

CRACKING RESISTANCE OF AlMg4.5Mn ALLOY TIG WELDED JOINTS OTPORNOST NA PRSLINE ZAVARENIH TIG SPOJEVA AlMg4.5Mn LEGURE

Originalni naučni rad / Original scientific paper
UDK /UDC: 621.791.754.05 : 669.715'721'74
Rad primljen / Paper received: 6.12.2011

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Keywords

- aluminium alloy
- AlMg4.5Mn
- TIG welding
- shielding gas mixtures
- fatigue crack growth
- critical stress intensity factor

Abstract

In this paper the AlMg4.5Mn TIG welded joints have been tested in order to investigate their cracking resistance. Testing plates, size of 500 × 250 × 12 mm, are welded by TIG procedure in a horizontal-vertical position. Various mixtures of inert gases are prepared and supplied by MESSER TEHNOGAS AD, Smederevo (Serbia), including Ar, Ar + 0.015% N₂, Ar + 15% He + 0.015% N₂, Ar + 30% He + 0.015% N₂, Ar + 50% He + 0.015% N₂. Non-destructive testing is used to check joint defects, primarily porosity, as typical for this type of alloys. The Charpy specimens, with the notch positioned in different regions of the welded joint, are tested using instrumented pendulum to separate crack initiation and growth energy. Crack resistance is evaluated by using static (K_{Ic}) and dynamic testing (Paris law – fatigue crack growth).

INTRODUCTION

Advanced aluminium alloys, as AlMg4.5Mn, are used more and more extensively for structures due to their low density, high strength and good weldability. Anyhow, welding problems still exist and more care is needed than for standard aluminium alloys. Typical problems with the AlMg4.5Mn alloy are porosity /1, 2/, Al₂O₃ oxide layer presence, hot and cold cracking, leading to the general conclusion that the crack resistance of AlMg4.5Mn welded joints need to be investigated with extreme care, not only using instrumented Charpy pendulum to evaluate crack initiation and crack growth energy, but also by testing fatigue crack growth and standard fracture toughness, as well.

The most common solution to all aforementioned problems is to apply the TIG process with a mixture of inert gases. In this paper four different mixtures (Ar + 0.015% N₂, Ar + 15% He + 0.015% N₂, Ar + 30% He + 0.015% N₂, Ar + 50% He + 0.015% N₂) are used, together with pure Ar, with other technology parameters being the same, to investigate its influence on the crack resistance of AlMg4.5Mn welded joints.

Ključne reči

- legura aluminijuma
- AlMg4.5Mn
- TIG zavarivanje
- mešavine zaštitnih gasova
- rast zamorne prsline
- kritični faktor intenziteta napona

Izvod

U ovom radu, zavareni spojevi AlMg4.5Mn legure, zavereni TIG postupkom, su testirani u cilju istraživanja njihove otpornosti na stvaranje prsline. Ploče, dimenzija 500 × 250 × 12 mm, su zavarene TIG procesom u horizontalno-vertikalnom položaju. Različite mešavine inertnih gasova su pripremljene i snabdevene od MESSER TEHNOGAS AD, Smederevo (Srbija), uključujući Ar, Ar + 0,015% N₂, Ar + 15% He + 0,015% N₂, Ar + 30% He + 0,015% N₂, Ar + 50% He + 0,015% N₂. Ispitivanjima bez razaranja su otkrivene greške zavarenih spojeva, poroznost, tipično za ovu vrstu legura. Šarpi epruvete sa zarezm postavljanim na različitim delovima zavarenog spoja, su ispitivane instrumentiranim klatnom sa mogućnošću razdvajanja energije inicijacije i rasta prsline. Otpornost na stvaranje prsline je određena statičkim (K_{Ic}) i dinamičkim ispitivanjem (rast zamorne prsline – Parisov zakon).

EXPERIMENTAL PROCEDURE

Welding plates of aluminium alloy AlMg4.5Mn, 12 mm thick are used. The chemical composition and mechanical properties, as tested here, are presented in Tables 1 and 2.

Table 1. Aluminium alloy AlMg4.5Mn chemical composition (vol. %).

