojene su toplotne moći i vlažnosti za drveća koja su na teritoriji opštine Čačak i one su date u tabeli 3.

Tabela 3. Usvojene toplotne moći i vlažnosti za drveća koja su zastupljena na teritoriji opštine Čačak

Vrsta drveta	Usvojena vlažnost oko 30%	
	Usvojene toplotne moći (MJ/kg)	Usvojene težine (kg/m^3)
Bukva	12	750
Hrast	12	700
Bor	13	600
Jela	12	510
Smrča	13	550
Ostalo drveće	10	400
Lišće i trava	12	200

2.2 Ukupni energetski potencijali od ogrevnog drveta iz redovnog gazdovanja šumama

Prema raspoloživim količinama ogrevnog drveta koje se poseče u toku godine, kao i usvojenih vrednosti za toplotnu moć i težine drveta iz tabela 2 i 3. (prema [5]), izračunati su energetski potencijali za opštinu Čačak (u MWh/god.), a one su date su tabeli 4.

Tabela 4. Energetski potencijal od ogrevnog drveta [4]

Lišćari	Ukupno (MWh/god)
20000*12*700/3600	210060,17

2.3 Energetski potencijali od otpadne drvne biomase koje nastaje prilikom korišćenja drveta iz šuma

Nakon seče drveća što za ogrev ili tehničku upotrebu u šumi ostaju znatne količine drvnih ostataka u vidu okrajaka, granja, panjeva i kore koji se mogu koristiti u energetske svrhe.

Iz navedenog se može konstatovati da se sav otpad ne može koristiti u energetske svrhe, ali organizovanim sakupljanjem i predklasiranjem otpada se značajna količina otpada može koristiti u tu namenu i povećati raspoložive biomase za rad toplanih postrojenja.

Prema raspoloživim količinama od 1200 m^3/god., kao i usvojenih vrednosti za toplotnu moć i težine drveta iz tabela 5 i 6., izračunati su energetski potencijali za opštinu Čačak (u MWh/god.) od drvnih ostataka koji nastaju pri seči drveća, a one su date su tabeli 5.

Tabela 5. Energetski potencijal od drvnih ostataka

Lišćari	Ukupno (MWh/god)
1200*12*700/3600	22622,13

2.4 Energetski potencijali od otpadne drvne biomase koje nastaje prilikom prerade drveta

Na teritoriji opštine Čačak svoje delatnosti u vezi prometa, primarne i sekundarne obrade drveta obavljaju i druga preduzeća, čije su aktivnosti veoma povezane sa tržišnim kretanjima u vezi potražnje i ponude drveta i proizvoda od drveta. Potražnja za rezanom građom četinara je jako promenljiva, a od toga isključivo zavisi i količina oblovine koja se proreže i količina drvnog ostatka. Četinarska rezana građa se koristi u građevinarstvu (za krovne konstrukcije, kao daska za šalovanje, krovna letva i sl.) koje je sada u Srbiji u stagnaciji.

Na teritoriji opštine Čačak nalazi se svega nekoliko pogona za preradu drveta koji su većeg kapaciteta i koji se bave primarnom preradom drveta, dok je većina pogona malog kapaciteta. Opšte karakteristike svih preduzeća je da se bave primarnom preradom pretežno četinara, da su veoma skromno opremljena mašinama, da pretežno proizvode rezanu građu za dalju upotrebu u građevinarstvu (daske i grede za krovne konstrukcije, plansku letvu) i da imaju mali stepen iskorišćenja ulazne sirovine.

Kao rezultat prerade drveta postoje tri glavne vrste ostatka prema veličini: kora, krupni ostaci nakon sečenja oblovine i sitni ostaci (piljevina, strugotina, drvna prašina). Obično je u pilanama od ukupne količine drveta koja se prerađuje između 50 i 65% je komercijalni proizvod, a ostatak je drvni otpad. Dakle, drvni otpad koji nastaje kod prerade drveta je u granicama od 35% do 50%. Usvojićemo da je za teritoriju opštine Čačak otpad kod prerade drveta oko 40%.

Gruba procena, na osnovu nepotpunih podataka, a što je dato u tabeli 6., energetski potencijal otpadanog drveta pri njegovoj preradi u fabrikama, sa teritorije opštine Čačak je oko 200000 MWh/god.

Tabela 6. Energetski potencijal pri preradi drveta [4]

Lišćari	Ukupno (MWh/god)
85000*12*700/3600	198333,33

2.5 Energetski potencijal od drvne biomase iz vanšumskog zelenila (fragmenti šume, drveće na međama, šumsko rastinje pored vodotoka, puteva i dr.)

Drvo iz vanšumskog zelenila (fragmenti šume, međe, šumsko rastinje pored vodotoka, puteva i dr.), Učešće šumskih ostataka u ukupno raspoloživih drvne biomase je oko 11%, dok je udeo pilane ostataka je oko 7%.

Možemo uzeti da je zapreminski prirast drveća sa fragremata oko 5,0 m^3/ha. Ako godišnje sečemo 60% od prirasta koji je oko 12000m^3/god . dobijamo sečivu masu od 1205m^3. Ovo drvo se uglavnom koristi u energetske svrhe.

U tabeli 7. dat je raspoloživi energetski potencijal od drveća iz vanšumskog zelenila.

Tabela 7. Eneregetski potencijal od vanšumskog zelenila [4]

Fragmenti šuma	Ukupno (MWh/god)
1205*12*700/3600	12145,0

2.6 Energetski potencijal od drvne biomase dobijene krčenjem i čišćenjem magistralnih i drugih puteva

Na teritoriji opštine Čačak Preduzeće za puteve održava puteve i na taj način sakupljaju drvnu i biljnu biomasu koja može da se koristi u energetske svrhe. Za izračunavanje raspoloživog energetskog potencijala ne postoje evidentirani podaci o količinama i vrstama energenata, ali prema preporukama odgovarajućih stručnih službi iz lokalne samouprave grada Čačka, usvojene su odgovarajuće količine i izračunat je energetski potencijal, a izračunate vrednosti za energetski potencijal (u MWh/god) date su u tabeli 8.

Tabela 8. Energetski potencijal od održavanja puteva

Vrsta energenta	Ukupno (MWh/god)
Pokošena trava	500
Opalo lišće	200
Orezano drveće	1400

2.7 Energetski potencijal od biomsanih otpada koji nastaje iz poljoprivredne proizvodnje

Potencijalni energenti i njihovi energetski potencijali iz poljoprivredne proizvodnje dobijeni za teritoriju opštine Čačak iz podataka: Popis poljoprivrede 2012. godine za teritoriju opštine Čačak.

Izračunati energetski potencijali od poljoprivrednih ostataka dati su u tabeli 9., a prema dobijenim podacima iz Popisa stanovništva 2012. god., i [5].

Tabela 9. Ukupni energetski potencijali od ostataka iz poljoprivrede [4]

Vrsta useva	Otpad	Raspoloživi energetski potencijal
Žitarice	2,1 t/ha	4400*2.1*14*1000/3600 = 35933,33
Kukuruz	3 t/ha	5100*3*13.5*1000/3600 = 57375
Povrće	1,1 t/ha	850*1.1*10*1000/3600 = 2597,22
Paradajz	2 t/ha	25*2*8*1000/3600 = 111,11
Krompir	1,5 t/ha	1500*2.5*12*1000/3600 = 12500
Malina	1 kg/m	87*15000*1*15/3600 = 5437,5
Kupina i vinogradi	1,1 kg/m	60*12000*1.1*16/3600 = 3520

NAPOMENA: Otpad kao produkt poljoprivredne proizvodnje može da se koristi kao energent prema [3], ¼ od proračunatih energetskih vrednosti. Otpad pri rezanju voća, maline, kupine i vinove vinove loze može da se koristi kao energent 100%. Na osnovu toga, ukupan potencijal raspoloživih energenata dat je tabeli 10.

