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Zavarivanje debelozidnog čelika u uskom žljebu
Welding of thick-walled steels in a narrow groove

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Key words: welding, narrow groove, software controlled arc, filler material saving

Rezime
Smanjenje otvora žljeba može značajno doprineti efikasnosti zavarivanja i produktivnosti teških metalnih konstrukcija Uobičajena je upotreba uglova žljeba od 45 ° i 60 °. Smanjenje ugla otvora žljeba smanjuje potreban broj zavara, čime se smanjuje trajanje zavarivanja, potrošnja materijala za ispunu i zaostali naponi i deformacije. Međutim, smanjivanje ugla žljba dovodi do određenih poteškoća. Teško je kontrolisati luk u uskom žljebu, što može dovesti do problema sa kvalitetom spoja. U ovom radu je prikazano zavarivanje sučeonih spojeva od čelika debljine 22 mm sa uglom žljeba od 20 °. Zavarivanje je izvršeno korišćenjem MAG postupkom zavarivanja, uz softversku kontrolu luka.

Abstract
Reduction in groove opening can significantly contribute to welding efficiency and productivity of heavy metal structures. It is common practice to use welded joint groove angles of 45° and 60°. Reduction of the groove opening angle decreases the necessary number of welding passes, thus decreasing the welding duration, filler material consumption and residual stresses and strain. However, groove angle reduction leads to certain difficulties. It is hard to control the arc in a narrow groove, which could lead to welded joint quality issues. In this paper, welding of butt joints made of 22 mm thick steel with the groove angle of 20° is shown. Welding was performed using the MAG procedure, with software controlled ar

1. Uvod
Zavarivanje u uskom žljebom može se primeniti na gotovo sve konvencionalne elektrolučne postupke zavarivanja. Ova tehnika zavarivanja ima za cilj smanjenje zapremine šava i vremena potrebnog za zavarivanje. U slučaju konvencionalnih V žljebova, vreme zavarivanja i zapremina šava povećavaju se sa povećanjem debljine metalnog materijala. Ako su uglovi žljeba smanjeni, zapremine i vremena zavarivanja se smanjuju, posebno u slučaju uskog žljeba sa paralelnim stranama. Pored ekonomskih koristi, uski žljeb ima i druge prednosti, kao što su smanjenje ugaonih deformacija i zaostalih napona kao i postizanje ravnomernijih karakteristika zavarenih spojeva. Zavareni spojevi sa uskim žljebom često imaju bolje mehaničke osobine u poređenju sa V zavarenim spojevima, zbog manjeg ukupnog unosa toplote.

Zavarivanje u uskom žljeba je, do sada, uglavnom korišćeno kod zavarivanju punjenom žicom. U poslednje vreme se uobičajeno koristi kod zavarivanja punim elektrodnim žicama u gasa i kod

1.Introduction
Welding in a narrow groove can be applied to nearly all conventional arc welding procedures. This welding technique aims to reduce the weld volume and the time needed for welding. In the case of conventional V grooves, welding time and weld volume increase with the increase in parent material thickness. If the groove opening angles is reduced, volume and welding time decrease, especially in the case of a narrow groove with parallel sides. In addition to economic benefits, the narrow groove has other advantages, such as the reduction of angular deformation and residual stresses and more uniform welded joint properties. Narrow groove welded joints often have better mechanical properties compared to V welded joints, due to lower total heat input.

Narrow groove welding was, up until now, mostly used in flux core arc welding. Recently, narrow groove welding is more commonly used in procedures with gas shielded consumable electrode wires and welding procedures using selfzavarivanja samo-zaštitnim žicama je posebno pogodno za zavarivanje velikih metalnih konstrukcija, kao što su brodovi, posude pod pritiskom, teške metalne konstrukcije, mostovi i slično, koji koriste osnovne materijale (PM) sa većom debljinom i za koje je promena pozicija vrlo teška ili nemoguća, pa je od velike važnosti zavarivanje u različitim položajima.

Postoje različiti načini pripreme uskih žljebova u zavisnosti od postupka zavarivanja i primene konstrukcije. Primer bi bio žljeb s paralelnim stranama i podkorenom trakom. Širina žljeba varira u zavisnosti od funkcije opreme i postupka zavarivanja. U mnogim slučajevima, koji uključuju specifičnu opremu za zavarivanje, moguće je kombinovati standardne generatore električne energije i sisteme dodavanja žice.

2.Specifični aspekti zavarivanja u uskom žljebu

U cilju zavarivanja tankih čelika, I žljebovi se koriste u konvencionalnim procedurama. Za srednje debljine čelika, koriste se V ili polu V žljebovi, a za zavarivanje debelih zidova koriste se žljebovi u obliku slova U i J. Prikazani u tabeli 1 su oblici i približne dimenzije za gore pomenute vrste žljebova, koje treba da budu zavarene postupkom MAG [1]. Tabela 1 i sledeći tekst odnose se na žljebove koji se koriste za jednostrane zavarene spojeve. Međutim, dodatna razmatranja mogu se u velikoj mjeri primeniti na žljebove koji se koriste za dvostrane zavarene spojeve.

protecting full wire. Narrow groove welding is especially suitable for welding of large metal structures, such as ships, pressure vessels, heavy metal structures, bridges, etc, which use parent materials (PM) with increased thickness and for which changing of positions is very hard or impossible, thus the possibility of welding in different positions is of great importance.

