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POROZNOST ZAVARENIH SPOJEVA LEGURE AlMg4,5Mn

POROSITY OF WELDED JOINTS OF AlMg4.5Mn ALLOY

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Ključne reči
- legura AlMg4,5Mn
- poroznost
- zaštitna atmosfera
- TIG zavarivanje

Izvod

Poroznost predstavlja ozbiljan problem zavarenih spojeva legura Al, jer se zbog toga značajno smanjuje mogućnost primene Al legura za izradu lakih konstrukcija. Da bi se poroznost smanjila ispitani su zavareni spojevi legure AlMg4,5Mn i analizom mikrostrukture je utvrđen uticaj sastava zaštitnog gasa primenjenog TIG postupka na poroznost metala šava. Na osnovu te analize je ocenjen kvalitet izvedenog zavarenog spoja. Kao zaštitni gasovi su korišćeni Ar, He i N_2*, samostalno ili u vidu mešavina. Najveća poroznost se dobija pri upotrebi čistog argona, a najbolji rezultat je dobijen mešavinom* Ar + 50%He + 0,015%N_2.

UVOD

Neophodnost smanjenja težine vozila, emisije štetnih gasova i potrošnje goriva je uslovila povećanu upotrebu lakih materijala, kao što su aluminijumske legure. Za mnoge konstrukcije se koristi legura AlMg4,5Mn. Prikladna je izradu rezervoara za skladištenje i prevoz tečnih gasova, za posude pod pritiskom, za vozila, a u novije vreme je osnovni materijal za izradu jahti i brodova. Ona je u grupi legura koje se termički ne obrađuju. Odlikuje se visokom čvrstoćom, otporna je na koroziju i habanje, i dobro se zavaruje. Sve veća primena ove legure je praćena daljim poboljšavanjem njenih karakteristika, a posebna pažnja se posvećuje usavršavanju postupaka zavarivanja i oblikovanja, /1/.

Keywords
- AlMg4.5Mn alloy
- porosity
- shielding atmosphere
- TIG welding

Abstract

Porosity represents a serious problem of welded joints of Al alloys, since it significantly reduces their applicability for producing light structures. In order to reduce porosity, welded joints of AlMg4.5Mn alloy have been tested and how the weld metal porosity is influenced by the shielding gas composition in the applied TIG process is also determined by microstructural analysis. Based on this analysis, the performed welded joint is quality assessed. Shielding gases Ar, He and N_2 *were used, individually, or in mixtures. Highest porosity is achieved with pure argon, and the best results with a mixture* Ar + 50%He + 0.015%N_2.

INTRODUCTION

The need to reduce the weight of vehicles, emission of noxious gases, and fuel consumption, has increased the demand for light materials, such as aluminium alloys. Alloy AlMg4.5Mn is applied in many structures. It is suitable for manufacturing tanks for storing and transporting liquefied gases, pressure vessels, vehicles, and recently as the main material in making yachts and ships. It belongs to a group of non-heat treatable alloys. It has high strength value, resistant to corrosion and wear, and has good weldability. Increased use of this alloy has further improved its characteristics, and particular attention is paid to developing welding and shaping procedures, /1/.

ZAVARIVANJE LEGURE AlMg4,5Mn

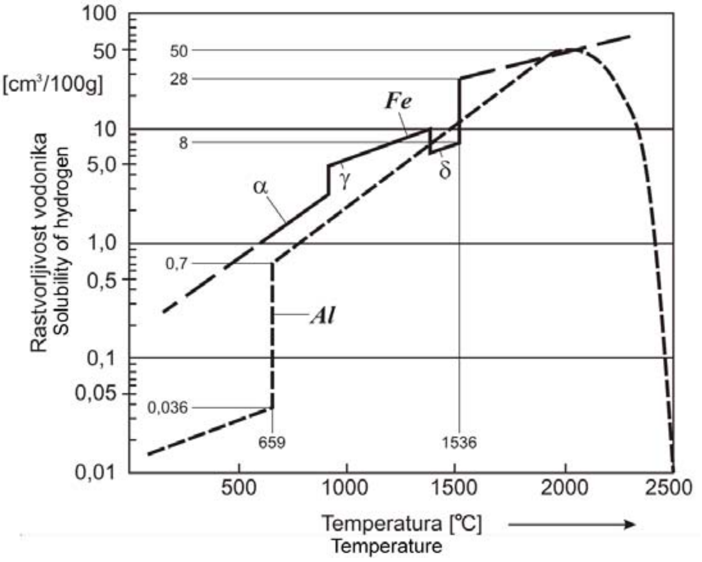
Za zavarivanje legure AlMg4,5Mn se najčešće koristi elektrolučno zavarivanje TIG postupkom (volframova netopljiva elektroda i zaštita gasom), jer omogućava preciznu kontrolu količine unete toplote.