Tabela 10. Energetski potencijali od ostataka iz poljoprivrede [4]

Vrsta energenta od otpada	Ukupno (MWh/god)
Žitarice (1/4)	8983,33
Kukuruz (1/4)	14343,75
Povrće(1/4)	649,31
Paradajiz(1/4)	27,78
Krompir (1/4)	3125
Voće	16450
Malina	5437,5
Kupinai vinogradi	3520
UKUPNO	116817,86

2.8 Energetski potencijal od biomsanih otpada pri sakupljanju u JKP Gradsko zelenilo Čačak

Sa teritorije kojom gazduje JKP Gradsko zelenilo Čačak, ze energetsko korišćenje mogu se koristiti biomase iz šumskih ekosistema, biomasa travne vegetacije (parkovi, održavanje oko vodnih tokova, i dr.).

Na teritoriji kojom gazduje JKP Gradsko zelenilo Čačak pri održavanju urbane zelene površine kao i puteve, na taj način sakupljaju drvnu i poljoprivrednu biomasu koja može da se koristi u energetske svrhe. Za izračunavanje raspoloživog energetskog potencijala postoje evidentirani podaci o količinama i vrstama energenata. Prema raspoloživim podacima koje sam dobio iz odgovarajućih službi JKP Gradsko zelenilo, a prema usvojenim vrednostima za toplotnu moć i težini odgovarajućih drvnih i biljnih biomasnih ostataka, prema tabelama 2 i 3., izračunati su vrednosti energetskih potencijala koje su date su u tabeli 11. (u MWh/god).

Tabela 11. Energetski potencijali od JKP Gradsko zelenilo u Čačku

Vrsta energenta	Količine na godišnjem nivou	Raspoloživi energetski potencijal (MWh/god)
Sakupljena travnasta masa	Oko 800 m^3 – vlažnosti oko 80%	800*8*250/3600 = 444,44
Sakupljeno granje	Oko 300 m^3 – vlažnosti oko 50%	300*10*300/3600 = 250,00
Sakupljeno otpadno drvo	Oko 300 m^3 – vlažnosti oko 50%	300*10*400/3600 = 333,33
Travnasta masa koja se ne sakuplja	Oko 100 m^3 – vlažnosti oko 80%	100*8*250/3600 = 55,56
Otpadno drvo koje se ne sakuplja	Oko 150 m^3 – vlažnosti oko 50%	150*10*400/3600 = 166,67
Ostali energetski otpad od drvne i biljne biomase	Oko 2500 kg – vlažnosti oko 20%	8*2500/3600 = 5,56
UKUPNO (MWh/god)		1255,56 (MWh/god)

2.9 Energetski potencijal od biomasnih otpada pri sakupljanju u JKP Komunalac Čačak

Na teritoriji kojom gazduje JKP Komunalac Čačak pri sakupljanju komunalnog otpada između ostalog sakupljaju razne biomasne ostatke koji se mogu koristiti za proizvodnju biogasa (ljuske krompira, ostaci od hrane, ostaci pri preradi poljoprivrednih proizvoda i sl.) koji se mogu koristi u energetske svrhe za proizvodnju biogasa. Za izračunavanje raspoloživog energetskog potencijala postoje evidentirani podaci o količinama i vrstama energenata. Prema raspoloživim podacima koji su dobijeni iz odgovarajućih službi JKP Komunalac, a prema usvojenim vrednostima za toplotnu moć i težini odgovarajućih drvnih i biljnih biomasnih ostataka, izračunati su vrednosti energetskih potencijala koje su date su u tabeli 12. (u MWh/god**)**.

Tabela 12. Eneregetski potencijali od JKP Komunalac u Čačku

Vrsta energenta	Količine na godišnjem nivou	Raspoloživi energetski potencijal (MWh/god)
Ljuska krompira	Oko 600 t – vlažnosti oko 80%	600*8*250/3600 = 333,33
Pomije od hrane	Oko 500 t – vlažnosti oko 50%	300*10*300/3600 = 250,00
Otpad od prerade polj. proizvoda	Oko 300 t – vlažnosti oko 50%	300*10*400/3600 = 333,33
Ostali biomsani otpad	Oko 100 t – vlažnosti oko 80%	100*8*250/3600 = 55,56
Otpadno drvo koje se ne sakuplja	Oko 150 m^3 – vlažnosti oko 50%	150*10*400/3600 = 166,67
Ostali energetski otpad od drvne i biljne biomase	Oko 2500 kg – vlažnosti oko 20%	8*2500/3600 = 5,56
UKUPNO (MWh/god)	Oko 600 t – vlažnosti oko 80%	1144,45 (MWh/god)

2.10 Energetski potencijal od biomase iz energetskih zasada u JKP Gradsko zelenilo Čačak

Plantaže za proizvodnju drvne biomase sa kratkim proizvodnim ciklusom - sečom, se takođe mogu smatrati alternativnom sirovinom za energetske potrebe.

Na teritoriji opštine Čačak prema podacima nadležnih institucija postoji oko 300 ha zemljišta koje se prema svojim karakteristikama može staviti u funkciju formiranja energetskih drvenastih zasada. U proizvodnom ciklusu od 4 godine drveća postižu srednje prečnike od 8,5-13,0 cm, visinu od 12,0-14,5 m i zapreminu od 50 m^3/ha godišnje. Energetska vrednost u ovim zasadima (formiranim na adekvatnom zemljištu) je vrlo slična i iznosi oko 250 GJ po hektaru godišnje. Korišćenjem površine zemljišta za "energetske zasade" od 300 ha (koliko bi se na teritoriji opštine Čačak moglo obezbediti za tu namenu), moglo bi se obezbediti svake godine količina biomase koja je po raspoloživoj energiji ekvivalentna polovini energetske produkcije iz svih ostalih resursa drvnih ostataka biomase opštine. Zapremina drvne mase bi u tom slučaju na godišnjem nivou iznosila oko 7000 m^3. Energetski potencijal na godišnjem nivou iznosila bi oko 7000x200x10 = $14x10^6$ MJ/god. = $14x10^6$/3600 = 3.888,89 MWh/god. Potencijali postoje, sa realnim mogućnostima plasmana drvne mase za termoenergetsko postrojenje i ostali činioci bi se pronašli.

3. ZAKLJUČCI

Sve veći rast svetske populacije, industrijalizacija i progresivno-tehnološki napredak i veći obim transporta, uzrokovao je da su u današnje vreme potrebe za energijom sve veće. Svetsko energetsko tržište ne može više da se zasniva na fosilno izvedenim gorivima čije su rezerve ograničene. Deficit rezervata konvencionalne fosilne energije stvorila je veliki interes za korišćenjem alternativnih izvora energije, od kojih je jedan biomasa. U poređenju sa korišćenjem drugih obnovljivih izvora energije, upotreba biomase se povećava iz dana u dan.

