Radica Prokić Cvetković[1], Olivera Popović[1], Sandra Kastelec Macura[2], Radomir Jovičić[3]

UTICAJ SASTAVA ZAŠTITNE ATMOSFERE NA ZAVARLJIVOST LEGURE AlMg4.5Mn

INFLUENCE OF GAS SHIELDING ATMOSPHERE ON WELDABILITY OF AlMg4.5Mn ALLOY

Originalni naučni rad / Original scientific paper
UDK / UDC: 621.791:669.715

Rad primljen / Paper received:
Februar 2016.

Adresa autora / Author's address:
[1]Univerzitet u Beogradu, Mašinski fakultet, Beograd, Srbija
[2]Tehnikum Taurunum, Zemun, Beograd, Srbija
[3]Univerzitet u Beogradu, Inovacioni centar Mašinskog fakulteta, Beograd, Srbija

Kljucne reči: aluminijum, legura AlMg4.5Mn, metal šava, zavarljivost, zaštitna atmosfera, poroznost

Key words: aluminium, AlMg4.5Mn alloy, weld metal, weldability, gas shielding atmosphere, porosity

Abstract

In this paper is shown the influence of gas shielding atmosphere on the weldability of AlMg4.5Mn alloy. Prepared plates were welded using tungsten inert gas (TIG) with four different shielding atmospheres. Metallographic testing, tensile testing and hardness testing of welded joints were carried out. It has been shown that composition of shielding atmosphere has effect on the weld appearance, depth of penetration, overflowing of filler material, porosity in the weld metal, as well as on values of tensile strength and hardness. Weldments obtained by welding in a shielding atmosphere Ar + 50% He + 0.015% N_2 have the best appearance of the weld metal, good overflowing of filler material and satisfactory width to hight ratio. It was also established that these welds have the lowest weld metal porosity.

Izvod

U ovom radu je prikazano kako vrsta zaštitne atmosfere utiče na zavarljivost legure aluminijuma AlMg4.5Mn. Pripremljene ploče su zavarene TIG postupkom u četiri različite zaštitne atmosfere. Posle izvedenog zavarivanja, urađena su metalografska ispitivanja, ispitivanje zatezne čvrstoće zavarenog spoja u celini, kao ispitivanje tvrdoće zavarenog spoja. Pokazano je kako vrsta zaštitne atmosfere utiče na oblik šava, dubinu uvarivanja, razlivanje dodatnog materijala, pojavu poroznosti u metalu šava, kao i na vrednosti zatezne čvrstoće i tvrdoće. Šavovi dobijeni zavarivanjem u zaštitnoj atmosferi Ar+50%He+0,015%N_2 pokazali su najbolji izgled metala šava, pri čemu je dobro razlivanje dodatnog materijala a odnos širine i visine šava zadovoljavajući. Takođe je pokazano da ovako dobijeni šavovi imaju najmanju poroznost metala šava.

INTRODUCTION

Weldability of aluminum and its alloys has not been fully resolved. On the weldability of these alloys is afected by various factors that require the use of complex welding technology compared with steel. The development of electric arc welding processes in a protective atmosphere of inert gases contributed to much easier welding of aluminum alloys. Modernization of welding technology directly affects the quality of welded joints, structural integrity and thus their longer service life. Through the physical properties of the shielding gas has an effect on the degassing of molten baths, regulation of weld penetration profile and wettability [1-4]. The most common problems encountered when welding Al-Mg alloys are: degradation of the mechanical properties of the HAZ [5], reducing the

UVOD

Zavarljivost aluminijuma i njegovih legura do danas nije u potpunosti razrešena. Na zavarljivost ovih legura utiču različiti faktori koji iziskuju primenu složenije tehnologije zavarivanja u poređenju sa čelicima. Razvoj elektrolučnih postupaka zavarivanja u zaštitnoj atmosferi inertnih gasova znatno je olakšao zavarivanje aluminijumskih legura. Osavremenjivanjem tehnologije zavarivanja direktno se utiče na kvalitet zavarenih spojeva, integritet konstrukcija a samim tim i na njihov duži radni vek. Preko fizičkih osobina zaštitnog gasa utiče se na degazaciju rastopljene kupke, regulisanje profila uvarivanja i sposobnost kvašenja [1-4]. Najčešći problemi koji se sreću pri zavarivanju Al-Mg legura su: degradacija mehaničkih osobina u ZUT [5], smanjenje corrosion resistance [6-8], the appearance of pores - as a result of the absorption of hydrogen in the air, cracking - primarily as a result of the warm phase transformations that occur in the weld metal and heat affected zone and the occurrence of inclusions - usually oxide Al_2O_3 [9].