Uneta toplota se određuje pogodno izabranim vrednostima parametara zavarivanja: jačine struje, brzine zavarivanja, dimenzija i sastava elektrode, brzine protoka i sastava zaštitnog gasa, /2–4/.

Argon i helijum se koriste kao zaštitni gasovi, jer obezbeđuju izradu zavarenog spoja sa najmanje grešaka. Pri izboru gasa treba imati u vidu značajne razlike njihovih osobina. Helijum je približno deset puta lakši od argona i poseduje visok potencijal jonizacije, 25 eV, dok je za argon 16 eV, pa je i napon luka veći, što je značajna prednost helijuma. Prednost argona je u većoj gustini, što obezbeđuje bolju zaštitu metalnog kupatila pri zavarivanju. Kako je cena helijuma znatno veća od cene argona, da bi se što bolje iskoristile navedene prednosti najčešće se primenjuju mešavine ta dva gasa. U novije vreme, mešavini ova dva gasa dodaje se kiseonik, što je primenljivo kod MIG postupka, ili azot u količini od nekoliko stotina ppm, /5–7/.

POROZNOST ZAVARENOG SPOJA

Jedan od najvećih problema pri zavarivanju aluminijuma i njegovih legura je pojava pora. Pore nastaju kao posledica adsorpcije, difuzije i rastvaranja gasova na površini i unutar očvrslog metala šava. Pore uglavnom stvara vodonik koji se rastvara u aluminijumu. Rastvorljivost vodonika u aluminijumu prikazana je na sl. 1. Radi poređenja, na sl. 1 je prikazana i rastvorljivost vodonika u čeliku, /8/.



Slika 1. Rastvorljivost vodonika u aluminijumu i čeliku u zavisnosti od temperature, /8/

Figure 1. Solubility of hydrogen in aluminium and steel, depending on temperature, /8/.

Sa povećanjem temperature rastvorljivost vodonika se povećava. Kako je na nižim temperaturama vodonik stabilan u molekulskom obliku, njegova rastvorljivost u metalu je mala. Na povišenim temperaturama molekuli vodonika se disociraju na atome, koji imaju manji prečnik od molekula pa lakše difunduju kroz kristalnu rešetku. Rastvorljivost vodonika u aluminijumu na temperaturi topljenja je

WELDING ALLOY AlMg4.5Mn

The electric arc welding procedure TIG (tungsten inert gas arc welding with nonconsumable electrode) is the most widely used procedure for welding AlMg4.5Mn, allowing a fine control of heat input.

The heat input is determined by carefully selecting the values of welding parameters: current, welding speed, size and composition of electrode, inert gas rate of flow and composition, /2-4/.

Argon and helium are used as shielding gases, since they provide a welded joint with the least errors. Upon selecting the gas, one should have in mind the considerable difference in properties. Helium is approximately ten times lighter than argon and has a high ionization potential, 25 eV, while argon has 16 eV, and thus the arc voltage is higher, giving helium a significant advantage. The advantage of argon is in much higher density, acting as a much better shield of the molten weld pool. Gas mixtures of helium and argon are often used so to compensate for disadvantages, since helium is more expensive. Recently, oxygen is added to the mixture, as has been applied in MIG procedure, or nitrogen in amounts of a few hundred ppm, /5–7/.

POROSITY OF WELDED JOINT

One of the serious problems in welding aluminium and its alloys is the appearance of pores. Pores are caused from adsorption, diffusion, and solubility of gases in the surface and within the solidified weld metal. Pores are mainly created from hydrogen, dissolved in aluminium. The solubility of hydrogen in aluminium is shown in Fig. 1, and also its solubility in steel, for sake of comparison, /8/.

Solubility of hydrogen increases with temperature. While molecular hydrogen is stable at lower temperatures, its solubility in metal is low. At higher temperatures hydrogen molecules dissociate into atoms, with a smaller diameter than molecules, allowing for easier diffusion through the crystal lattice. The solubility of hydrogen in aluminium at melting point is very high, and thus the higher concentration vrlo velika, pa otuda i povećano prisustvo vodonika u metalu šava. Tokom hlađenja, vodonik iz atomskog prelazi u molekulski oblik i može da ostane zarobljen u metalu šava i u zoni uticaja toplote (ZUT), u vidu pora.

Vodonik se pri zavarivanju unosi u zavareni spoj sa površine osnovnog i dodatnog metala, i iz vlage u zaštitnom gasu. Vodonik se na površini osnovnog metala zadržava fizičkom adsorpcijom, koja se smanjuje zagrevanjem. Zbog toga je potrebno predgrevanje, koje se najčešće izvodi acetilenskim plamenom.