S obzirom na činjenicu da su klimatske promene blisko povezane sa obrascima korišćenja energije i da se na njih može uticati smanjenom upotrebom fosilnih goriva koja se svakodnevno koriste, uz prelazak na obnovljive izvore, posebno na energiju biomase kao izvor koji je potpuno CO_2 neutralan, široka je primena mogućih rešenja za njenu konverziju i upotrebu na teritoriji Republike Srbije. Takođe, na mnogim poljoprivrednim gazdinstvima, mogu da se izgrade mini postrojenja na obnovljive izvore energije radi upotrebe u sopstvenom procesu proizvodnje, odnosno za napajanje električnom energijom štala, hala i preradnih pogona, kao i toplotne energije za njihovo zagrevanje.

3.1 Zaključci za energetske potencijale sa teritorije opštine Čačak

Za racionalno iskorišćavanje raspoloživih količina biljne i drvne biomase kao energenta, kao i otpada koji nastaje pri korišćenju šuma pri rezanju i njihovoj preradi, sa područja teritorije opštine Čačak, definisane su odgovarajuće količine i energetski potencijali od drvene i biljne biomase koje su godišnje na raspolaganju.

Na osnovu dobijenih rezultata istraživanja raspoloživi energetski potencijal u MWh/god. je:

- od ogrevnog drveta iz redovnog gazdovanja šumama 210060,17 MWh/god.
- od otpada koji nastaje prilikom korišćenja šuma (otpad koji nastaje kod seče i izrade oblog i prostornog drveta, panjevi, granje i sl.) 22622,13MWh/god.
- od drveta izvan šumskog zelenila (šume, međe, šumsko rastinje pored vodotoka, puteva i dr., 12145,0MWh/god.
- drvne i biljne biomase dobijena krčenjem i čišćenjem magistralnih i drugih puteva 1200MWh/god.
- od drvnog otpada koji nastaje kod prerade drveta 200000 MWh/god.

– otpad koji nastaje iz poljoprivredne proizvodnje (ratarstvo, povrtarstvo) 76850,48 MWh/god.
– energetski potencijal od sirovina koje sakuplja JKP Komunalac Čačak je 1144,45 (MWh/god)
– energetski potencijal od uzgajanja MISKANTUSA je $14x10^6/3600$ = 3888,89 (MWh/god).

Na osnovu dobijenih rezultata istraživanja energetski potencijal od raspoloživih energenata koje sakuplja JKP Gradsko zelenilo Čačak je 1255,56 (MWh/god).

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ENERGY POTENTIALS OF BIOMASS AND USE OF HIGH ENERGY PLANTS AS A RENEWABLE ENERGY SOURCE ON THE TERRITORY OF THE CITY OF ČAČAK

Abstract: *Use of biomass forest and agricultural ecosystems as renewable energy sources, in recent years, is a practical and reliable way to obtain energy in most EU countries. Numerous scientific and practical research is aimed at the possibility of using different forms of wood and plant biomasses as potential energy sources. In this paper, they are given to the energy potentials of biomass, as well as the possibilities of using high energy plants in the territory of the city of Čačak.*

Key words: *wood and plant biomass, energy potential, territory of the Municipality of Cacak.*

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MOGUĆNOSTI PROIZVODNJE BIOGASA OD RASPOLOŽIVIH OTPADNIH SIROVINA

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Rezime*: Savremena bioenergija, poput biogasa i korišćenje otpadnih sirovina u energetske svrhe, donosi mnoge koristi poput povećanja energetske sigurnosti, stvaranja prihoda i smanjenja emisije stakleničkih gasova. U scenariju održivog razvoja, moderna bioenergija može da raste i do 75% naredne decenije, pri čemu biogas i biometan rastu više od 20 puta kako bi obezbedili toplotu, proizveli električnu energiju za vozila na gorivo.*

Povećavanje svetske populacije i promena u ishrani, kako bi u namernice ušlo više proteina na bazi mesa, imaće značajan negativan uticaj na životnu sredinu, velikim delom zbog upotrebe zemljišta i promene namene zemljišta. Svako udaljavanje od fosilnih goriva neizbežno znači povećanje upotrebe biomase zajedno sa svim ostalim obnovljivim izvorima i skladištenjem ugljenika.

Izgradnja ekonomije na biološkoj osnovi znači smanjenje upotrebe fosilnih goriva, efikasno korišćenje resursa, potpunu valorizaciju otpada i ostataka, održavanje ciklusa ugljenika i hranljivih sastojaka i proširivanje visokokvalitetne upotrebe biomase. Iako su postojeći pristupi uglavnom ograničeni na hranu, obnovljive izvore energije i recikliranje biootpada, neophodno je razvijati proizvode na biološkoj osnovi. Dugoročno skladištenje C u zemljištu ugradnjom bio uglja, za koji je poznato da poboljšava sposobnost zadržavanja vlage u zemlji, istovremeno pomaže u rekonstrukciji strukture tla, poboljšanju okruženja za mikroorganizme u tlu, regulaciji pH tla, pomažu u zadržavanju hranljivih sastojaka, istovremeno omogućavajući sporo otpuštanje za zdrav rast useva, i usporavanje ispiranja hranljivih materija i emisije N_2O.

Ključne reči*: otpadne sirovine, proizvodnja biogasa.*

1. UVODNA RAZMATRANJA

Korišćenje raspoloživih otpadnih sirovina u energetske ili druge svrhe, je značajno zbog siromašnih energetskih potencijala uopšte, kao i zbog smanjenja uvozne zavisnosti, obezbeđenja snabdevanja energijom, smanjenja zagađenja okoline, zadovoljenja međunarodnih obaveza za smanjenje emisije CO_2. Takođe, racionalno korišćenje raspoložive poljoprivredne otpadne drvne i biljne biomase u energetske i druge svrhe, značajno bi imalo uticaj na podizanje tehnološkog nivoa energetike, mašinogradnje, prehrambene industrije i dr., bržeg razvoja slabo razvijenih regiona bogatih otpadnom od poljopivredne drvne i biljne biomase koji se ostvaruje kroz: realizaciju investicija, angažovanjem lokalne radne snage, otvaranjem novih radnih mesta, poboljšanjem lokalne infrastrukture, i ostvarivanjem prihoda kroz razne vrste proizvodnje.

Postoje velike mogućnosti za korišćenje otpadne biomase (prema [1], [2], [3], [4], [5]) u poljoprivredi: za proizvodnju humusa (zaoravanjem), stajnjaka (prostiranjem), stočne hrane (bez tretiranja, sa tretiranjem hemijskim sredstvima, mešanjem sa proteinskim hranivima i dr.), toplotne energije (loženjem), građevinskog materijala (razne presovane ploče i kocke), delova nameštaja (ploče „iverice”), alkohola (vrenjem), biogasa (anaerobnim vrenjem), za proizvodnju papira i ambalaže, sredstava za čišćenje metalnih površina (poliranjem), pudera i drugih kozmetičkih sredstava, ukrasnih predmeta (tapiserija, slamnatih šešira, i dr.) itd.

Evropske zemlje poput Nemačke, Francuske, Danske, Holandije ili daleke Kine, koje imaju veliki problem životinjskog otpada, rešavaju ovaj, i ekološki problem, kroz procese fermentacije. U SAD je benzin sve češće mešavina benzina i biogoriva-etanola.

Za racionalnu upotrebu otpadnih sirovina u energetske svrhe treba da definišu eneregetski potencijli za definisanu teritoriju od:

- drvnih ostataka koji nastaju, na prvom mestu, krčenjem drvnih zasada: neiskorišćeno drvo, ostaci klada, panjevi, granje, i dr.,
- poljoprivrednih ostataka: slama, lišće, delovi voćaka, otpadi pri proizvodnji maline i kupine, vinove loze, stabljike kukuruza i dr.
- otpadne drvne i biljne biomase iz: fragmenata šuma, međa, uvala, klizišta, održavanja: elektrovodova, puteva i sl.,
- komunalnog drvnog i biljnog otpada iz domaćinstava, od prehrambene industrije i sl.