High thermal conductivity of aluminum influences on the width of the HAZ, and thus the degradation of the mechanical properties. In the case of welding of aluminum alloys in cast or hot-rolled condition, the decline in mechanical properties is minimal. But in the case that the process is carried out at a heat-welding or deformation strengthened alloys, the loss in strength and toughness can be substantial. Degradation of mechanical properties is attributed to the recrystallization process, which, in reinforced alloys strain begins to take place at temperatures above 200°C and completely ends at temperatures above 300°C [10-13]. The change in mechanical properties is often associated with the size of grains. Due to the increase of grain in the HAZ, a decrease in strength [14]. In aluminum alloys to increase the impact of grain is reflected more through increased tendency to hot cracking occurrence. Addition of elements such as titanium, zirconium and strontium, reducing the mobility of the grain boundary, preventing the recovering process, and thus allows the unwinding of the dynamic recrystallization. This leads to the formation of finer grains, thereby contributing to the quality of welded joints [15,16]. In the literature one can find another possible reason for the degradation of the mechanical properties of the weld metal due to chemical changes all together. It is known that magnesium, because of its low boiling point, and lithium due to the high degree of oxidation can be lost during the welding process. The loss of magnesium is particularly pronounced in the case of the MIG welding process [17].

The formation of pores is also one of the important problems in welding of aluminum and its alloys. The pores are formed as a result of absorption, diffusion and dissolution of gases on the surface and inside the hardened weld metal. Pore mainly produces hydrogen, which dissolves in the liquid metal bath and it is distributed throughout the volume. Hydrogen has the highest solubility in pure aluminum. When solidification solubility abruptly decreases, whereby hydrogen is trapped in the weld metal in the form of pores [18-21].

Argon and helium are the most commonly used shielding gases and significantly affect the quality of the weld. However, they differ from each other. Helium is one of the lightest gas, compared with the

korozione postojanosti [6-8], pojava pora - kao posledica apsorpcije vodonika iz vazduha, pojava prslina - prvenstveno toplih kao posledica faznih transformacija koje se javljaju u metalu šava i zoni uticaja toplote i pojava uključaka - najčešće oksida Al_2O_3 [9].

Visoka toplotna provodljivost aluminijuma utiče na širinu ZUT, a samim tim na degradaciju mehaničkih karakteristika. U slučaju zavarivanja aluminijumskih legura u livenom ili toplo valjanom stanju, pad mehaničkih svojstava je minimalan. Ali u slučaju da se proces zavarivanja izvodi na termički ili deformaciono ojačanim legurama, gubitak u čvrstoći i tvrdoći može biti značajan. Degradacija mehaničkih svojstava pripisuje se procesu rekristalizacije, koja kod deformaciono ojačanih legura počinje da se odvija na temperaturama iznad 200°C i u potpunosti se završava na temperaturama iznad 300°C [10-13]. Promena u mehaničkim svojstvima često je povezana sa veličinom zrna. Usled porasta zrna u ZUT dolazi do smanjenja čvrstoće [14]. U aluminijumskim legurama uticaj povećanja zrna ogleda se više kroz povećanu sklonost ka obrazovanju toplih prslina. Dodatak elemenata poput titana, cirkonijuma i stroncijuma, smanjuje pokretljivost granica zrna, onemogućavajući proces oporavljanja, pri čemu se omogućava odvijanje dinamične rekristalizacije. Na taj način dolazi do stvaranja sitnijeg zrna, čime se doprinosi i kvalitetu zavarenog spoja [15,16]. U literaturi se može pronaći i još jedan mogući razlog degradacije mehaničkih svojstava u metalu šava, usled promene hemijskog sasatava. Poznato je da magnezijum, zbog svoje niske tačke ključanja, i litijum zbog visokog stepena oksidacije, mogu biti izgubljeni za vreme procesa zavarivanja. Gubitak magnezijuma je posebno izražen u slučaju primene MIG postupka zavarivanja [17].

Nastajanje pora je takođe jedan od značajnih problema pri zavarivanju aluminijuma i njegovih legura. Pore nastaju kao posledica apsorpcije, difuzije i rastvaranja gasova na površini i unutar očvrslog metala šava. Pore uglavnom stvara vodonik, koji se rastvara u tečnom metalnom kupatilu i u njemu se raspoređuje po celoj zapremini. Najveću rastvorljivost vodonik ima u čistom aluminijumu. Prilikom očvršćavanja rastvorljivost naglo opada, pri čemu vodonik ostaje zarobljen u metalu šava u vidu pora [18-21].