Pri većoj vlažnosti, oksid aluminijuma apsorbuje vodenu paru. Vezana vlaga se tokom zavarivanja razlaže na vodonik i kiseonik, pri čemu se vodonik rastvara u čitavoj zapremini rastopljenog metala kupatila. Sa hlađenjem metala smanjuje se rastvorljivost vodonika. Kako je brzina hlađenja velika, vodonik se ne izdvaja blagovremeno i ostaje zarobljen u očvrslom metalu, što dovodi do poroznosti.

Postupci zavarivanja u kojima se metal šava duže zadržava u tečnom stanju pružaju veću mogućnost za degazaciju zavarivačkog kupatila, pa je i poroznost šava manja. Sem toga, poroznost zavisi i od izabranih parametara tehnologije zavarivanja, od usvojenog osnovnog i dodatnog materijala, kao i od sastava zaštitnog gasa.

Da bi se dobio kvalitetni zavareni spoj pri zavarivanju volframovom elektrodom bitno je da površine osnovnog i dodatnog materijala budu čiste, tako da nema oksida Al_2O_3. Najmanja poroznost se postiže primenom TIG zavarivanja, što se objašnjava većom mogućnošću degazacije rastopljenog metala. Kako je atom vodonika malog prečnika, lako difunduje kroz metal u čvrstom stanju, pa se poroznost može pojaviti i u ZUT. Za razliku od čelika, pore u aluminijumu se uglavnom raspoređuju u unutrašnjosti šava, mogu se sresti i u okolini linije stapanja sa osnovnim metalom, a ponekad se sreću i u ZUT. Na sl. 2 je prikazana pora u ZUT legure AlMg4,5Mn. Jasno se vidi da je ova pora blizu metala šava. Pora na sl. 2 ima veoma veliki prečnik, gotovo jednak širini ZUT.

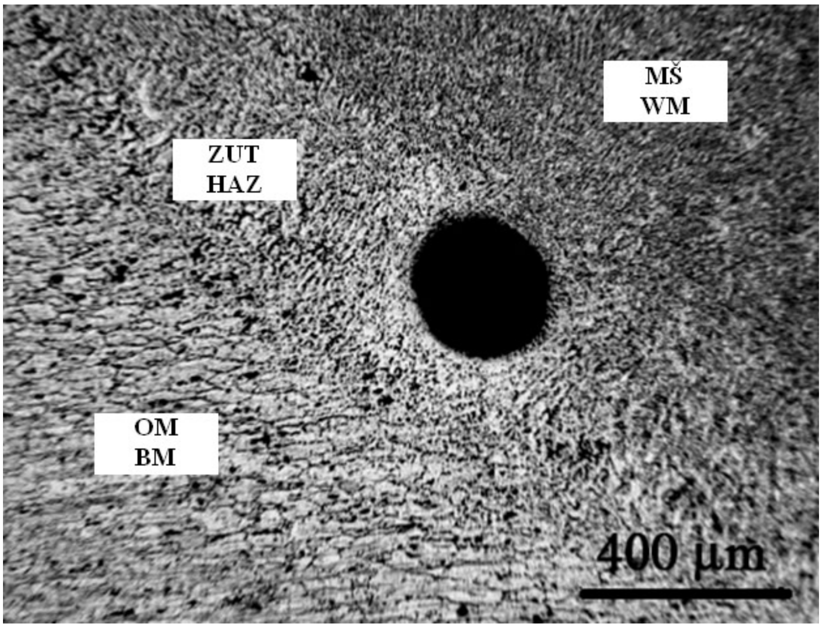
of hydrogen in weld metal. During cooling, hydrogen changes from atomic to molecular form and can remain trapped in the weld metal and heat affected zone (HAZ) in the form of pores.

During the welding process, hydrogen is dissolved into the welded joint from surfaces of the base metal and the consumable, and from the moisture in the shielding gas. Hydrogen accumulates at base metal surface by physical adsorption that is reduced by heating. This requires preheating, usually performed by acetylene flame.

At higher humidity, aluminium oxide absorbs water vapour. During welding the entrapped moisture separates into hydrogen and oxygen, where the hydrogen dissolves in the entire volume of the molten weld puddle. Upon cooling, the solubility of hydrogen decreases. Since the cooling rate is high, hydrogen is not rejected in due time and is retained in the solidified metal, bringing up porosity.

Welding procedures, where the weld metal remains in a liquefied state for a longer period, offer more possibilities for degassing the weld pool, assuring less porosity in the weld. Aside to this, porosity depends also on chosen welding technology parameters, the selected base and filler material, as well as on the content of the shielding gas.