2. PROIZVODNJA BIOGASA OD RASPOLOŽIVIH OTPADNIH SIROVINA

Razne vrste mikroorganizama mogu da uklanjaju i pretvaraju neke organske materije u bezopasne, čak upotrebljive nusproizvode, kao što je metan. Čvrsti otpaci iz gradova i mulj iz postrojenja za preradu otpadnih voda, prerađuju se u posebnim kadama u kojima relativno brzo dolazi do anaerobnog mikrobiološkog razlaganja iz kojeg nastaje koristan gas, metan. Anaerobna fermentacija može se porediti sa situacijom u močvarama i drugim sličnim vodenim oblastima gde nastaje metan. Metan se sakuplja i koristi kao izvor energije, a u svim kontrolisanim tehnikama fermentacije otpada konačni proizvod koji se emituje u atmosferu je CO_2. Posle fermentacije organskog otpada izdvojenog na izvoru, ostatak fermentacije se normalno tretira aerobno do komposta. Na taj način je konačni rezultat fermentacije otpada u većini slučajeva sličan aerobnom kompostiranju. Proces razlaganja konvertuje organsku frakciju u biogas, kompost i vodu. Proizvodnja biogasa je 130-150m^3 po toni otpada u zavisnosti od sastava organske materije. Biogas je ekološko gorivo sa toplotnom moći od 6-7 kWh/m^3. Može biti upotrebljen za proizvodnju električne energije preko gasnih motora ili kao gorivo za vozila.

Uslovna podela biogasa po mestu nastanka je:

- deponijski gas,
- biogas iz poljoprivrede,
- biogas iz drvenog otpada,
- biogas iz otpadnih voda.

Količina bigasa koji se luči po toni otpada data je u tabeli 1.

Tabela 1. Količina biogasa koji se luči po toni odpada [6]

PROIZVODI/NUSPROIZVODI	m^3 BIOGASA/t
Kukuruz	200
Sirak	145
Suncokret	175
Tritikal	160
Ječam	140
Mulj	130

Trava	120
[redacted]	
Goveđe đubrivo	80
Goveđe tečno đubrivo	30
Svinjsko tečno đubrivo	20
Ovčije đubrivo	60
Zečije đubrivo	40
Kokošije đubrivo	60
[redacted]	
Kočanji kukuruza	295
Slama žitarica	220
Pulpa agruma	120
Komina maslina	85
Ljuske od paradajiza	130
Crni luk	100
Pulpa šećerne repe	130
Krompir	130
Odpadci voća i povrća	100
Otpadci iz proizvodnje piva	100
[redacted]	
Čvrsti komunalni otpad	80/110
Pekarski proizvodi	650
Slatkiši isteklog roka trajanja	670
Upotrebljeno kuhinjsko ulje	550
Klasični odpad	100
Mlečna sirutka	25

U današnje vreme, sve je veća upotreba biogasa dobijenog sa deponija i iz otpadnih voda. Čak i kada se ne koristi za dobijanje toplotne i/ili električne energije, deponijski gas se mora propisno odložiti i prečistiti, jer sadrži opasne zapaljive materije, od kojih mnoge stvaraju smog. Biogasni digestori koriste biorazgradljive materije, od kojih se dobijaju dva korisna proizvoda: biogas i fermentisano biođubrivo vrhunskog kvaliteta. Biogas prečišćen do nivoa čistoće za gasovod naziva se obnovljivi prirodni gas i moguće ga je koristiti u svakoj primeni u kojoj se inače koristi zemni gas. To uključuje distribuciju takvog gasa putem gasovoda, proizvodnju struje, grejanje, zagrevanje vode i upotrebu u raznim tehnološkim procesima. Kompresovan, biogas može da se koristi i kao pogonsko gorivo za vozila. Biogas je mešavina metana i ugljen-dioksida, koja se dobija prilikom razgradnje organskih materija pod anaerobnim uslovima. To je kvalitetno gorivo, koje može da zameni fosilna goriva, a takođe je i CO_2 neutralno. U vreme kada rezerve fosilnih goriva opadaju, energetski troškovi rastu, a životnu sredinu ugrožava nepravilno odlaganje smeća, pronalaženje rešenja za problem biološkog otpada i tretman otpadnih organskih materija, postaje pitanje od najveće važnosti Biogas je metabolički proizvod bakterija koje proizvode metan, i koje su uzrok raspadanju. Osim odsustva kiseonika, neophodni uslovi su konstantna temperatura i pH vrednost od 6,5 do 7,5. Raspadanje je najefektivnije na temperaturi od 15°C (psihrofilne bakterije), 35°C (mezofilne) i 55°C (termofilne). U praksi se pokazalo da je zadržavanje od oko 10 dana najefektivnije za termofilne bakterije, 25 do 30 za mezofilne i 90 do 120 za psihrofilne. Većina postrojenja koja danas rade, rade u mezofilnom temperaturnom rangu.

Pošto se biogas proizvodi tamo gde se organski materijal razgrađuje bez vazduha, postoji širok spektar organskih materija koje su pogodne za anaerobnu razgradnju.

Neke od tih materija su:

- tečno i čvrsto stajsko đubrivo,
- posebno prikupljan biolški otpad iz stambenih delova,
- obnovljivi materijali, kao što su kukuruzna silaža, semenke koje se ne koriste za ishranu, itd.,
- mulj iz kanalizacije i masti,
- korišćeni podmazivači,
- trava (npr. u EU neobrađena zemlja),
- biloški otpad iz klanica; pivara, destilerija; prerade voća i proizvodnje vina; mlekara; industrije celuloze, šećerana.

Napomena: drvo nije pogodno za proizvodnju biogasa, jer bakterije koje proizvode metan ne mogu da svare lignin, kojeg ima u drvetu. Takođe i pesticidi, dezinfekcija i antibiotici imaju negativan efekat na bakterije.

2.1 Prečišćavanje otpadnih voda – izvor energije

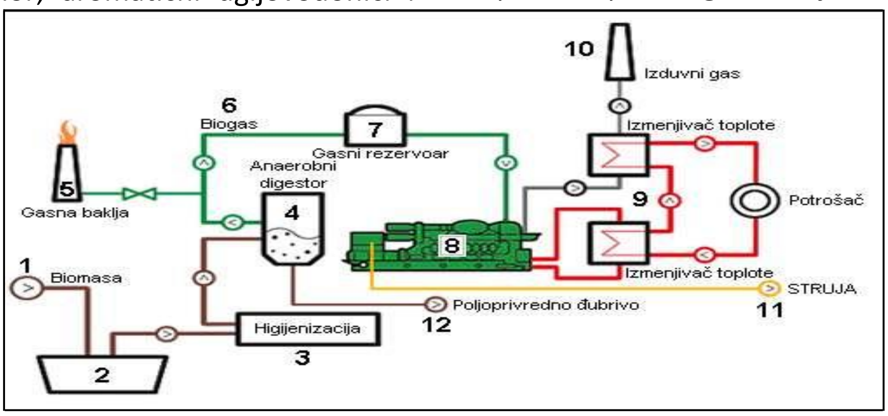
U postrojenjima za prečišćavanje otpadnih voda sa anaerobnom stabilizacijom mulja nastaje biogas, koji bi mogao predstavljati značajan izvor energije. Efikasnost produkcije biogasa obezbeđuje se održavanjem temperature (oko 35°C), pH vrednosti, mešanjem i odstranjivanjem kiseonika i toksičnih materija. U anaerobnim reaktorima (digestor) nastaje biogas kao mešavina gorivih i negorivih gasova prosečnog sastava (u zapreminskim %): metan 55-75%, ugljen-dioksid 25-45%, i ostalih gasova, kao što su vodonik, kiseonik, ugljen-monoksid, azot, vodonik-sulfid, amonijak i vodena para. Proizvodnja biogasa se može proceniti na bazi sledećih praktičnih i iskustvenih podataka: kod industrijskih otpadnih voda (šećerane, prerada melase, prerada krompira, proizvodnja voćnih sokova, mlekare, pivare, papir i celuloza) prosečna proizvodnja metana je 0,20 - 0,40 m_3/kg NRK sa udelom metana u biogasu od 60 - 80%; na stočnim farmama očekivana proizvodnja biogasa varira u zavisnosti od životinjske vrste i načina uzgoja i kreće se u granicama od 20 - 40 m^3 biogasa/m^3.