Argon i helijum su najčešće korišćeni zaštitni gasovi i značajno utiču na kvalitet zavarenog spoja. Međutim, oni se međusobno razlikuju. Helijum je jedan od najlakših gasova, od argona lakši približno deset puta.

argon, around ten times lighter. It also has a high ionization potential, 25eV to 16eV compared with the argon and thus a higher arc voltage. In contrast to the benefits of helium, argon, because of its higher density provides better protection weld pool during welding. Price helium is much higher compared to argon, and for this reason most commonly used mixtures of these two gases. In recent times also apply to the combination of these two gases in addition to oxygen (only with MIG procedure) or nitrogen from a few hundred ppm [22-23].

Experiment

Welding were used plates of aluminum alloy AlMg4.5Mn, with dimensions 500x250x12mm, and V grooves are prepared by milling. Chemical composition and mechanical properties of the alloy are shown in Tables 1 and 2. As additional material used is aluminum alloy wire AlMg4.5Mn (classification DIN1732 / SG- AlMg4.5Mn or BS2901 / 5183 or AWS A5.10 / ER 5183), Ø5 mm and a length of 1000 mm (table 3).

Test plates are butt-welded in four types of shielding atmosphere in TIG process, in 4 passes: 1 root pass +3 filling passes, as shown in Figure 1. All passes are executed by welding in advance.

Takođe, poseduje i visok potencijal jonizacije, 25eV u poređenju sa 16eV kod argona, a time i veći napon luka. Nasuprot prednostima helijuma, argon, zbog svoje veće gustine, pruža bolju zaštitu metalnog kupatila pri zavarivanju. Cena helijuma je znatno veća u odnosu na argon, pa se iz tog razloga najčešće primenjuju mešavine ta dva gasa. U novije vreme primenjuju se i kombinacije ova dva gasa uz dodatak kiseonika (samo kod MIG postupka) ili azota od nekoliko stotina ppm [22-23].

Eksperimentalni rad

Za zavarivanje su korišćene ploče od legure aluminijuma AlMg4.5Mn, dimenzija 500x250x12*mm*, i V žljebovi su pripremljeni glodanjem. Hemijski sastav i mehaničke osobine legure prikazani su u tabelama 1 i 2. Kao dodatni materijal korišćena je žica od legure aluminijuma AlMg4.5Mn (klasifikacija DIN1732/SG- AlMg4.5Mn ili BS2901/5183 ili AWS A5.10/ER 5183), Ø5 *mm* i dužine 1000 *mm* (tabela 3).

Probne ploče su sučeono zavarene, u četiri vrste zaštitne atmosfere TIG postupkom, u 4 prolaza i to 1 koreni prolaz +3 prolaza popune, kao što je prikazano na slici 1. Svi prolazi su izvedeni tehnikom zavarivanja unapred

Hem. element Chem. element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
mas %	0,13	0,21	0,04	0,66	3,95	0,03	0,06	0,025

***Table 1.** Chemical composition of aluminum alloy AlMg4.5Mn*
***Tabela 1.** Hemijski sastav legure aluminijuma AlMg4.5Mn*

	Zatezna čvrstoća, Tensile strength R_m (MPa)	Napon tečenja, Yield strength $R_{0.2}$(MPa)	Procentualno izduženje The percentage elongation A (%)	Ukupna energija udara, The total impact energy (J)
Pravac valjanja Rolling direction	293	133	25	41
Poprečni pravac The transverse direction	304	143	24	32

***Table 2.** Mechanical properties of aluminum alloys AlMg4.5Mn*
***Tabela 2.** Mehaničke osobine legure aluminijuma AlMg4.5Mn*

Hem. element Chem. element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	drugi/others	
									svaki each	ukupno total
mas %	< 0,40	< 0,40	< 0,10	0,5-1,0	4,3-5,2	<0,25	0,05-0,25	0,15	<0,05	<0,15

***Table 3.** Chemical composition of welding wire AlMg4.5Mn*
***Tabela 3.** Hemijski sastav žice za zavarivanje AlMg4.5Mn*

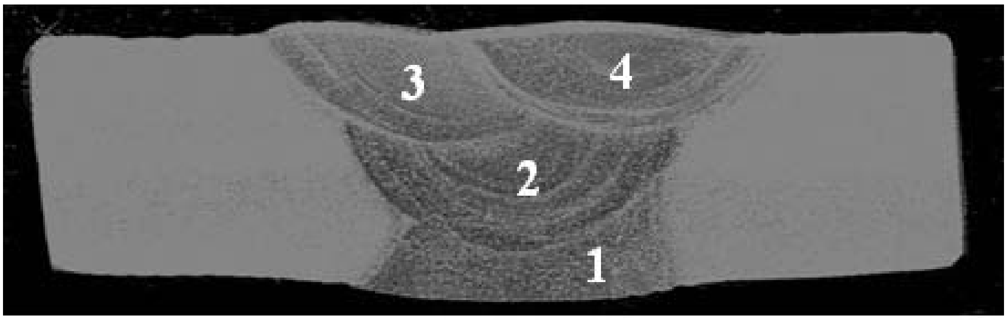


Figure 1. *The weld metal with marked passes*
Slika 1. *Zavareni spoj sa označenim prolazima*

Welding parameters: current, voltage, welding speed and the calculated amount of welding input heat, as the shielding atmosphere compositions are shown in Table 4. The flow of shielding gas is 17-19 l/min. Ambient temperature during welding was 20^{0}C. Interpass temperature was always above 110^{0}C (controlled by the contact thermometer). Preheat temperature of the plate is above 110^{0}C.