There are different ways of preparing narrow grooves depending on the welding procedure and the structure's application. The simples example would be a groove with parallel sides and a sub-root strip. Groove width varies based on the equipment function and welding procedure. In many cases, involving specific welding equipment, it is possible to combine standard electricity generators and wire adding systems.

2.Specific aspects of narrow groove welding

For the purpose of welding thinner steels, I grooves are used in conventional procedures. For medium thickness steels, V or half V grooves are used, and for welding of thick-walled steels, U and J shaped grooves are used. Shown in table 1 are the shapes and approximate dimensions for the aforementioned types of grooves, which are meant to be welded by the MAG procedure [1]. Table 1 and the following text refer to grooves used for one-sided welded joints. However, further considerations can be largely applied to grooves used for two-sided welded joints as well.

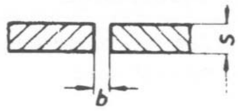
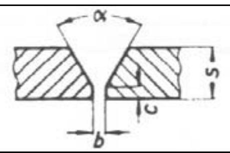
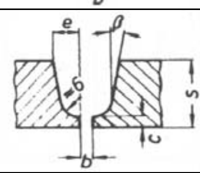
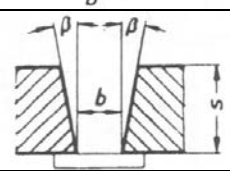
	Groove Žljeb	Thickness, Debljina s mm	Groove opening angle, Ugao otvora žljeba α, β °	Root gap, Zazor u korenu b mm	Root blunting, Visina korena c mm
1		3 - 8	-	1 - 4	-
2		3 -10	40 - 60	0 - 4	0 - 2
3		12	8 - 12	0 - 4	2 - 3
4		16	5 - 20	65- 15	0

***Table 1.** Shapes and dimensions of grooves used for one-sided welded joints*
***Tabela 1.** Oblici i dimenzije žljebova za jednostrano zavarivanje*

Sa povećanjem debljine, postaje teže pristupiti korenskom delu I žljeba. Da bi ovaj pristup bio olakšan, može se proširiti. Ovo se postiže povećavanjem ugla otvora žljeba ili praznine u korenu zavara ili oboje. Korenski razmak (zazor), u slučaju MAG zavarivanja, obično se kreće do 4 mm, kako je prikazano u tabeli 1. Njegovo dalje povećanje ometa kontrolu rastopa tokom korenog prolaza, što rezultuje slabim izgledom šava, pojave nedostatka uvarivanja i prekomerne penetracije korena. U određenim slučajevima, ovi nedostaci mogu biti izbegnuti korišćenjem keramičkih ili metalnih podkorenih traka.

Povećanje ugla žljeba rezultuje povećanom zapreminom metala šava (WM), što dovodi do povećanja potrošnje dodatnog materijala (FM), više vremena potrebnog za zavarivanje, povećanih zaostalih napona i deformacija i verovatnoće pojave defekata. Zapremina žljeba se u manjoj meri može smanjiti visinom korena. Veličina visine korena zavisi od dubine uvarivanja koja se može postići korišćenjem definisanih parametara zavarivanja. Visina korena tipično se kreće od 0 do 2 mm u slučaju zavarivanja MAG, tabela 1. Zapremina žljeba može se značajno smanjiti primenom U ili J umesto V ili polu V spojeva. Za ove tipove spojeva, ugao žljeba je manji, širina žljeba je manja, a dostupnost korena je bolja nego u slučaju V i polu V. Međutim, izrada U i J šavova je složenija i skupa u poređenju sa V i polu V i zahteva mašinsku obradu ivica žljebova. Ovakvi šavovi primenjuju se na debljinu PM iznad 12 mm. U praksi, ti šavovi se koriste za deblje osnovne materijale

Iz gore navedenog može se videti da bi optimalni oblik bio V-žljeb sa smanjenim uglom i povećanim zazorom. Ovakva geometrija šava ne zahteva mašinsku obradu, omogućava povećanu produktivnost zavarivanja usled smanjene zapremine spoja, smanjene potrošnje FM-a i smanjenog vremena potrebnog za zavarivanje. Osim toga, smanjuje zaostale napone i deformacije, čime se smanjuje verovatnoća oštećenja nastalih u žljebu. Zbog povećanja zazora, ovaj oblik žljeba zahteva korišćtenje pod-korenih traka. Takvi uski žljebovi su prikazani u tabeli 1 i korišćeni u eksperimentalnom delu ovog istraživanja

Teškoće prilikom zavarivanja u uskom žljebu potiču od komplikovanog pristupa korenom delu. Zavarivanje završnih slojeva i lica šava ne predstavljaju poteškoće. Ovi šavovi mogu biti zavareni korišćenjem opreme i parametara zavarivanja tipičnih za postupak MAG. Da bi zavarili koreni prolaz i prvi zavar ispune, često je

With an increase in thickness, it becomes more difficult to access the root part of the I groove. In order to make this access easier, it can be expanded. This is achieved by increasing the groove opening angle, or the gap in the weld root, or both. The root gap, in the case of MAG welding, typically ranges up to 4 mm, as shown in table 1. Its further increase hinders the control of the melt during the root pass, which results in poor visual appearance of the weld back, occurrence of lack of penetration and excessive root penetration. These defects can be, in certain cases, avoided by using ceramic of metal sub-root strips.