In order to produce a quality welded joint in gas-tungsten arc welding, it is important that the base and filler material surfaces are clean, without traces of Al_2O_3. Minimal porosity is achieved in TIG welding, and is explained by higher degassing level of the molten metal. Since the hydrogen atom has a small diameter, it is easily diffused into the solid state metal, and porosity can also occur in HAZ. As opposed to steel, pores in aluminium are majorly distributed within the weld metal, and may also be located around the base metal fusion line, and sometimes in HAZ. A pore in the HAZ of alloy AlMg4.5Mn is shown in Fig. 2. Clearly, this pore is located in the vicinity of the weld metal. The pore in Fig. 2 has a very large diameter, almost equal to the width of the HAZ.



Slika 2. Velika pora u zoni uticaja toplote legure AlMg4,5Mn
Figure 2. Large pore in heat-affected-zone of alloy AlMg4.5Mn.

Iako su pore su mnogo manje opasne greške u zavarenim spojevima od prslina, ne treba ih zanemarivati, jer zbog koncentracije napona iz pora mogu da se razviju prsline. Postojanje prslina u zavarenom spoju, koje se u radnim uslovima mogu razvijati različitim mehanizmima, ugrožava integritet zavarenog spoja, a time i zavarene konstrukcije.

EKSPERIMENTALNO ISTRAŽIVANJE POROZNOSTI

Dobro poznavanje uslova stvaranja pora i eventualne inicijacije prslina iz njih je potrebno radi obezbeđenja integriteta zavarene konstrukcije u eksploataciji.

Pri montaži i zavarivanju postrojenja za proizvodnju utečnjenih atmosferskih gasova firme Messer–Tehnogas, u Smederevu je utvrđena poroznost u metalu šava, veća od dozvoljene, pa su izvedena ispitivanja sa namerom da se istraži mogućnost smanjenja poroznosti. U ovom istraživanju su korišćene ploče dimenzija 500×200×12 mm legure AlMg4,5Mn, koja je upotrebljena za izradu postrojenja. Proučavano je korišćenje prikladnih mešavina inertnih gasova umesto čistog argona kao zaštitne atmosfere, kao moguća mera smanjenja poroznosti zavarenog spoja.

Zavarivanje uzoraka

Hemijski sastav ispitivane legure AlMg4,5Mn dat je u tab. 1, a mehaničke karakteristike legure su date u tab. 2.

Tabela 1. Hemijski sastav legure aluminijuma AlMg4,5Mn, mas. %

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
0,13	0,21	0,04	0,66	3,95	0,03	0,06	0,025

Tabela 2. Mehaničke osobine legure aluminijuma AlMg4,5Mn

Pravac	Epruveta broj	Zatezna čvrstoća	Napon tečenja	Izduženje
		R_m, MPa	$R_{0,2}$, MPa	A, %
valjanja	1	293,6	135	26,3
	2	293,0	131	23,7
poprečni	1	304,4	145	25,7
	2	304,8	142	28,3

Probne ploče sa pripremljenim nesimetričnim V žlebom su sučeono zavarene uz primenu korene letve od aluminijumske legure, sa žlebom na sredini u koji su stavljene trake od nerđajućeg čelika (sl. 3 i 4). Uloga ovih traka je da usmere odvod toplote i obezbede potpuni provar u korenu šava, i da spreče curenje istopljenog metala.

Za zavarivanje je primenjen TIG postupak. Sve probne ploče su zavarene sa četiri prolaza, i to prvi koreni prolaz i tri prolaza popune (sl. 5).

Kao zaštitna atmosfera korišćeni su inertni gasovi argon i helijum uz dodatak azota i nekoliko kombinacija njihove mešavine radi utvrđivanja najpovoljnije varijante, s obzirom na pojavu poroznosti. Gasovi su isporučeni od strane firme Messer–Tehnogas u bocama od 10 l pod pritiskom od 150 bar (tab. 3).

Kao dodatni materijal korišćena je žica aluminijumske legure istog sastava, prečnika 5 mm i dužine 1000 mm.

Temperatura okoline prilikom zavarivanja bila je 20°C. Temperatura predgrevanja ploča bila je 110°C, a međuprolazna temperatura, kontrolisana kontaktnim termometrom, je uvek bila iznad 110°C. Ove temperature treba obavezno održavati da bi se postigla minimalna poroznost.

Although pores are much less dangerous flaws in welded joints than cracks, they should not be underestimated, since cracks can develop from pores due to stress concentration. Presence of cracks in welded joints, that can develop by various mechanisms in working conditions, threaten welded joint integrity, and thereby the welded structure as a whole.

EXPERIMENTAL INVESTIGATION OF POROSITY

Good knowledge of conditions for pore formation and as sources for eventual crack initiation is a requirement for assuring integrity of welded structures in exploitation.