It is important to point out that another plate was welded in a protective atmosphere of pure argon or without preheating. In these plates in the weld metal was observed higher porosity than the plates welded under the same conditions but with preheating. Given this fact, it was concluded that the preheating is necessary, no matter what the literature recommends preheating the sheet thickness of over 14 mm.

Welding parameters, as well as the results of plate testing that is welded in a shielding atmosphere of pure argon without preheating are not presented in this paper.

Parametri zavarivanja: jačina struje, napon, brzina zavarivanja i izračunata uneta količina toplote pri zavarivanju, kao i sastavi zaštitnih atmosfera prikazani su u tabeli 4. Protok zaštitnog gasa je od 17-19 *l/min*. Temperatura okoline prilikom zavarivanja bila je 20^{0}C. Međuprolazna temperatura je uvek bila iznad 110^{0}C (kontrolisana je kontaktnim termometrom). Temperatura predgrevanja svih ploča bila je iznad 110^{0}C.

Važno je istaći i to da je još jedna ploča bila zavarena u zaštitnoj atmosferi čistog argona ali bez predgrevanja. Kod te ploče u metalu šava je uočena veća poroznost nego kod ploče zavarene pod istim uslovima ali sa predgrevanjem. Imajući u vidu ovu činjenicu, došlo se do zaključka da je predgrevanje neophodno, bez obzira što se u literaturi predgrevanje preporučuje za limove debljine preko 14 mm.

Parametri zavarivanja, kao i rezultati ispitivanja ploče koja je zavarena u zaštitnoj atmosferi čistog argona bez predgrevanja nisu prikazani u ovom radu.

Vrsta zaštitnog gasa Shielding gas	Redni br. ProlazaNo of pass	Jacina struje Current A	Napon, Voltage V	V_z, cm/min	Q, kJ/cm	Q_{sr}, kJ/cm
Ar	1	220	21,8	15,2	18,9	17-26
	2	215	22,1	11	25,9	
	3	215	20,2	15,2	17,1	
	4	220	20,6	11,5	23,6	
Ar+0,015%N_2	1	220	20,2	9,9	26,9	20-26
	2	224	20,2	10	27,1	
	3	217	21,2	13,9	19,9	
	4	214	21,3	13,3	20,6	
Ar+15%He+0,015%N_2	1	232	17,2	11,8	20,3	18-26
	2	232	17,1	9,3	25,6	
	3	232	17,2	14,4	16,6	
	4	232	16,8	12,5	18,7	
Ar+50%He+0,015%N_2	1	234	20,3	17,2	16,6	13-17
	2	234	20,2	16,7	17,0	
	3	234	19,5	21	13,0	
	4	234	19,1	20,2	13,3	

Table 4. *Welding parameters*
Tabela 4. *Parametri zavarivanja*

From Table 1 it is clear that the welding in the shielding atmosphere of gas mixtures, increasing the content of helium causing an increase in arc voltage at the same currents (plate 1,5), because helium has a higher ionization potential than argon. This increase in voltage directly increase welding speed, which is also shown in Table 1. The amount of welding heat input was from 17 to 26 kJ / cm in all cases except in the last (Ar + 50% He + 0.015% N2) where was 13-17 kJ / cm, which is explained by the increase of welding speed.

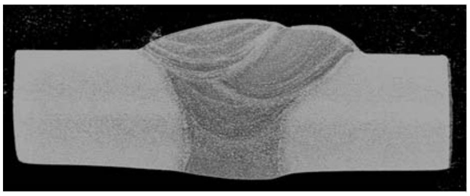
Macroscopic and microstructural analysis

From the welded plates are cut samples for testing macrostructure. These samples were etched and photographed as shown in Figure 2.

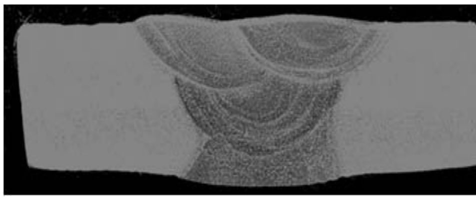
Iz tabele 1 se jasno vidi da pri zavarivanju u zaštitnoj atmosferi mešavine gasa, povećanje sadržaja helijuma utiče na povećanje napona luka pri istim jačinama struje (ploče 1,5), jer helijum ima veći potencijal jonizacije od argona. Ovo povećanje napona direktno utiče na povećanje brzine zavarivanja, što je takođe prikazano u tabeli 1. Količina unete toplote pri zavarivanju je bila od 17-26 kJ/cm u svim slučajevima osim u poslednjem (Ar+50%He+0,015%N_2) gde je bila od 13-17 kJ/cm, što se objašnjava povećanjem brzine zavarivanja.