2.2 Deponije smeća - izvor energije

U industrijskim zemljama nastaje 300-400 kg smeća godišnje po osobi (prema [7]). Ovo smeće se skuplja i odlaže na bezbednim i sanitarnim deponijama, koje podrazumevaju zaštitu podzemnih voda kao i zaštitu vazduha od prljavog i opasnog deponijskog gasa. Pomenuti deponijski gas nastaje razgradnjom organskih supstanci pod uticajem mikroorganizama u anaerobnim uslovima. U središtu deponije nastaje nadpritisak, pa deponijski gas prelazi u okolinu. Prosečan sastav deponijskog gasa je 35-60% metana, 37-50% ugljen-dioksida i u manjim količinama se mogu naći ugljen-monoksid, azot, vodonik-sulfid, fluor, hlor, aromatični ugljovodonici i drugi gasovi u tragovima. Na osnovu navedenog sastava deponijskog gasa, može se uočiti da je on vrlo opasan po čovekovu okolinu, kako za zdravlje živih organizama, tako i po infrastrukturne objekte u blizini deponija, jer je metan u određenim uslovima vrlo eksplozivan. Metan je više od 20 puta (prema [5]) štetniji po klimu i ozonski omotač nego ugljendioksid, što praktično znači da 1 tona metana oštećuje ozonski omotač (efekat staklene bašte) kao 21 tona ugljen dioksida. Da bi se odstranili negativni uticaji nekontrolisanog širenja deponijskog gasa, izvodi se plansko sakupljanje i prisilno usmeravanje gasa ka mestu sagorevanja, što takođe pospešuje bržu stabilizaciju svežih delova deponije, smanjuje zagađivanje otpadnih voda, omogućava korišćenje energije na deponiji (grejanje, topla voda, struja). Zakonska obaveza sakupljanja i spaljivanja deponijskog gasa nameće pravo rešenje: sagorevanje gasa u energetske svrhe uz stvaranje ekonomske dobiti.

3. TEHNOLOGIJE ZA KORIŠĆENJE BIOGASA OD OTPADNIH SIROVINA

Biogas prečišćen do nivoa čistoće za gasovod, naziva se obnovljivi prirodni gas i moguće ga je koristiti u svakoj primeni u kojoj se inače koristi zemni gas. To uključuje distribuciju takvog gasa kroz gasovod, proizvodnju struje, grejanje, zagrevanje vode, dobijanje vodonika iz biogasa, gorivo za kotlove i upotrebu u raznim tehnološkim procesima. Kad je kompresovan, onda se biogas može koristiti i kao pogonsko gorivo za motorna vozila i poljoprivrednu mehanizaciju. Uprošćen proces gasifikacije data je na slici 1.



Slika1. Proces gasifikacije biomase i proizvodnja toplotne i električne energije [7]

Sastav biogasa, najviše zavisi od sirovine od koje se dobija, te su radi analize, odnosno procene ekonomske opravdanosti proizvodnje biogasa, pored vrste sirovine korišćeni i tehnički podaci, glavni procesni parametri i količina proizvedene energije. Polaznu osnovu za ekonomsko vrednovanje biogasa čini sadržaj metana koji direktno utiče na toplotnu moć ovog energenta, čijim se sagorevanjem oslobađa toplotna energija. Biogas u proseku sadrži oko 50-70% metana, 25-45% ugljen-dioksida, 2-7% vode od 20-40°C, 2-5% azota, 0-2% kiseonika i manje od 1% vodonika. Prilikom vrednovanja biogasa mora se imati u vidu činjenica da se oko 1/3 dobijenog biogasa mora upotrebiti za održavanje potrebne temperature u fermentoru. Biogas se može prečistiti do praktično čistog metana (99,9%), koji se može ubacivati u javnu gasovodnu mrežu ili se može koristiti za pogon motora sa unutrašnjim sagorevanjem. Proizvodnja biogasa se kreće u proseku od 130 do 150 m^3 po toni otpada u zavisnosti od sastava organske materije. Biogas je ekološko gorivo sa toplotnom moći od 6-7 kWh/m^3.

Na osnovu svega navedenog, treba napomenuti još i to da pored dobijanja energije, proizvodnja biogasa ima još dva veoma značajna efekta. To su dobijanje kvalitetnog stabilnog đubriva sa poboljšanom vrednošću, kao i doprinos zaštiti životne sredine. Kada se osoka poreklom iz svinjarske proizvodnje direktno koristi kao đubrivo, dolazi do oslobađanja ugljen-dioksida i amonijaka u atmosferu. Veoma značajni rezultati se postižu i sa aspekta smanjenja bakteriološkog zagađenja. Naime, u otpadnim vodama stočarske proizvodnje, često se nalaze različiti mikroorganizmi, koji mogu biti patogeni i izazvati širenje oboljenja, pa čak i epidemije. U procesu anaerobnog vrenja uništava se najveći deo patogenih organizama.

Sam postupak proizvodnje biogasa sastoji se od zone prethodnog tretmana poljoprivredne biomase (ili komunalnog otpada), anaerobne digestije (fermentacije) koja procesom razlaganja konvertuje organsku frakciju u biogas, kompost i vodu.

Prema slici 1., organski materijal se prvo skuplja u tanku za skupljanje i mešanje. Ovaj tank služi za mešanje i homogenizaciju različitih fermentacionih materija. Nakon čišćenja na 70°C, gde se uništavaju sve bakterije – negativne po proces fermentacije, materijal se prebacuje u anaerobni digestor. U slučaju prestanka rada postrojenja (npr. redovan servis), kao i u slučaju veće proizvodnje gasa, neophodna je gasna baklja, koja taj višak sagoreva. Prečišćena biomasa predstavlja početak anaerobne razgradnje. Neophodni uslov je konstantna temperatura i pH vrednost 6,5 do 7,5. Kako bi se osigurao stalni dotok gasa, nezavisno od protoka inputa, proizvedeni biogas se skuplja u gasnom rezervoaru, odakle se zatim prosleđuje u gasni motor. Toplota koja se stvara tokom rada motora, može efektivno da se iskoristi preko izmenjivača toplote. Korišćenjem generatora, mehanička energija gasnog motora se pretvara u električnu energiju. Nusproizvod je kvalitetno đubrivo koje može da se iskoristi na njivi kao zamena za mineralno đubrivo.