Increase in groove angle results in increased WM volume, which results in increased use of filler material (FM), more time needed for welding, increased residual stresses and strain and the probability of defects occurring in the weld. Groove volume can, to a lesser extent, be decreased by root blunting. The blunting size depends on the welding depth which can be achieved by using the defined welding parameters. Blunting height typically ranges from 0 to 2 mm in the case of MAG welding, table 1. Groove volume can be significantly reduced by applying U or J welds instead of V or half V welds. For these weld types, the groove angle is smaller, groove width is smaller and root accessibility is better than in the case of V and half V welds. However, making of U and J welds is more complex and expensive compared to V and half V welds, and requires the machining of groove edges. Such welds are applicable to PM thickness above 12 mm. In practice, these welds are used for thicker parent materials.

From the above, it can be seen that the optimal shape would be a V groove with reduced angle and increased root gap. Such weld geometry does not require the machining of edges, enables increased welding productivity due to reduced welded joint volume, reduced FM consumption and reduced time needed for welding. In addition, it decreases the residual stresses and strain, thus reducing the probability of defects occurring in the groove. Due to the increase in the root gap, this groove shape requires the use of sub-root strips. Such types of narrow grooves are shown in table 1, and used in the experimental part of this research.

Difficulties during narrow groove welding stem from complicated access to its root part. Welding of the finishing layers and weld face do not present any difficulties. These welds can be welded using equipment and welding parameters typical for the MAG procedure. In order to weld the root pass and the first filling welds, it is often necessary to use special guns and control systems, which makes the neophodno koristiti specijalne pištolje i kontrolne sisteme, što čini proceduru složenijom i skupom [2]. Zbog ograničene dostupnosti korenom delu žljebova, vođenje i kontrola dužine luka i praćenje rastopa metala su donekle teški. Pored toga, postoji mogućnost nedostatka stapanja, naročito na ivicama žljeba [3,4]. Uski i duboki žljebovi zahtevaju povećanu slobodnu dužinu žice, što smanjuje jačinu struje zavarivanja i stabilnost luka.

Povećavanje dužine slobodnog kraja može povećati količinu rastopljenog FM, što otežava kontrolu i može smanjiti dubinu zavarivanja. Uski i duboki žljeb takođe uslovljava smanjenje ugla u odnosu na ivicu žljeba. Navedeni faktori smanjuju dubinu zavarivanja, što dovodi do nedostataka kao što je nedostatak stapanja posebno na ivicama žljeba. Verovatnoća nastanka ovih nedostataka može se smanjiti korišćenjem punjene žice umesto pune, koristeći adekvatnu tehniku usmeravanja luka, što podrazumeva usmeravanje luka ka ivici žlejba i zadržavanje tamo, kao i odabiranje parametara zavarivanja koji omogućavaju fokusiranje luka [3]. Penetracija se može kontrolisati preko distribucije prolaza, primjenom dva zavara umesto jednog, unutar jednog sloja.

Iz gore navedenog može se videti da se uslovi pod kojima se zavarivanje vrši u uskom žljebu može poboljšati obezbeđivanjem fokusiranog luka i sprečavanjem promene struje pomoću dužine slobodnog kraja žice. Ovo se može postići korišćenjem uređaja za zavarivanje sa softverskom kontrolom luka. Za eksperiment prikazan u ovom radu korišćeni su softver ViceFusion i VisePenetration, koji je napravio Kemppi Oi iz Finske. Softver ViceFusion omogućava fokusiranje luka, čime se njegova koncentracija povećava, što rezultuje dubokim i pouzdanim penetracijama, što povećava brzinu zavarivanja i smanjuje unošenje toplote i zaostale napone i deformacije. Sve ovo olakšava zavarivanje u uskim i dubokim žljebovima. Ovaj softver takođe obezbeđuje malu količinu tečnog metala što olakšava kontrolu, što je pogodno za zavarivanje na neugodnim mestima [4]. Softver VicePenetration omogućava jačini struje da ostane konstantna sa promenama dužine slobodnog kraja. Povećanje dužine slobodnog kraja žice obično smanjuje amperažu, što može rezultovati nedostatkom penetracije, nejednakim dubinama zavarivanja i promenama u oblicima prenosa dodatnog materijala. Ovaj softver je pogodan za primenu u slučajevima kada je dostupnost lokacije za prepoznavanje i zavarivanje ograničena, a sam softver je ograničen na maksimalnu dužinu slobodnog karaja od 30 mm [5]. Kada istovremeno koristite oba programa,

procedure more complex and expensive [2]. Due to limited accessibility of the root part of the groove, guiding and controlling the length of the arc and monitoring of molten metal are somewhat difficult. In addition, there is a possibility of lack of fusion, especially at the groove edges [3,4]. A narrow and deep groove requires increased free end length of the wire, which reduces the welding amperage and arc stability.