Makroskopska i mikrostrukturna ispitivanja

Iz zavarenih ploča su isečeni uzorci za makrostrukturna ispitivanja. Ovi uzorci su nagriženi i fotografisani što je prikazano na slici 2.



a) Ar



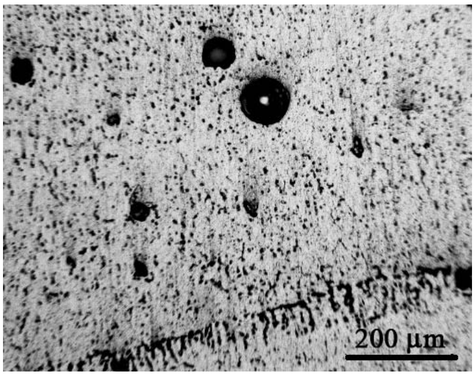
b) Ar+50%He+0.015%N_2

Figure 2. *Appearance of macro snapshot of welded joints*
Slika 2. *Izgled makrosnimaka zavarenih spojeva*

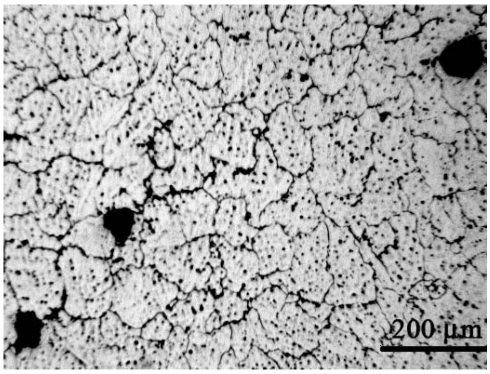
Figure 2a shows that the welding in the shielding atmosphere of pure argon gives lower seam width and less overflowing of filler material. At higher contents of He in the gas mixture, the seam width is increased, a overflowing of filler material is better. The most beautiful appearance of weld (no undercuts, good overflowing, no big weld reinforcement) is obtained for welding in protective atmosphere Ar + 50% He + 0.015% N2 can be clearly seen in Figure 2b. The structure of the weld metal of welded plates is the same, which is to be expected, because the welding conditions about the same, that is, the only difference between the individual plate is a kind of shielding atmosphere is used in welding. In the weld metal are present intermetallic phases at grain boundaries. The main difference in the structure of the tested weld metal plates is in the porosity, which is predominantly distributed around the fusion line between the two passes and fusion line between the base metal and weld metal. The maximum porosity was observed in the weld metal plates welded in an atmosphere of pure argon, Figure 3a. The weld metal plates welded under shielding gas mixture Ar + 0.015% N2 (Figure 3b), show a slightly lower porosity than in the previous case. Increase of the percentage of helium in a shielding atmosphere causes the decrease of porosity, so that the welding in the shielding atmosphere of Ar + 50% He + 0.015% N2 is almost negligible, Figure 3d.

Na slici 2a se vidi da je pri zavarivanju u zaštitnoj atmosferi čistog argona manja širina šava kao i slabije razlivanje dodatnog materijala. Pri većim sadržajima He u zaštitnom gasu, širina šava se povećava, a razlivanje dodatnog materijala je bolje. Najlepši izgled šava (nema zajeda, dobro razlivanje, nema velikog nadvišenja) je dobijen pri zavarivanju u zaštitnoj atmosferi Ar+50%He+0.015%N_2 što se jasno vidi na slici 2b. Struktura metala šava svih zavarenih ploča je ista, što se i može očekivati, jer su uslovi zavarivanja približno isti, odnosno, jedina razlika između pojedinačnih ploča je vrsta zaštitne atmosfere koja je korišćena pri zavarivanju.