4. ZAKLJUČCI

Sve veći rast svetske populacije, industrijalizacija i progresivno-tehnološki napredak i veći obim transporta, uzrokovao je da su u današnje vreme potrebe za energijom sve veće. Svetsko energetsko tržište ne može više da se zasniva na fosilno izvedenim gorivima čije su rezerve ograničene. Deficit rezervata konvencionalne fosilne energije stvorila je veliki interes za korišćenjem alternativnih izvora energije, od kojih je jedan biomasa. U poređenju sa korišćenjem drugih obnovljivih izvora energije, upotreba biomase se povećava iz dana u dan.

Energiju je moguće proizvoditi primenom različitih tehničko-tehnoloških rešenja, pri čemu postoje značajne razlike ulaganja i troškova proizvodnje u zavisnosti od vrste i snage postrojenja. Uvek je neophodno uraditi opsežne analize koje bi dovele do izbora optimalne tehnologije kako sa ekonomskog tako i sa aspekta zaštite okoline, bezbednosti i zdravlja.

S obzirom na činjenicu da su klimatske promene blisko povezane sa obrascima korišćenja energije i da se na njih uticaj može uticati smanjenom upotrebom fosilnih goriva koja se svakodnevno koriste, uz prelazak na obnovljive izvore, posebno na energiju biomase kao izvor koji je potpuno CO_2 neutralan, široka je primena mogućih rešenja za njenu konverziju i upotrebu na teritoriji Republike Srbije. Takođe, na mnogim poljoprivrednim gazdinstvima, mogu da se izgrade mini postrojenja na obnovljive izvore energije radi upotrebe u sopstvenom procesu proizvodnje, odnosno za napajanje električnom energijom štala, hala i preradnih pogona, kao i toplotne energije za njihovo zagrevanje.

U oblasti proizvodnje biogoriva iz biomase, takođe postoji mogućnost šire primene: dobijanje biogasa, bioetanola ili biodizela, kao dodatak ili zamena sve više nedostajućih fosilnih goriva.

Proces dobijanja biogasa, uz proizvodnju energije doprinosi i supstituciji hranljivih elemenata neophodnih za ishranu biljaka iz veštačkih đubriva, kao i smanjenju zagađenja životne sredine.

Smanjenje uvozne energetske zavisnosti, uz razvoj ruralnih krajeva i mogućnost novog zapošljavanja lokalnog stanovništva, a takođe je jedan od očekivanih benefita ove privredne aktivnosti.

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POSSIBILITIES PRODUCTION OF BIOGAS RAPED WASTE RAW MATERIALS

Summary: *Contemporary bioenergy, such as biogas and use of waste raw materials, brings many benefits such as energy security, income generation and greenhouse gas emissions. In the Sustainable Development Scenario, modern bioenergy can also grow up to 75% of the next decade, where biogas and biomethane grow more than 20 times to provide heat, producing electricity for fuel vehicles. Increasing the world population and dietary change, in order to enter multiple meat-based proteins, will have a significant negative impact on the environment, large due to land use and land purposes. Any removal of fossil fuels inevitably means increasing the use of biomass together with all other renewable sources and carbon storage. Construction of economics on biological basis means reducing the use of fossil fuels, efficient use of resources, complete valorization of waste and residues, maintaining carbon and nutrient cycles and highquality biomass use. Although the existing approaches are mainly limited to food, renewable energy sources and bio-recycling, it is necessary to develop products on biological basis. Long-term storage C in the land installation, which is known to improve the ability to maintain soil, in improving the environment for microorganisms in soil, augment of nutrients, while maintaining slow dismissal for Healthy growth of crops, and slowing down the flush of nutrients and* N_2O *emissions.*

Key words: *wasteworthy raw materials, biogas production.*

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SELECTION OF MATERIALS OF TRANSVERSE ARMS OF INDEPENDENT VEHICLE SUSPENSION SYSTEM USING QUANTITATIVE METHOD OF INFLUENCE OF PROPERTIES

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Abstract: *This paper describes the procedure for selecting the material of the transverse arms of an independent passenger vehicle suspension system using the quantitative method of impact properties. After defining the basic criteria, ie. requirements that potential materials must meet, a digital-logical method has been applied to calculate the importance factor of the properties. The material selection process included the application of CES EduPack software (Cambridge Engineering Selector EduPack) for the analysis of diagrams and values of the properties of potential materials. The obtained results indicate that the method of influence of properties leads to the conclusion that the optimal material of the transverse arms is low alloy steel 25CrMo4.*

Keywords: *material selection, transverse arm, property impact method, independent support, CES EduPack*

1. INTRODUCTION

The choice of material is one of the most important activities in the construction of components of any system [1]. The fact that there are more than 70,000 types of materials [2], of which more than 40,000 are metal-based alloys [3] makes the material selection process extremely challenging. A large number of available materials, as well as a large number of requirements and criteria in the selection of materials result in increased complexity and uncertainty in decision making, so it is useful to use quantitative methods [4]. The goal of applying quantitative methods of material selection is not to replace experience, but to avoid excluding some of the possibilities, as well as to reduce the subjectivity of the process [1]. This paper presents the application of a quantitative method of material selection - the method of influence of properties. In the selection process, the material properties were ranked depending on the importance factors, obtained by the digital-logical method, and based on this, the optimal material of the transverse arms of the independent suspension system of the passenger vehicle was selected.

2. TRANSVERSE ARMS OF INDEPENDENT SUSPENSION SYSTEM

The vehicle suspension system has two basic functions: maintaining the desired position (guidance) of the wheels in relation to the ground and the body of the vehicle in all conditions of movement, and the reception and transmission of forces and moments [5]. It is necessary for the suspension system to ensure that all four points, and especially the drive, maintain contact with the ground in all conditions of movement. It is of great importance that the suspension system contributes to the appropriate characteristics of road behavior, then to insulate the vehicle from bumps and impacts from the ground surface, as well as to ensure road holding, in the entire range of power transmission and speed. Road holding and comfort are essentially opposite requirements, so a compromise needs to be reached between them. There are two types of suspension systems: dependent and independent. The wheels of the dependent suspension system are placed on a rigid axle, which leads to the direct transmission of the disturbance from one wheel to another wheel of the same axle, which is unfavorable. The positive side of this type of support is the constant position of the wheels in relation to the ground. A major drawback is also the large unsupported mass, especially in the drive shafts, as well as the relatively large space required for system installation. An independent suspension system, unlike a dependent one, allows vertical displacements of one axle point, without affecting another wheel of the same axle [6]. Most passenger cars and light trucks are equipped with an independent suspension system on the front axle, as this gives significantly more space to accommodate the engine, greater wheel movement, increased vibration resistance, better vehicle handling, and overall better driving comfort. The disadvantage of this system is the complexity of construction and production costs, due to the increased number of parts [7,8]. There are several constructions of the independent suspension system, of which the most widely used is the system with two transverse arms of different lengths (*Double Wishbone Independent Suspension*), shown in Figure 1. This system design is able to compensate for tilting the vehicle body and keep the wheel in a constant position in relation to the ground, and creates conditions for providing the best characteristics of vehicle stability [5].

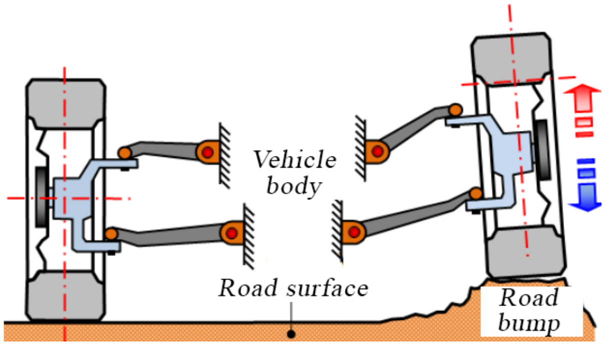

Figure 1. Independent vehicle suspension system with two transverse arms [7]

The upper transverse arms are generally shorter than the lower ones, which directly affects the values of the wheel inclination. The transverse arms are connected on one side by means of ball joints with wheel sleeves, and on the other by strong blocks with the vehicle body.