Increasing the free end length can increase the amount of molten FM, which makes controlling it difficult and could reduce the welding depth. A narrow and deep groove also conditions the reduction of angle relative to the groove edge. Aforementioned factors reduce the welding depth, leading to defects such sa lack of fusion, especially at the groove edges. The probability of these defects occurring can be reduced by using filled wire instead of full ones, by using the adequate arc guiding technique, which involves directing the arc towards the groove edge and keeping it there, as well as by choosing the welding parameters which enable arc focusing [3]. Penetration can be controlled via pass distribution, by applying two welds instead of one, within a single layer.

From the above it can be seen that conditions under which welding is performed in a narrow groove can be improved by providing a focused arc and preventing the amperage from changing with the free end length of the wire. This can be achieved by using welding devices with have software arc control. For the experiment shown in this paper, software WiceFusion and WisePenetration, made by Kemppi Oy, Finland, were used. WiceFusion software enables arc focusing, thus making its energy more concentrated, resulting in deep and reliable penetration, which increases the welding speed and reduces heat input and residual stresses and strain. All of this makes welding in narrow and deep groove much easier. This software also provides a small volume of liquid metal which makes it easy to control, which is suitable for welding in inconvenient positions [4]. WicePenetration software enables the amperage to remain constant with changes in free end length. Increase of the free end length of the wire typically reduces the amperage, which can result in lack of penetration, non-uniform welding depths and changes in the forms of FM transfer. This software is suitable for application in cases where visibility and welding location availability are limited, and the software itself is limited to a maximum free end length of 30 mm [5]. When using both programmes simultaneously, WicePenetration provides constant amperage and

VicePenetration obezbeđuje konstantnu amperažu i ViceFusion pruža i optimalno kratki i fokusirani luk.

3.Eksperiment i rezultati ispitivanja

Dva sučeona zavarena spoja su napravljena i ispitana. Kao PM je korišćen niskolegirani čelik debljine 22 mm. Spojevi su zavareni kao jednostrani, koristeći MAG postupak, sa mešavinom gasova 82% Ar-18% CO_2. Zavarivanje je obavljeno korišćenjem uređaja Kemppi FastMig Pulse 350.

Prvi spoj zavaren je u V žljebu, sa uglom od 20 °, zazorom u korenu od 6 mm i bez visine slika 1. Korišćena je keramička podloška širine žlejba 10 mm. Dodatni materijal je puna elektrodna žica VAC 60, proizvođača Elektroda Jesenice (G42 5M / C G3Si1-EN ISO 14341-A) prečnika 1,2 mm. Spoj je zavaren sa dužinom slobodnog kraja žice od 25 mm u položaju PA, slika 2. Parametri zavarivanja za zavareni spoj 1 su dati u tabeli 2.

WiceFusion provides and optimally short and focused arc. Both programmes can be used with standard welding guns.

3.The experiment and test results

Two butt joints were welded and tested. Low-alloyed steel with a thickness of 22 mm was used as the PM. Joints were welded as one-sided, using the MAG procedure, with an 82% Ar – 18% CO_2 mix used as the shielding gas. Welding was performed using Kemppi FastMig Pulse 350 device. The first joint was welded in a V groove, with the opening angle of 20°, a root gap of 6 mm and without blunting, figure 1. A ceramic washer with a groove width of 10 mm was used. Filler material was a full VAC 60 wire, manufactured by Elektrode Jesenice (G42 5M/C G3Si1- EN ISO 14341-A), with a 1.2 mm diameter. The joint was welded with free end length of the wire of 25 mm in the PA position, figure 2. Welding parameters for welded joint 1 are given in table 2.

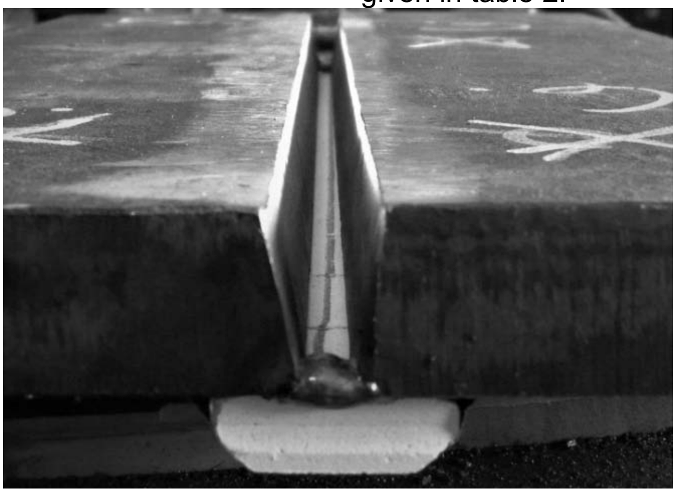


Figure 1. *The narrow groove with a 20° opening angle*
Slika 1. *Uski žjeb sa otvorom ugla od 20^0*

Figure 2. *Increased free end length during narrow groove welding*
Slika 2. *Povećana dužina slobodnog kraja tokom zavarivanja u uskom žlebu*

Zavarivanje drugog spoja izvršeno je sa V žljebom, sa uglom od 20 °, zazorom od 4,5 do 5 mm i bez visine korena. Ista keramička podloška korišćena je kao u prvom slučaju. Dodatni j je TISVELD T 71C (T42 4RC / M 2H10 - EN ISO 17632-A) prečnika 1,2 mm. Zavareni spoj je napravljen na poziciji PF. Parametri zavarivanja za spoj 2 su navedeni u tabeli 3.