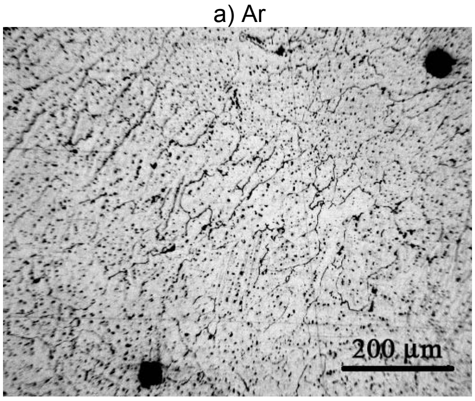
U metalu šava su prisutne intermetalne faze po granicama zrna. Osnovna razlika u strukturi metala šava ispitivanih ploča je u poroznosti, koja je dominantno raspoređena u okolini linije spoja između dva prolaza i linije spoja između osnovnog metala i metala šava. Najveća poroznost je uočena u metalu šava ploče zavarene u atmosferi čistog argona, slika 3a. U metalu šava ploče zavarene u atmosferi Ar+0.015%N_2 (slika 3b), uočena je nešto manja poroznost nego u prethodnom slučaju. Povećanje udela helijuma u zaštitnoj atmosferi utiče na smanjenje poroznosti, tako da je pri zavarivanju u zaštitnoj atmosferi Ar+50%He+0.015%N_2 gotovo zanemarljiva, slika 3d.



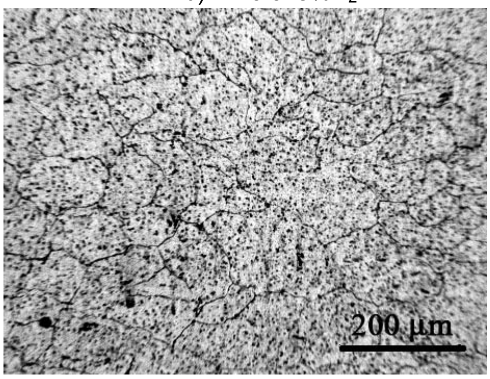
a) Ar



b) Ar+0.015%N_2



c) Ar+15%He+0.015%N_2



d) Ar+50%He+0.015%N_2

Figure 3. *Appearance of weld meatl microstructure*

Slika 3. *Izgled mikrostrukture metala šava*

Tensile testing

Tensile tests were performed at room temperature. From the welded plates are made specimens with parallel sides for testing tensile strength of the whole welded joint. During the test of specimens to determine the tensile strength of the welded joint as a whole (specimens with parallel sides) to the fracture occurred most often in the HAZ, regardless of the composition of the shielding gas mixtures. Tensile strength values ranged from 271-290 MPa, which is slightly lower (about 10%) of the tensile strength of base metal 293-305 MPa, which shows that there has been a degradation of strength in the HAZ. Bearing in mind the shown results, it can be said that the strength of the welded joint does not significantly affected by the type of shielding atmosphere.

Hardness test

The hardness of the welded joints was measured by Vickers method HV5. On the polished samples was measured hardness welds along three lines: to the weld face, in the middle and towards the root, where it is in all cases covered by the base metal, weld metal and HAZ. The hardness of the base material ranged from 65-85 HV. Figure 3 shows changes in hardness samples, along the middle of the plate using various types of shielding atmosphere.

Ispitivanje zatezanjem

Ispitivanja zatezanjem rađena su na sobnoj temperaturi. Iz zavarenih ploča napravljene su epruvete sa paralelnim bokovima za ispitivanje zatezne čvrstoće spoja u celini. Pri ispitivanju epruveta za određivanje zatezne čvrstoće zavarenog spoja u celini (epruvete sa paralelnim stranicama) do loma je dolazilo najčešće u ZUT, bez obzira na sastav mešavine zaštitnog gasa. Vrednosti zatezne čvrstoće su se kretale od 271-290 MPa, što je nešto niže (oko 10%) od zatezne čvrstoće osnovnog metala 293-305 MPa, što pokazuje da je došlo do degradacije čvrstoće u ZUT. Imajući u vidu prikazane rezultate, može se reći da na čvrstoću zavarenog spoja bitno ne utiče vrsta zaštitne atmosfere.

Ispitivanje tvrdoće

Tvrdoća zavarenih spojeva merena je Vikersovom metodom HV5. Na ispoliranim uzorcima merena je tvrdoća zavarenih spojeva duž tri linije: ka licu šava, u sredini i ka korenu, pri čemu je u svim slučajevima obuhvaćen osnovni metal, metal šava i ZUT. Tvrdoća osnovnog materijala se kretala od 65-85 HV. Na slici 3 su prikazane promene tvrdoće uzoraka, duž sredine ploče pri korišćenju različitih vrsta zaštitne atmosfere.