The transverse arms (Figure 2) must be able to withstand the loads that occur when braking, turning and accelerating the vehicle, as well as the effects of the ground [9].

Figure 2. Transverse arms [10]

There is a difference between the loads that act on the lower and upper arms. In the lower arm, especially if there are spring supports on them, relatively large loads occur, while the loads in the upper arms can be extremely low [5]. The length of the upper transverse arms is of great importance, because it directly affects the movement of the center of lateral tilt of the vehicle. It is recommended that the length of the upper transverse arms be between 50 and 80% of the length of the lower arms [11]. Available technologies for the construction of transverse arms of the independent suspension system of passenger vehicles are: hot forging, casting (casting in metal molds, high pressure casting, vacuum casting, die casting), and semi-solid metal processing (*thixoforming, thixocasting* i *rheocasting*).

Figure 3 shows a comparison of different technologies for making transverse arms, depending on the characteristics of the obtained parts and the cost of the process. Metal molding, vacuum casting and high pressure casting processes have poorer part characteristics compared to modern casting processes, such as die casting, rheocasting and thixocasting.

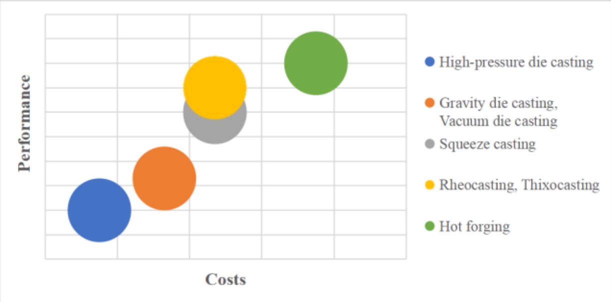

Figure 3. Comparison of different technologies of making transverse arms [12]

However, modern casting procedures also lead to an increase in costs, which must be taken into account when choosing the technology of making transverse arms. Hot forging provides even better characteristics of the parts, but the costs of the same exceed the costs of modern casting procedures.

3. MATERIALS FOR THE CROSS ARMS OF THE INDEPENDENT VEHICLE SUPPORT SYSTEM

3.1 Low alloy steels

Low-alloy steels have better tensile properties compared to low-carbon and medium-carbon steels. Low-alloy steels in which the main alloying elements are chromium and molybdenum (1% Cr; 0.2% Mo) are widely used in the manufacture of components of an independent support system. Chromium is usually added to steel to increase corrosion and oxidation resistance, as well as to improve hardenability [13]. Molybdenum alloying up to 0.2% contributes to an additional increase in the hardenability of low-alloy steels [14]. Another advantage of Cr-Mo low-alloy steels is the good creep characteristics [13]. The addition of nickel to the mentioned steels raises their hardenability to an even higher level, and also has a positive effect on increasing the resistance to the appearance of release brittleness [15].

3.2 Aluminum alloys

Aluminum alloys are used to fabricate the components of an independent support system primarily for mass savings [16]. It is estimated that every 10% savings in vehicle weight leads to a reduction in fuel consumption of 5 to 7% [17]. Weight loss will be followed by fatigue and constant tiredness, gyroscopic torque, which occurs as a result of simultaneous wheel rotation and turning, and has a negative impact on the handling of the vehicle [17].

In addition, the fabrication of aluminum alloy parts leads to high reliability [18], efficient vibration damping, as well as vehicle noise reduction, compared to other materials used to fabricate the components of an independent suspension system.

According to the method of processing, aluminum alloys are divided into those used for casting and those that are processed by deformation. The second division is into aluminum alloys that thermally strengthen, and those that do not thermally strengthen. When it comes to aluminum alloys intended for casting, there are alloys for casting in sand and alloys for casting in metal molds. The processing of deformation alloys is performed by forging on mechanical presses, and the preparations are heated to temperatures of 400-500 °C before processing.

3.2 Magnesium alloys

Of all the materials used to make the vehicle's independent suspension components, magnesium alloys have the lowest density, 1.74 g/cm^3, which makes them 35% lighter than aluminum alloys, and over four times lighter than steel [19]. Magnesium alloys are characterized by good ductility, better noise and vibration damping characteristics compared to aluminum alloys, and excellent casting [20].

The biggest disadvantage of magnesium alloys is the high cost and poor corrosion resistance [21]. However, if the reduction in fuel consumption is taken into account, as well as the lower life cycle costs of components made of magnesium alloys compared to other applied metals [22], exploring the possibility of wider implementation has potential. Another disadvantage of magnesium alloys is the poor creep characteristics, which can be removed by using Mg-Al-Si alloys, but casting of these alloys is problematic [23].

4. SELECTION OF MATERIALS OF CROSS SIDES OF INDEPENDENT SUPPORT SYSTEM

The choice of independent suspension cross-section material will be made for a medium-class passenger vehicle, weighing approximately 1,500 kg, in which the independent suspension arm with cross arms of different lengths can be applied on both the front and rear axles, depending on the vehicle drive concept.

4.1 Method of influence of properties

The method of influence of properties is of special importance when it is necessary to evaluate a large number of properties of a component. It consists of considering the essential properties, multiplying their numerical values by the appropriate importance factor (*Bi*), which leads to the relative importance of each individual property, in relation to another. Summarizing the properties evaluated in this way leads to a quantity called the performance characteristic (*Vr*).

Determining the importance factor of properties is often greatly influenced by experience, so the digital-logical method is applied. Within this method, each property is compared with each, so the more important one is joined by 1, and the less important one by 0. For n requirements, the total number of decisions is $n \cdot (n-1)/2$. The importance factor is equal to the ratio of the number of positive decisions for the observed property and the total number of decisions [24].

The requirements to be met when choosing the material of the transverse arms are as follows:

1. Maximum tensile strength (Rm), since the transverse arms are under the influence of large axial stresses,
2. Minimum density (ρ), in order to reduce the mass, and thus the emission of harmful substances,
3. Maximum elongation (A), in order to provide the strongest possible material,
4. Maximum machinability (O), in order to ensure the best machinability - by deformation or casting,
5. Maximum corrosion resistance (OK), due to different climatic conditions during vehicle operation.
6. Minimum price per unit mass (C/kg), because it, in addition to technical criteria, directly defines the competitiveness of products on the market.

Since the number of given properties is n=6, the total number of decisions is 15. The results of the application of the digital-logical method for the material of the transverse arms are given in Table 1.

Table 1. Results of application of digital-logical method for material of transverse arms

Property	**Decision**														
R_m	1	0	0	1	0										
A	0					1	0	0	1						
ρ		1				0				1	1	0			
O			1				1			0			1	1	
OK				0				1			0		0		1
C/kg					1				0			1		0	0

Table 2. Importance factors of material properties of transverse arms

Property	Positive decisions	Importance factor B_i
R_m	2	0,13
A	2	0,13
ρ	3	0,20
O	4	0,27
OK	2	0,13
C/m^3	2	0,13
Total	15	1,00

Table 2 shows the calculated values of the importance factors of the material properties of the transverse arms.