Welding of the second joint was performed in a V groove, with the opening angle of 20°, a root gap of 4.5 to 5 mm and without blunting. The same ceramic washer was used as in the first case. Filled TYSWELD T 71C (T42 4RC/M 2H10 – EN ISO 17632-A) was used as the filler material, with a diameter of 1.2 mm. The welded joint was made in the PF position. Welding parameters for joint 2 are given in table 3.

Number Broj	Weld Šav	I(A)	U(V)	vw (mm/sec)	Q (KJ/mm)	Remainig groove depth (mm) Zaostala dubina žljeba	Software used Korišćeni softver
1	Root// Koren	267	31.1	3.64	1.82	Not measured	WP+WF
2	First fill// prvi zavar ispune	278	29.7	5.33	1.24	11	WP+WF
3	Second fill// Drugi zavar	279	29.7	4.73	1.40	6	WP+WF
4	Third fill /Treći zavar	277	29.3	4.25	1.53	2	WP+WF
5	Finishing//završni	240	26.8	3.43	1.50	-	WF

*****WP – Weldpenetration- uvarivanje; WF – Weldfusion-stapanje*

***Table 2**. Welding parameters for joint 1.*

***Tabela 2.** Parametri zavaraivanja za spoj 1*

Number	Weld	I(A)	U(V)	vw (mm/sec)	Q (KJ/mm)	Remainig groove depth (mm)	Software used
1	Root	189	25.2	1.91	1.99	14	WP+WF
2	First fill	189	24.2	3.29	1.11	9	WP+WF
3	Second fill	198	25.5	3.31	1.22	6	WP+WF
4	Third fill	188	23.0	2.22	1.56	3	WP+WF
5	Finishing	192	22.2	2.37	1.44	-	WF

**WP – WicePenetration; WF – WiceFusion*

***Table 3.** Welding parameters for joint 2.*

***Tabela 3.** Pararmetri zavaraivanja za spoj 2*

Na slici 3 prikazan je zavareni spoj 1, nakon što su završeni koreni i prvi zavar ispune, dok slika 4 prikazuje isti zavareni spoj nakon što je zavaren treći zavar ispune. Tokom zavarivanja oba spoja izvršena je vizuelna kontrola dimenzija. Svi zavareni spojevi su imali uniformne širine i visine. Stepen ispune, tj. debljina svakog pojedinačnog zavara može se odrediti iz tabela 2 i 3. Nisu otkriveni nedostaci, kao što su nejednako uvarivanje ivica žljeba ili nagrizanje.

Shown in figure 3 is the welded joint 1, after the root and first fill passes were done, whereas figure 4 shows the same welded joint after the third fill pass was welded. During the welding of both joints, visual dimension control was performed. All welds had uniform widths and heights. Degree of filling, i.e. the thickness of each individual weld can be determined from tables 2 and 3. No defects, such as non-uniform penetration of groove edges or etching, were detected.

***Figure 3.** Joint 1 after the welding of root and first fill welds.*
***Slika 3.** Spoj 1posle zavarivanja korenog i prvog zavara ispune*

***Figure 4**. Joint 1 after the welding of the third fill weld.*
***Slika 4.** Spoj 1posle zavarivanja trećeg zavara ispune*

Nakon zavarivanja, izvršena je vizuelna kontrola dimenzija korena i lica šava, uz ispitivanje ultrazvukom i makrostrukturno ispitivanje. Rezultati kontrole dimenzija prikazani su u tabeli 4. Vizuelni pregled otkrio je da i koren i lice zavarenih spojeva imaju ravnu visinu i širinu. Zavareni spoj 1 ima blagi prelazak na PM duž cele dužine. Što se tiče korena ovog zavarenog spoja, postoje povremeni oštri prelazi u PM. U centru zavarenog spoja 2 je primećena nedovoljna ispuna. Koreni zavar spoja 2 takođe ima blagi prelazak na PM duž cele dužine.

After welding, visual dimension control of the weld root and face was performed, along with ultrasound and macro-structural tests. Results of dimension control are shown in table 4. Visual examination revealed that both root and face of the welded joints have uniform height and width. Welded joint 1 face has a slight transition to the PM along its whole length. As for the root of this welded joint, there are occasional sharp transitions to the PM. An underfill was observed in the centre of weld joint 2 face. Root weld of joint 2 also has slight transition to the PM along its whole length.

	Face/Lice		Root/Koren		Angular deformation Ugaona defrmacija (°)
	Width /Širina (mm)	Height/ Visina (mm)	Width /Širina (mm)	Height / Visina (mm)	
Welded joint 1 /Zavareni spoj 1.	16.5	1.2	13.5	2.5	3
Welded joint 1 Zavareni spoj 2	14.5	0.9	11.0	2.0	4

***Table 4.** Face and root dimensions of welded joints 1 and 2.*
***Tabela 4.** Dimenzije lica I korena zavarenih spojeva 1 i 2*

Ultrazvučno ispitivanje nije otkrilo nedostatak stapanja između prolaza ili nedostatak uvarivanja po ivicama žljebova. Slika 5 i 6 pokazuju makro-strukture oba zavarena spoja. Ispitivanje makrostrukture nije otkrilo nikakve defekte zavarenog spoja.