Tabela 1. Hemijski sastav legure AlMg4.5Mn (vol. %)

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. Aluminium alloy AlMg4.5Mn mechanical properties.

Tabela 2. Mehaničke osobine legure AlMg4.5Mn

	Record no.	Tensile strength, R_m (MPa)	Yield stress, $R_{0.2}$ (MPa)	Elongation A (%)
Rolling direction	1	293.6	135	26.3
	2	293.0	131	23.7
Cross direction	1	304.4	145	25.7
	2	304.8	142	28.3

The aluminium alloy AlMg4.5Mn microstructure used in this experiment is shown in Fig. 1. It is typical for rolled plates, with a fine Mg₂Al₃ precipitate on the grain boundary and relatively large Mg₂Si and (Fe,Mn)Al₆ microconstituents.

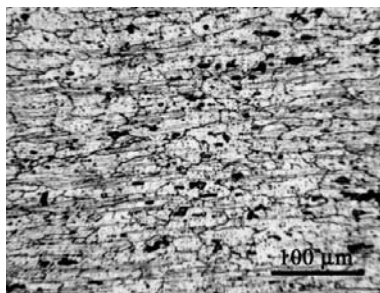


Figure 1. Aluminium alloy AlMg4.5Mn microstructure.
Slika 1. Mikrostruktura aluminijumske legure AlMg4.5Mn

The filler metal is a wire of the same composition AlMg4.5Mn, Ø5 mm, and 1000 mm length. The chemical composition is shown in Table 3.

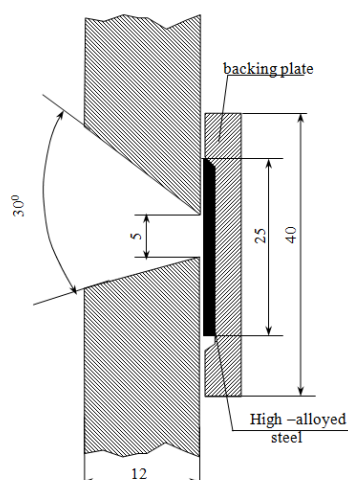
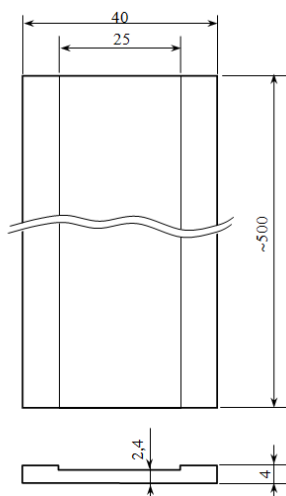


Figure 2. Shape and size of "V" groove with backing plate.
Slika 2. Izgled i dimenzije „V“ žleba sa korenom letve

Table 4. Welding parameters – TIG procedure.
Tabela 4. Parametri zavarivanja – TIG postupak

Protection gas	Pass no.	Amperage (A)	Voltage (V)	Welding speed (cm/min)	Heat input (kJ/cm)	Interpass temper. (°C)	Plate no.
Ar	1	220	21.8	15.2	18.9	110	4
	2	215	22.1	11	25.9	110	
	3	215	20.2	15.2	17.1	124	
	4	220	20.6	11.5	23.6	125	
Ar + 0.015%N ₂	1	220	20.2	9.9	26.9	120	2
	2	224	20.2	10	27.1	130	
	3	217	21.2	13.9	19.9	110	
	4	214	21.3	13.3	20.6	120	
Ar + 15%He + 0.015%N ₂	1	232	17.2	11.8	20.3	120	1
	2	232	17.1	9.3	25.6	127	
	3	232	17.2	14.4	16.6	115	
	4	232	16.8	12.5	18.7	118	
Ar + 30%He + 0.015%N ₂	1	234	18.5	15.1	17.2	122	3
	2	234	18	10	25.3	120	
	3	234	18.1	16.2	15.7	124	
	4	234	17.7	14.1	17.6	123	
Ar + 50%He + 0.015%N ₂	1	234	20.3	17.2	16.6	123	5
	2	234	20.2	16.7	17.0	125	
	3	234	19.5	21	13.0	120	
	4	234	19.1	20.2	13.3	118	