Presence of porosity, above the allowed limit, has been detected in the weld metal upon the assembly and welding of Messer–Tehnogas installations, in Smederevo, required for producing liquefied atmospheric gases. So, tests were performed for investigating the possibilities for reducing this porosity. Testing included 500×200×12 mm plates made of alloy AlMg4.5Mn, also used for manufacturing the plant. Instead of pure argon, appropriate mixtures of inert gases were investigated as a shielding atmosphere to be used as a precaution in reducing welded joint porosity.

Welding of samples

The chemical composition of the tested alloy AlMg4.5Mn is given in Table 1, and mechanical characteristics of the alloy in Table 2.

Table 1. Chemical composition of alloy AlMg4.5Mn, mass %.

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
0.13	0.21	0.04	0.66	3.95	0.03	0.06	0.025

Table 2. Mechanical properties of alloy AlMg4.5Mn.

Direction	Spec. no.	Ultimate strength	Yield strength	Elongation
		R_m , MPa	$R_{0.2}$, MPa	A, %
rolling	1	293.6	135	26.3
	2	293.0	131	23.7
perpendicular	1	304.4	145	25.7
	2	304.8	142	28.3

Experimental plates with an asymmetrical V-shaped groove are butt welded with a root placed backing bar made of aluminium alloy, where the central groove root is fitted with stainless steel sheets (Figs. 3 and 4). The role of these sheets is to direct the removal of heat and provide complete root penetration, and prevent a melt-thru.

Welding was performed by TIG procedure. All experimental plates are welded in four passes, with a root-pass and three filler passes (Fig. 5).

Shielding inert gases, argon and helium, with an addition of nitrogen are used, and several combinations of their mixtures for determining the most favourable in regards to porosity. Gases are delivered from Messer–Tehnogas in cylinders of 10 l under pressure of 150 bar (Table 3).

An aluminium alloy wire of the same composition, 5 mm diameter and 1000 mm length, is used as filler material.

The environmental temperature while welding was 20°C. Plate pre-heating temperature was 110°C, and interpassing temperature was above 110°C. These temperatures must be maintained in order to achieve minimal porosity.

Osnovni parametri režima zavarivanja dati su u tab. 3.

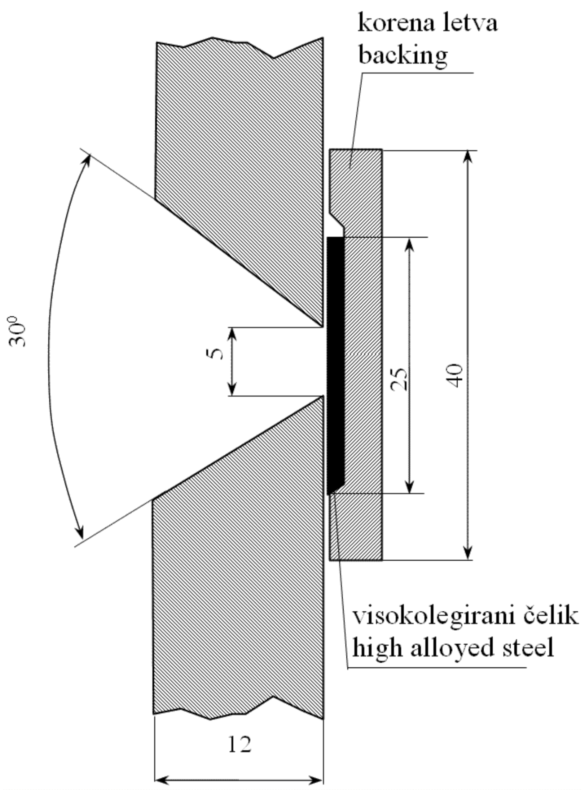
Tabela 3. Parametri režima zavarivanja

Ploča	Sastav gasa, %			Količina uneta toplote
	Ar	He	N_2	kJ/cm
1	99,99999	-	-	17-26
2	Ostatak	-	0,015	20-26
3	Ostatak	15	0,015	18-26
4	Ostatak	30	0,015	16-25
5	Ostatak	50	0,015	13-17

Basic parameters of the welding regime are given in Table 3.