Ultrasound testing did not reveal any lack of fusion between passes or lack of penetration in groove edges. Figure 5 and 6 show the macro-structures of both welded joints. Macro-structure testing did not reveal any welded joint defects.

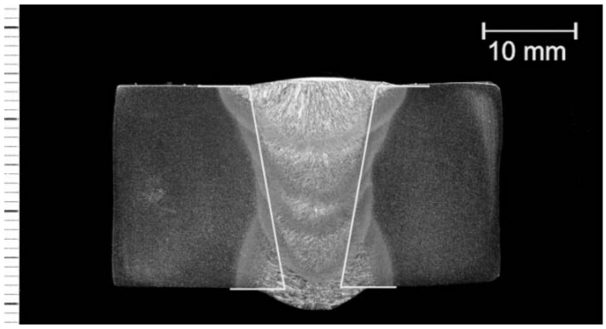


Figure 5. *Welded joint 1 macro-structure.*
Slika 5. *Makrostruktura spoja 1*

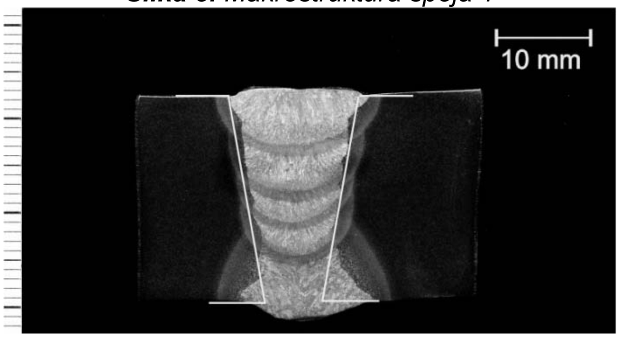


Figure 6. *Welded joint 2 macro-structure.*
Slika 6. *Makrostruktura spoja 2*

4.Analiza rezultata

U tabeli 5 , prikazane su zavisnosti preseka žljeba i mase WM zavisno od uglova žljeba, za debljinu PM od 10 do 30 mm. Žljeb sa uglom od 60 ° i 45 °, sa razmakom korena od 4 mm bez visine korena, i ugao od 20 °, sa razmakom od 6 mm, takođe bez visine korena su razmatrani.

Podaci o masi WM su dati bez nadvišenja korena i lica. Precizniji uvid u efekte oblika i dimenzija na masu WM se dobija ako se ova nadvišenja zanemare, s obzirom na to da se njihove dimenzije i masa razlikuju u zavisnosti od parametara zavarivanja. Iz tabele 5 se vidi da sa povećanjem debljine PM, masa WMse povećava u svim slučajevima. Za uglove žljebova od 60 °, masa WM se povećava za faktor od 6,4, dok za ugao žljba od 45 ° masa WM se povećava za faktor od 6,5. U slučaju ugla žljebova od 20 °, masa WM se povećava 4,5 puta.

U tabeli 6 prikazane su uštede u dodatnom materijalu kada se koristi ugao žljeba od 20 °, u poređenju sa uglovima od 45 ° i 60 °, na osnovu podataka iz tabele 5.

4.Result Analysis

Shown in table 5 are the dependencies of groove cross-section and WM mass from groove angles, for PM thickness of 10 to 30 mm. Groove with opening angle of 60° and 45°, with a 4 mm root gap without blunting, and the angle of 20°, with a 6 mm gap, also without blunting, were considered.

Data about WM mass are given without root and face reinforcement masses. A more accurate insight into the efects of shape and dimensions on WM mass is obtained if these reinforcements are neglected, since their dimensions and mass vary depending of welding parameters. It can be seen from table 5 that with an increase in PM thicknes, the WM mass increases in all cases. For groove angles of 60°, WM mass increases by a factor of 6.4, whereas for the groove angle of 45°, WM mass increases by a factor of 6.5. In the case of the 20° groove angle, WM mass increases 4.5 times.

Shown in table 6 are the savings in WM material when using the groove angle of 20°, compared to angles of 45° and 60°, based on the data from table 5.

PM thickness (mm)	Opening angle 60°		Opening angle 45°		Opening angle 20°	
	Cross-section area, mm^2	WM mass, kg/m	Cross-section area, mm^2	WM mass, kg/m	Cross-section area, mm^2	WM mass, kg/m
10	98	0.8	81	0.6	78	0.6
15	190.5	1.5	152.3	1.2	130.5	1.0
20	312	2.5	244	2.0	192	1.5
25	462	3.7	356.3	2.9	262.5	2.1
30	642	5.1	489	3.9	342	2.7

Table 5. *Dependence of groove cross-section areas and WM mass from PM thickness and groove opening angle*
Tabela 5. *Zavisnost površine poprečnog preseka žljeba i mase WM od debljine PM i ugla otvora žljeba*