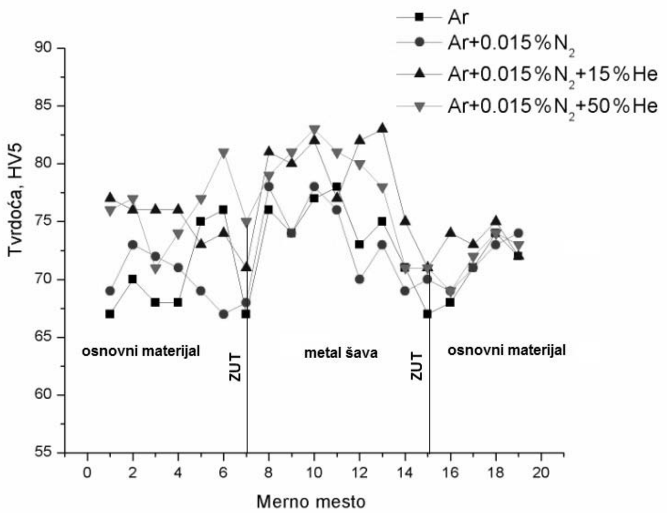


Figure 4. *Distribution of hardness in the welded joints of various shielding atmosphere*

Slika 4. *Raspodela tvrdoće u zavarenom spoju za različite zaštitne atmosfere*

(tvrdoća-hardness; merno mesto-testing place; osnovni materijal-base material; metal šava-weld metal; ZUT-HAZ)

As can be seen from Figure 3, the hardness of the weld metal is slightly higher than the hardness of the base metal, the most by about 10% in individual cases and ranged from 67-87 HV. In the HAZ is observed a slight decrease compared to the hardness of the base material, indicating the degradation of the mechanical properties of the HAZ. Based on these results we can freely say that the hardness of the weld metal of welded joints do not significantly influence the composition of the shielding atmosphere.

Conclusions

1. When welding sheet metal alloy AlMg4.5Mn required to be applied preheating above 100 ° C. Preheating reduces porosity in the weld metal..
2. Overflowing of filler material increases with increasing helium thereby reducing the weld reinforcement, and increases the width of the seam. Also, an increase in helium content in the shielding atmosphere causes the reduction of porosity, and as the best shielding atmosphere Ar + 50% He + 0.015% N2 is shown, in which the observed the minimum porosity.
3. Adding nitrogen to shielding gas in TIG process causes more overflowing of filler material and reducing porosity.
4. Tensile strength of the welded joint in its entirety for all samples differ up to 10% with respect to the tensile strength of the base material. Bearing in mind that the specimens ruptures occurred in almost all cases in the HAZ, it is safe to say that the type of shielding atmosphere has no significant impact on the strength of the weld metal. It should be taken into account that in the Bearing in mind that the specimens ruptures occurred in almost all cases in the HAZ, it is safe

Kao što se sa slike 3 vidi, tvrdoća metala šava je nešto veća nego tvrdoća osnovnog metala, najviše za oko 10% u pojedinačnim slučajevima i kretala se od 67-87 HV. U ZUT je uočen blagi pad tvrdoće u odnosu na osnovni materijal, što ukazuje na degradaciju mehaničkih svojstava u ZUT.

Na osnovu dobijenih rezultata se slobodno može reći da na tvrdoću metala šava zavarenog spoja bitno ne utiče sastav zaštitne atmosfere.

Zaključci

1. Pri zavarivanju limova legure AlMg4.5Mn obavezno treba primeniti predgrevanje iznad 100°C. Predgrevanjem se smanjuje poroznost u metalu šava.
2. Razlivanje dodatnog materijala se povećava sa povećanjem sadržaja helijuma pri čemu se smanjuje nadvišenje, a povećava širina šava. Takođe, povećanje sadržaja helijuma u zaštitnoj atmosferi utiče na smanjenje poroznosti, pa se kao najbolja pokazala zaštitna atmosfera Ar+50%He+0.015%N_2, kod koje je uočena i najmanja poroznost.
3. Dodavanje azota zaštitnom gasu kod TIG postupka utiče na bolje razlivanje dodatnog materijala i smanjenje poroznosti.
4. Zatezna čvrstoća zavarenog spoja u celini kod svih uzoraka se razlikuje najviše do 10% u odnosu na zateznu čvrstoću osnovnog materijala. Imajući u vidu da je do loma epruveta dolazilo gotovo u svim slučajevima u ZUT, onda se slobodno može reći da vrsta zaštitne atmosfere nema bitnog uticaja na čvrstoću metala šava. Treba uzeti u obzir da se kod zavarenih spojeva legura aluminijuma

to say that welded joints of aluminum alloys allows the tensile strength of weld metal is 10% lower than the tensile strength of the base metal.

5. The hardness of the weld metal is slightly higher than the hardness of base metal, for the most about 10%, in individual cases, while in the HAZ hardness observed a slight decrease compared to the base material, indicating the degradation of the mechanical properties of the HAZ. Based on these results, we can freely say that the hardness of the weld metal of welded joints do not significantly influenced by the composition of the shielding atmosphere

dozvoljava da zatezna čvrstoća metala šava bude 10% manja od zatezne čvrstoće osnovnog metala.