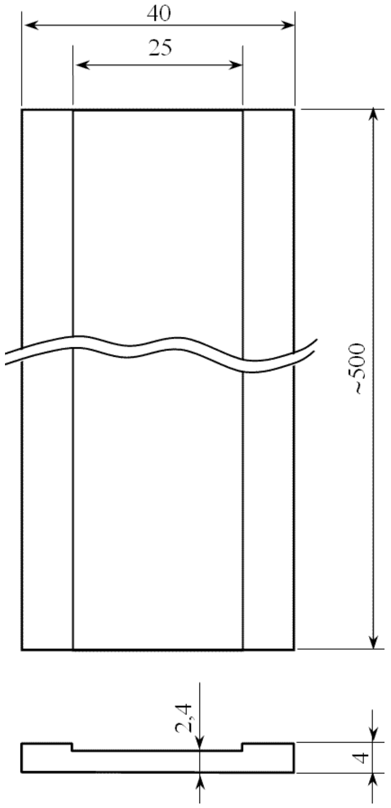
Table 3. Welding regime parameters.

Plate	Gas content, %			Input heat
	Ar	He	N_2	kJ/cm
1	99.99999	-	-	17-26
2	remainder	-	0.015	20-26
3	remainder	15	0.015	18-26
4	remainder	30	0.015	16-25
5	remainder	50	0.015	13-17



Slika 3. Oblik i dimenzije „V” žleba

Figure 3. Shape and size of the V-shaped groove.



Slika 4. Izgled i dimenzije korene letve

Figure 4. Shape and size of backing bar.

Metalografska ispitivanja

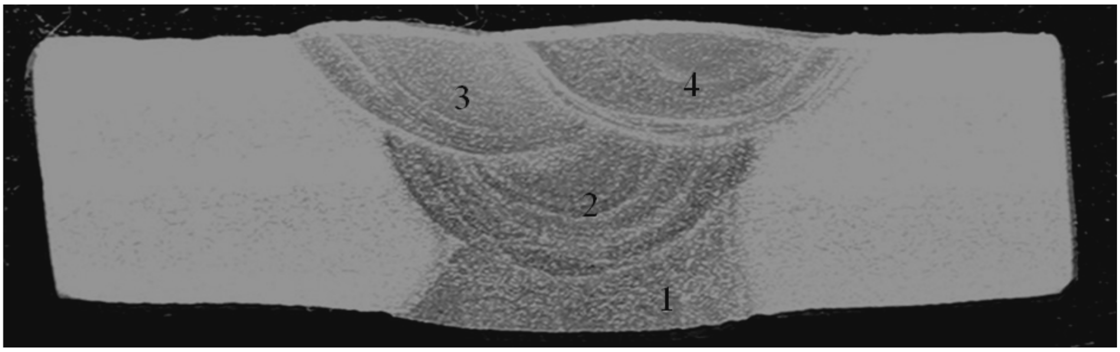
Mikrostrukturna ispitivanja su izvedena na isečenim i ispoliranim uzorcima, nagriženim sa 10% H_3PO_4 (sl. 5).

Mikrostruktura metala šava svih zavarenih ploča prikazana je na sl. 6.

Metallography testing

Microstructural tests are performed on cut and polished samples, etched with 10% H_3PO_4 (Fig. 5).

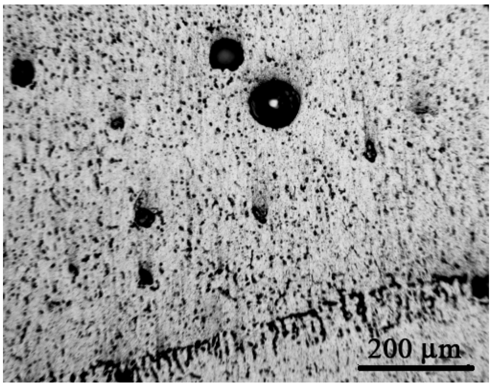
Weld metal microstructure of all welded plates is shown in Fig. 6.



Slika 5. Makrosnimak zavarenog spoja sa označenim prolazima

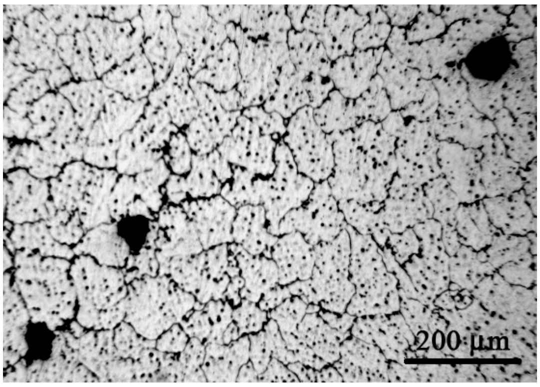
Figure 5. Macro image of welded joint with multi-pass notation.