Groove opening angle	Parent material thickness (mm)									
	10		15		20		25		30	
	kg/m	%	kg/m	%	kg/m	%	kg/m	%	kg/m	%
45°	0	0	0.2	17	0.5	25	0.7	28	1.2	31
60°	0.2	25	0.5	33	1.0	40	1.6	43	2.4	47

Table 6. *Reduction of filler material consumption (savings) with the decrease of the groove opening angle for different parent material thicknesses.*
Tavela 6. *Smanjenje potrošnje dodatnog materijala (uštede) sa smanjenjem ugla otvora žljeba kod različitih debljina osnovnog materijala*

Iz tabele 6 se vidi da se, uz upotrebu uskog žljeba, ušteda mase povećava sa debljinom PM i uglom otvora žljeba. Pri zavarivanju PM debljine 10 mm, uz ugao žljeba od 45 °, nema uštede mase, tako da uski žljeb u ovom slučaju ne daje nikakve prednosti, u poređenju sa V-žljebom. Najveća ušteda potrošnje WM od skoro 50% postiže se pri zavarivanju PM debljine 30 mm, i V žljebom sa uglom od 60 °.
Može se pretpostaviti da će vreme zavarivanja smanjiti proporcionalno smanjenju mase WM. Tokom ovog eksperimenta, nije bila određena ušteda vremena zavarivanja. Prema literaturi [2], pri zavarivanju PM sa debljinom 25 mm u uskim žljebovima (ugao od 20 °), ušteda vremena zavarivanja bila je 38%, a ušteda potrošnje FM bila je 25% u poređenju sa zavarivanjem istog PM u V žljebu, sa uglom od 45 °.
Iz tabela 2 i 3 može se videti da su koreni zavari u oba spoja zavareni povećanom amperažom. Ovo je bilo moguće zahvaljujući korišćenju pod-korenih traka. Amperaža zavarivanja, uz relativno visoku brzinu zavarivanja, omogućuje prodiranje na ivice žljeba i sprečava nedostatak stapanja. Tabele 2 i 3 takođe pokazuju da su završni zavari bili zavareni bez VicePenetration softvera. S obzirom da je preostala dubina šava za oba spoja, nakon drugog zavara ispune, bila 6 mm, moguće je zavariti treći zavar ispune, kao i zavaršni prolaz, bez korišćenja VicePenetration. Prema literaturi [3], slobodna dužina žice tokom klasičnog MAG postupka, sa sprej načinom prenosa kapi, kreće se od 13 do 20 mm. Prema tome, zavarivanje završnih prolaza u uskom žljebu može se izvesti pomoću klasičnog MAG postupka.

It can be seen from table 6 that, with the use of a narrow groove, the mass saving increases with PM thickness and groove opening angle. When welding a 10 mm thick PM, with the groove angle of 45°, there is no mass saving, thus there narrow groove welding does not give any advantages in this case, compared to a V groove. Largest WM material consumption saving, of almost 50%, is achieved by welding PM with a thickness of 30 mm, in a V weld with the opening angle of 60°.
It can be assumed that the welding time will decrease in proportion to the WM mass reduction. During this experiment, welding time saving was not determined. According to the literature [2], when welding PMs with a thickness of 25 mm in a narrow groove (20° angle), welding time saving was 38% and FM consumption saving was 25% compared to welding of the same PM in a V groove, with the angle of 45°.
It can be seen from tables 2 and 3 that the root welds in both joints were welded with increased amperage. This was possible thanks to the use of sub-root strips. Welding amperage, along with relatively high welding speed, enable good groove edge penetration and prevent the lack of fusion from occurring. Tables 2 and 3 also show that the finishing welds were welded without the WicePenetration software. Since the remaining weld depth for both joints, after the second filling weld, was 6 mm, it was possible to weld the third filling pass, as well as the final pass, without using WicePenetration. According to literature [3], free end length of the wire during a classic MAG procedure, with spraying transfer, ranges from 13 to 20 mm. Thus, welding of finishing passes in the

Oba spoja su zavarena bez prethodnog savijanja ploča i bez ojačanja koja bi smanjila njihovu ugaonu deformaciju. Cilj ovog procesa zavarivanja bio je da se utvrdi magnituda takve deformacije. Ugaona deformacija zavisi od količine ulazne toplote i širine lica zavara. Oba spoja su zavarena relativno velikom toplotnom energijom u završnim prolazima, tabele 2 i 3. Širina lica iznosila je 16,5 i 14,5 mm, a ugaoni deformacije su bile 3 ° i 4 °, tabela 4. Iskustvo je pokazalo da se ove ugaone deformacije mogu smatrati malim u slučajevima jednostranih zavarenih spojeva debljih materijala, sa visokim energetskim ulazom.

Lice šava spoja 1 zadovoljava nivo kvaliteta B za zavarene spojeve [7]. Lice šava spoja 2 ima povremene prokapine duž sredine, prihvatljive dubine za nivo kvaliteta B. Prokapine se mogu izbeći ispravljanjem kretanja luka. Pored dimenzija žljeba i parametara zavarivanja, na dimenzije korena utiču širina i dubina žljeba u traci. Tokom zavarivanja ovih spojeva korišćena je traka sa 10 mm širokim žljebom. Dimenzije korenog zavara, tabela 4, zadovoljavaju nivo kvaliteta B. Uzimajući u obzir da ultrazvučno ispitivanje nije otkrilo nedostatke u zavarenim spojevima, može se zaključiti da oni takođe zadovoljavaju nivo kvaliteta B.