5. Tvrdoća metala šava je nešto veća nego tvrdoća osnovnog metala, najviše za oko 10% u pojedinačnim slučajevima, dok je u ZUT uočen blagi pad tvrdoće u odnosu na osnovni materijal, što ukazuje na degradaciju mehaničkih svojstava u ZUT. Na osnovu dobijenih rezultata se slobodno može reći da na tvrdoću metala šava zavarenog spoja bitno ne utiče sastav zaštitne atmosfere.

Literatura

[1] N. Moyer, *The evolution of Shielding gas*, Welding Journal, Vol. 81, N°9, p.51-52, 2002

[2] F. Schweighardt, *Choosing shielding gases for arc welding*, The Fabricator, September 2007

[3] M. Smiljanić, *Zaštitni gasovi u zavarivanju*, seminar DUZS, juni 2006

[4] K.C.Yang, D.G. Lee, J.M. Kuk, I.S. Kim, *Welding and environmental test condition effect in weldability and strenght of Al alloy*, Materials Processing Technology Vol. 164-165, p.1038-1045, 2005

[5] Z. Burzić, *Savremene metode provere mehaničko-tehnoloških osobina zavarenih spojeva–Deo 2*, Zavarivanje i zavarene konstrukcije, Vol. 47, No. 3, str. 151-158, 2002

[6] S. Katsas, J. Nikolaou, G. Papadimitriou, *Corrosion resistance of repair welded naval aluminium alloys,* Materials and Design, 28, p. 831-836, 2007

[7] J. R. Pickens, J. R. Gordon, J. Green, *The effect of loading mode on the stress corrosion cracking of aluminium alloy 5083,* Metalls Transaction, 14A, p. 925-930, 1983

[8] D. R. Baer, C. F. Windisch, *Influence of Mg on the corrosion of Al,* Vacuum Science Technology, No 18, p. 131-136, 2000

[9] B. Dogan, U. Ceyhan, K. M. Nikbin, B. Petrovski, and D. W. Dean, *European Code of Practice for Creep Crack Initiation and Growth Testing of Industrially Relevant Specimens*, Journal of ASTM International, Vol. 3, No. 2, p. 121-139, 2006

[10] R. Iascone, C. C. Menzemer, *Reestablishing the Shear Strenght of Aluminium Alloy Filet Welds*, Welding journal, Vol. 81, N°4, p.29-31, April 2007

[11] D. Mandal, I. Baker, *The effects of fine second phase particles on primary recristallization as a function of strain*, Elsevier Science, Acta Metallurgica No 2. p 453-461, 1997

[12] L. S. Kramer, W. T. Track, Adv. Mater. Processesing, 10, 1997, p.23-24

[13] J. Canas, R. Picon, F. Paris, *A simplified numerical analysis of residual stresses in aluminium welded plates*, Elsevier Science, Computers & Structures, Vol. 58, p. 59-69, 1996.

[14] C.M. Sonsino, D. Radaj, U. Brandt, *Fatigue assesment of welded joints in AlMg4.5Mn aluminium alloy by local approaches*, International Journal of Fatigue, No. 21, p. 985-999, 1999

[15] Metals Handbook, *Metallography and Microstructures*, ASM, Vol. 9, Ohio, USA, 1985

[16] M. A. Wahab, M.J.Painter, M. H. Davies, Journal of Materials Processesing Technology, 77, 1998, p.233-239

[17] A. K. Mukophadhyay, G. M. Reddy, K. S. Prassad, S. V. Kamat, J. T. Staley Honorary Symp. on Aluminium Alloys, ASM Materials Solution Conference, Indianapollis, USA, 2001

[18] Aluminium alloys – Physical and mechanical properties',EMAS, vol III, p. 1441-1481, West Midlands, UK, 1986.

[19] Dipl. ing. Sven-Frithjof Goecke:` Auswirkungen von Aktivgaszumischungen im vpm – Bereich zu Argon auf das MIG-impulsschweisen von Aluminium`; Doktor Dissertation, Berlin, 2004.

[20] M. A. R. Yarmuch, B. M. Patchet: `Variable AC polarity GTAW Fusion Behaviour in 5083 Aluminium`; Welding reseach, vol. 86 p. 196-200, july 2007.

[21] I. V. Dovbišenko, A. S. Išenko: 'Primenie gelis pri svarke alominievih splavov plavšims elektrodom'; Avtomatičeska svarka, No. 2, (527), str. 14-18, 1997.

[22] J.M. Kuk, D.G. Lee:"Effects of shielding gas composition on low temperature toghness of Al-5083-O gas metal arc weld"; Sci. & Tech. of Welding and Joining, Vol.9, No6, 2004.

[23] C. Matz: 'Improved arc stability with O_2 dose to inert gas',Aluminium international today, september/october, 2005.