1



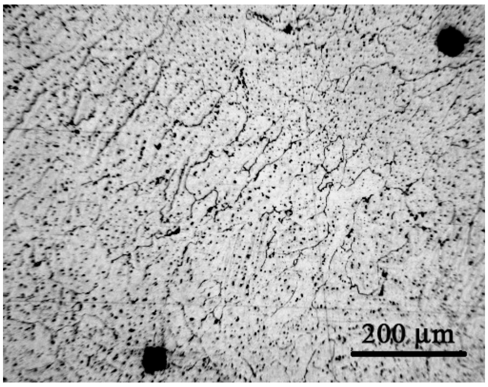
Ar

2



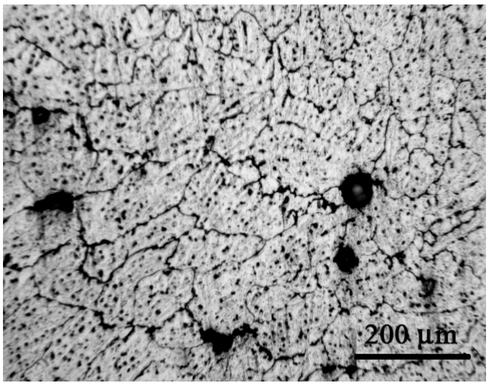
Ar + 0.015% N_2

3



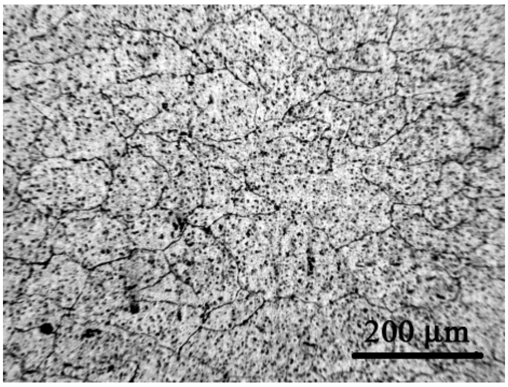
Ar + 15% He + 0.015% N_2

4



Ar + 30% He + 0.015% N_2

5



Ar + 50% He + 0.015% N_2

Slika 6. Izgled mikrostrukture metala šava zavarenih ploča
Figure 6. Microstructural images of weld metal in the welded plates.

Struktura metala šava svih zavarenih ploča je gotovo ista, što je i očekivano, jer su uslovi zavarivanja približno isti, odnosno, jedina razlika između pojedinačnih ploča je sastav zaštitne atmosfere koja je korišćena pri zavarivanju.

U mikrostrukturi se uočava tipično prisustvo dendrita, nastalih brzim očvršćavanjem tečnog metalnog kupatila, čiji je rast usmeren u pravcu odvođenja toplote. U metalu šava su prisutne intermetalne faze po granicama zrna. Uočljiva je razlika u poroznosti strukture metala šava ispitivanih ploča, koja je dominantno raspoređena u okolini linije stapanja dva prolaza i linije stapanja osnovnog metala i metala šava.

Najveća poroznost je otkrivena u metalu šava ploče 1 (zaštitna atmosfera–čist argon). Poroznost u ovom slučaju je najizraženija između prolaza. U metalu šava ploče 2 uočena je nešto manja poroznost nego u prethodnom slučaju

As expected, the microstructure of all welded plates is almost the same, because welding conditions are approximately the same, or, the only difference between individual plates is in the applied composition of shielding atmosphere.

The microstructure depicts typical dendrite presence, formed by rapid cooling of molten weld pool, whose growth is directed towards heat removal. Presence of intermetallic phases on grain boundaries is also depicted. The difference in porosity in weld metal structure of tested plates is visible, and dominantly distributed in the vicinity of fusion zones: of two consecutive passes; and of base- and weld metal.

The highest porosity level is discovered in weld metal of plate 1 (shielding atmosphere–pure argon). In this case, porosity is dominant in between passes. The weld metal in plate 2 shows somewhat less porosity (shielding atmosphere (zaštitna atmosfera Ar + 0,015% N_2). Još manja poroznost je ustanovljena kod metala šava ploče 3 (zaštitna atmosfera Ar + 15% He + 0,015% N_2). U metalu šava ploče 4 je povećanje poroznosti neočekivano (Ar + 30% He + 0,015% N_2) u poređenju sa drugim pločama, manja je jedino od poroznosti ploče 1. Gotovo da nema poroznosti u metalu šava ploče 5 (Ar + 50% He + 0,015% N_2), odnosno, ona je zanemarljiva.

Uočeno je da se sa povećanjem sadržaja helijuma u mešavini povećava razlivanje dodatnog materijala, a samim tim se smanjuje nadvišenje. Povećanje sadržaja helijuma u zaštitnom gasu utiče na povećanje dubine uvarivanja.

Rezultati ovog istraživanja su pokazali da primena zaštitne atmosfere Ar + 50% He + 0,015% N_2 pri zavarivanju legure AlMg4,5Mn omogućava izradu zavarenog spoja sa pojavom minimalne poroznosti.