Tačkaste linije na slikama 5 i 6 pokazuju ivice žljebova tokom zavarivanja spojeva 1 i 2. Kao što se može videti iz ovih slika, širine u korenu metala šava i ZUT su veće nego u zavarenom spoju, uprkos činjenici da su žljebovi bili širi prema centru. Ovo se dogodilo korišćenjem keramičke podkorene trake koja usporava rasipanje toplote tokom zavarivanja korena. Smanjenje rasipanja toplote rezultuje većim zagrevanjem PM, pa je dubina penetracije veća, a ZUT je širi. Ovo usporeno hlađenje očigledno povećava dubinu penetracije i povoljno utiče na sprečavanje nedostatka stapanja u korenom delu zavarenog spoja.

Zaključci

Zavarivanje u uskim žljebovima s uglom otvora od 20 ° omogućava uštedu u masi WM i vremenu zavarivanja, kao i u količini dodatnog materijala, u poređenju sa V žljebovima, sa uglovima od 45 ° do 60 °. Ušteda raste sa debljinom osnovnog materijala, kao i povećanjem ugla otvora žljebova, u slučaju ugla od 45 ° i do 47% u slučaju ugla od 60 °, za debljinu PM 30 mm. Rezultati ispitivanja pokazali su da su zavareni spojevi u uskom žljebu, od kojih je jedan napravljen korišćenjem pune žice u horizontalnom položaju, a drugi punjenom žicom u vertikalnom položaju, nije

narrow groove can be performed using the classic MAG procedure.

Both joints were welded without pre-bending of plates and without stiffeners which would reduce their angular deformation. The aim of this welding procedure was to determine the magnitude of such deformation. Angular deformation depends on the amount of heat input and weld face width. Both joints were welded with a relatively high heat input in the final passes, tables 2 and 3. Weld face widths were 16.5 and 14.5 mm, and the angular deformations were 3° and 4°, table 4. Experience has shown that these angular deformations can be considered small in the case of one-sided welded joints of thick materials, with a high energy input.

Weld face of joint 1 satisfies quality level B for welded joints [7]. Weld face of joint 2 has occasional underfills along the middle, of acceptable depth for quality level B. Underfills can be avoided by correcting the arc movement. In addition to groove dimensions and welding parameters, the dimensions of the root are affected by width and depth of the groove in the strip. During the welding of these joints, a strip with a 10 mm wide groove was used. Root weld dimensions, table 4, satisfy quality level B. Taking into account that ultrasound testing did not reveal any defects in the welded joints, it can be concluded that they also satisfy quality level B. Dotted lines in figures 5 and 6 show the groove edges during the welding of joints 1 and 2. As can be seen from these figures, widths in the root WM and the HAZ are greater than in the welded joint centre, despite the fact that grooves were wider towards the centre. This was due to the use of ceramic sub-root strip which slows down the heat dissipation during the welding of the root. Reduction of heat dissipation results in higher heating of the PM, hence the penetration depth is greater and the HAZ is wider. This slowed cooling obviously increases the penetration depth and favourably affects the prevention of lack of fusion in the root part of the welded joint.

Conclusions

Welding in a narrow groove with the opening angle of 20° enables savings in WM mass and welding time, as well as in the amount of filler material used, compared to welding in V grooves, with angles ranging from 45° to 60°. Savings increase with the parent material thickness, as well as with the increase in groove opening angle, reaching up to 31% in the case of the 45° angle and up to 47% in the case of the 60° angle, for PM thickness of 30 mm.

Test results had shown that narrow groove welded joints, one of which was made using a full wire in bilo nedostatka stapanja i potpunom penetracijom duž debljina osnovnog materijala, sa malom uglovnom deformacijom.

Kod zavarivanja u uskom žljebu, koristeći gore navedene softverske pakete, mogu se koristiti klasični MAG zavarivačke pištolje. Međutim, oprema za zavarivanje mora biti nove generacije, tako da se može koristiti sa tim programima. Završni zavari i lice šava mogu biti zavareni klasičnom opremom za MAG, u ovom slučaju.

Zbog ograničene dostupnosti korenom delu šava i teškog usmeravanja luka, kontrola dužine luka i praćenje rastopa metala, neophodna je posebna obuka zavarivača. Oprema za zavarivanje sa instaliranim softverom za zavarivanje u uskom žljebu je složenija za korišćenje, a time postoji i potreba za dodatnom obukom.

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the horizontal position and the other using a filled wire in the vertical position, did not have any lack of fusion and were made with full penetration along the parent material thickness, with small angular deformation.

When welding in a narrow groove, using the software packages mentioned above, classic MAG welding guns can be used. However, welding equipment must be new generation, so that it can be used with these programmes. Finishing filling and weld face passes can be welded using classic MAG equipment in this case.

Due to limited accessibility of the root part of the weld and difficult arc guiding, arc length control and molten metal monitoring, special training of welders is required. Welding equipment with installed narrow groove welding software is more complex to use, hence the need for additional training.

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