As there is a relatively large number of requirements (properties), with different units of measurement, it is necessary to introduce the notion of scaled value of properties (S_v), which makes it possible to convert dimensional into dimensionless values [1].

Therefore, the ranking of the values of the properties of the observed materials is performed, so that the best value received a score of 100, and the ranking of the others is done in proportion to that value [2]. Depending on the nature of the requirement associated with the observed property, the best value may be the maximum or minimum value in the list [3]. For example, in the case of transverse arms, the minimum value of density and price is sought, while in the case of tensile strength, elongation, workability and corrosion resistance, the maximum value of the property is sought.

In the case of difficult-to-measure properties (such as corrosion resistance and workability), each is rated 1 to 5 when choosing a material [4].

If the lowest value of the property is the best, ie 100 [25], the expression for the scaled value is [1]:

$$S_v = \frac{\text{maximum vaue in list}}{\text{numeric property value}} \cdot 100 \qquad (1)$$

and if the maximum value is required from the property, the expression is [1]:

$$S_v = \frac{\text{numeric property value}}{\text{maximum value in list}} \cdot 100 \qquad (2)$$

The performance indicator V_r is used to rank potential materials, and is calculated based on the following expression [26]:

$$V_r = \sum_{i=1}^{n} B_i \cdot S_{v_i} \rightarrow \max \qquad (3)$$

Based on the values of the properties of potential cross-section materials, taken from the CES EduPack software, which uses data from manufacturers, textbooks, websites, standards, as well as various databases and expert systems, performance indicators were calculated.

From each of the mentioned groups of materials for the construction of the transverse arms of the independent suspension system of passenger vehicles, two relevant representatives were selected.

As suitable materials from the group of low-alloy steels, steel 30NiCrMo2-2 and steel 25CrMo4 were chosen. Steel 30NiCrMo2-2 is characterized by favorable mechanical characteristics, and on the basis of price it is competitive even in comparison with steels with a higher content of alloying elements. Steel 25CrMo4 is characterized by good tensile and fatigue characteristics, as well as high impact resistance [13]. Both low-alloy steels are subjected to normalization rolling and tempering (N+T) processes, which lead to a significant improvement in the mechanical properties of the steel, such as yield strength, tensile strength, elongation, cross-sectional contraction and toughness.

When it comes to casting aluminum alloys, the most suitable alloys are those in which the main alloying elements are copper or silicon, in the presence of other alloying elements. Among the first, the aluminum alloy AlCu5MnMgTi was subjected to heat treatment with the T7, regime, due to the high value of tensile strength, corrosion resistance, and excellent casting [28]. Aluminum alloy AlSi7Mg0.3 was chosen from the second group, due to excellent castability and high corrosion resistance [28]. Treatment of this alloy with the T6 heat treatment regime leads to a significant improvement of its mechanical characteristics [28].

When it comes to casting magnesium alloys, the most suitable are Mg-Al-Zn alloys, among which the magnesium alloy MgAl8Zn1 was chosen first, thanks to good mechanical characteristics, excellent toughness and castability. The magnesium alloy MgAl9Zn0.7 was also considered, as one of the most commonly used casting magnesium alloys, which is characterized by favorable mechanical characteristics, very good casting and corrosion resistance [28]. Selected magnesium alloys are not subjected to heat treatment.

The property values of the potential materials of the transverse arms (Table 3) were taken from the CES EduPack software.

Table 3. Values of properties of the candidate for the material of making the transverse arms

Material	R_m [MPa]	ρ [g/cm^3]	*A* [%]	*O*	*OK*	*C/kg* [€]
30NiCrMo2-2 N+T [1]	744	7,85	20	4	4	5,00
25CrMo4 N+T [3]	670	7,85	18	4	4	5,02
AlCu5MnMgTi T7 [2]	450	2,8	10	5	5	6,16
AlSi7Mg0.3 T6 [4]	307	2,68	3,2	5	5	5,25
MgAl8Zn1 [3]	225	1,81	2,5	4	4	5,79
MgAl9Zn0.7 [5]	275	1,81	7	4	4	5,59

[1] – Soluble annealing and stabilization, thus reducing residual stresses [27].

[2] – Strengthening by soluble annealing and artificial aging [29].

[3] – Mark according to standard EN10025: 2019.

[4] – Mark according to ISO standard 3522: 2007.

[5] – Mark according to ISO standard 3116: 2019.

Based on the values of the properties of potential materials and indicators of the importance of the properties of the material of the transverse arms, the performance indicators of the candidates for the material of the transverse arms were calculated (Table 4).

Table 4. Performance indicators of potential transverse arms materials

Material group	Material	V_r	Rank
Low alloy steels	30NiCrMo2-2 N+T	76,61	3
	25CrMo4 N+T	**79,22**	**1**
Aluminum alloys	AlCu5MnMgTi T7	78,48	2
	AlSi7Mg0.3 T6	73,84	4
Magnesium alloys	MgAl8Zn1	69,21	6
	MgAl9Zn0.7	73,52	5

The highest values of performance indicators have low-alloy steel 25CrMo4 N+T, and aluminum alloy AlCu5MnMgTi T7. They are followed by low-alloy steel 30NiCrMo2-2 N+T, aluminum alloy AlSi7Mg0.3 T6, and finally magnesium alloy MgAl8Zn1i MgAl9Zn0.7.

Based on that, it follows that the low-alloy steel 25CrMo4, subjected to normalization rolling and tempering, was chosen as the optimal material for the production of transverse arms of the independent support system by the method of influence of properties.

5. CONCLUSION

Making the right decision on the choice of materials is of great importance when constructing responsible structures. A large number of available materials, as well as a large number of requirements lead to a very complex material selection process, so it is useful to apply certain quantitative methods of material selection. Within these methods, numerous values of material properties are used in the form of measured or estimated values.

The selection of the material of the transverse arms of the independent suspension system of the passenger vehicle was done by applying a quantitative method of material selection - the method of influence of properties. Using this method, low-alloy steel 25CrMo4 N+T was chosen as the optimal material for the production of cross arms, as the material with the highest value of performance characteristics. This method gives preference to materials with generally better mechanical properties.

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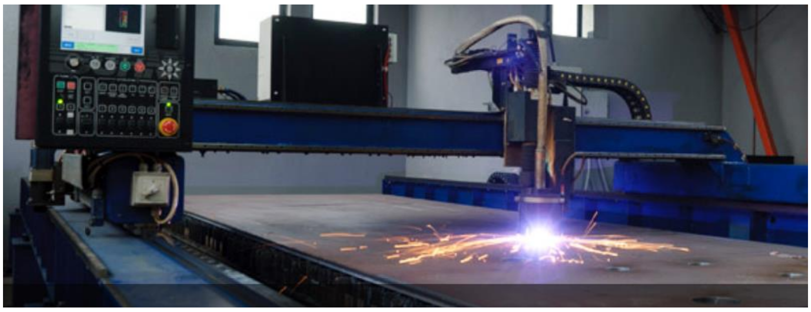

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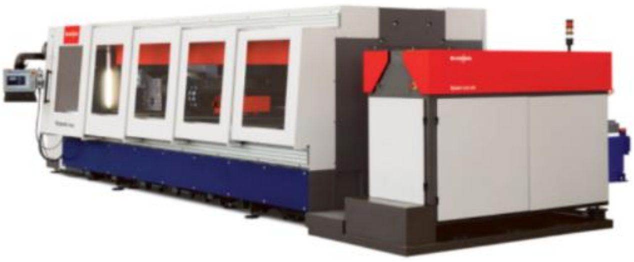

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