ZAKLJUČAK

- Pri zavarivanju limova legure AlMg4,5Mn obavezno treba primeniti predgrevanje iznad 100°C, bez obzira što u ovom slučaju se radi o debljini 12 mm. U literaturi se mogu naći preporuke da se ove legure predgrevaju prilikom zavarivanja tek kada su debljine veće od 14 mm, dok se bez predgrevanja mogu zavarivati tanji limovi. Predgrevanjem se smanjuje poroznost u metalu šava.
- Dodavanje samo azota argonu ne utiče bitno na kvalitet metala šava. Imajući u vidu ovu činjenicu koja je potvrđena izvedenim ispitivanjima, ne može se dati prednost ni jednom zaštitnom gasu, bilo da je u pitanju čist Ar ili mešavina Ar + 0,015% N_2. Takođe ne treba zaboraviti i činjenicu da se u oba slučaja javljala poroznost u unutrašnjosti metala šava, bez obzira na primenjeno predgrevanje.
- Dodavanjem helijuma mešavini Ar i azota, poroznost u metalu šava se smanjuje. Razlivanje dodatnog materijala se povećava sa povećanjem sadržaja helijuma pri čemu se smanjuje nadvišenje, a povećava širina šava. Kao najbolja se pokazala zaštitna atmosfera Ar + 50% He + 0,015% N_2.

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Ar + 0.015% N_2). Yet, a lower level of porosity is found to be in weld metal of plate 4 (shielding atmosphere Ar + 15% He + 0.015% N_2). The weld metal of plate 4 reveals an unexpected increase in porosity (Ar + 30% He + 0.015% N_2) compared to other plates, and it is only lower than the porosity in plate 1. There is hardly any porosity in the weld metal of plate 5 (Ar + 50% He + 0.015% N_2), or it is negligible.

It is observed that an increased level of helium in the mixture also increases the flow of the filler material, decreasing the overlap. The increase in helium content in the shielding gas influences the increase in depth penetration.

Results in the investigation showed that the applied shielding atmosphere Ar + 50% He + 0.015% N_2 in the performed welding of AlMg4.5Mn material produces welded joints with a minimal porosity level.

CONCLUSION

- Pre-heating above 100°C is obligatory when welding plates of AlMg4.5Mn alloy, despite the 12 mm thickness in this case. Guidelines in some literature references say that these alloys should be pre-heated upon welding only at thickness levels above 14 mm, while thinner plates do not require pre-heating. Preheating decreases the level of porosity in the weld metal.
- Adding only nitrogen has no substantial impact on the quality of the weld metal. Having in mind this fact, confirmed from tests, no advantage may be given to any particular shielding gas, whether it is pure Ar or a mixture Ar + 0.015% N_2. Also, one should always bear the fact that porosity occurred within the weld metal volume, in both cases, despite the applied pre-heating.
- Adding helium to Ar and nitrogen mixture decreases the porosity level in weld metal. The flow of filler material increases due from the increased level of helium, whereupon overlapping diminishes and the width of the weld increases. The shielding atmosphere Ar + 50% He + 0.015% N_2 has shown to be most efficient.

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LITERATURA – REFERENCES

1. Jang, K.C., Kuk, J.M., *Welding and environmental test condition effect in weldability and strength of Al alloy*", Materials Process. Techn., 164-165, p. 1038-1045, 2005.
2. Yarmuch, M.A.R., Patchet, B.M., *Variable AC polarity GTAW Fusion Behaviour in 5083 Aluminium*, Welding Research, vol. 86, p. 196-200, July 2007.
3. *Facts about aluminium welding*, AGA Gas AB SKG-203, Sweden, Member of the Linde Gas Group, www.aga.se, 1996.
4. Aesh, M.A., *Optimization of weld bead dimensions in GTAW of aluminium-magnesium alloy*, Materials & Manufact. Processes, 16(5), p. 725-736, 2001.
5. Smiljanić, M., *Zaštitni gasovi u zavarivanju*, DUZS, Seminar, str. 7-11, jul, 2006.
6. Kuk, J.M., Lee, D.G., *Effects of shielding gas composition on low temperature toughness of Al-5083-O gas metal arc weld*, Sci. & Tech. of Welding and Joining, Vol.9, No 6, 2004.
7. Matz, C., *Improved arc stability with O_2 dose to inert gas*, Aluminium International Today, September/October, 2005.
8. Sven-Frithjof Goecke, *Auswirkungen von Aktivgaszumischungen im VPM – Bereich zu Argon auf das MIG-impulsschweisen von Aluminium*, Doktor Dissertation, Berlin, 2004.
9. Aluminium alloys – physical and mechanical properties, EMAS, vol III, p. 1441-1481, West Midlands, UK, 1986.