Table 3. Filler metal AlMg4.5Mn chemical composition (mass %).
Tabela 3. Hemijski sastav žice za zavarivanje AlMg4.5Mn (mas. %)

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
< 0.40	< 0.40	< 0.10	0.5–1.0	4.3–5.2	< 0.25	0.05–0.25	0.15

The shielding atmosphere is obtained by pure Ar or by a mixture of inert gases, (Ar + 0, 15, 30, 50% He + 0.015% N₂). Gases are specially prepared and supplied by MESSER TEHNOGAS AD, Smederevo, with typical flow 17–19 l/min.

Testing plates of size 500 × 250 × 12 mm, are welded by TIG procedure, in a horizontal-vertical position, using back-up plates, in 4 passes (1 root pass), Fig. 2. Welding parameters are chosen so that the heat input is 17–26 kJ/cm in all cases except in the last one (50% He), where it was 13–17 kJ/cm (Table 4). Interpass weld and the pre-heating temperature was at least 110°C, Table 4.

Table 5. Flaws detected by non-destructive testing.
Tabela 5. Prikaz grešaka identifikovanih ispitivanjima bez razaranja

Protective gas type	Description of defect	Plate mark
Ar-plate is not overheat	-on the side of the root is defect 40 mm length -individual and group porosity in weld metal	0
Ar	- no defects on the side of the face - on the side of the root is one defect of the root - individual porosity in weld metal	4
Ar + 0.015%N ₂	- no defects on the side of the face - on the side of the root are two defects of the root - individual porosity in weld metal	2
Ar + 15%He + 0.015%N ₂	- no defects on the side of the face - on the side of the root is one defect of the root - without porosity in weld metal	1
Ar + 30%He + 0.015%N ₂	- on the side of the root is one defect of root in the centre of weld - without porosity in weld metal	3
Ar + 50%He + 0.015%N ₂	- no defects on the side of the face - on the side of the root are three defects of the root - without porosity in weld metal	5

Table 6. Results of impact testing.
Tabela 6. Rezultati udarnih ispitivanja

Shielding gas	Specimen No.	Room temperature			-196°C
		E_t (J)	E_{in} (J)	E_{gr} (J)	E_u (J)
Ar	1	32	11	21	7.5
	2	31	11	20	7
	3	31	11	20	7
Ar + 0.015%N ₂	1	25	10	15	6
	2	24	9	15	6.5
	3	24	10	14	6
Ar + 15%He + 0.015%N ₂	1	24	10	14	6.5
	2	26	11	15	8.5
	3	24	10	14	6.5
Ar + 30%He + 0.015%N ₂	1	19	8	11	8
	2	21	9	12	6.5
	3	21	9	12	7
Ar + 50%He + 0.015%N ₂	1	36	12	24	8
	2	32	11	21	7
	3	35	11	24	9

RESULTS AND DISCUSSION

Standard X-ray non-destructive testing is performed. Results are given in Table 5 and discussed in more detail elsewhere. Attention should be paid on the in-line porosity, as indicated in Table 6 for the plate, as a possible initiation site for crack-like defects.

Impact testing using instrumented Charpy pendulum and specimens with 2 mm V notch in the base metal (BM) and weld metal (WM) is done at room temperature (20°C) and at low temperature (-196°C), according to the standards EN 10045 and ASTM E 23-95. The total impact energy (E_u) is divided into the crack initiation energy (E_{in}) and crack propagation energy (E_{lom}), as shown in Table 6, except for the -196°C tests (values are too small), /3, 4/.

The highest impact energy, both for crack initiation and propagation, at room temperature, is obtained for the gas mixture Ar + 50%He + 0.015%N₂, indicating toughness at the level of the BM, whereas the lowest impact energy for the gas mixture Ar + 30%He + 0.015%N₂ is in agreement with other results.

The fracture toughness of weld metal was tested at room temperature, using 3 point bending specimens. Results are shown in Fig. 3, as diagramme K_{Ic} vs shielding gas mixture.

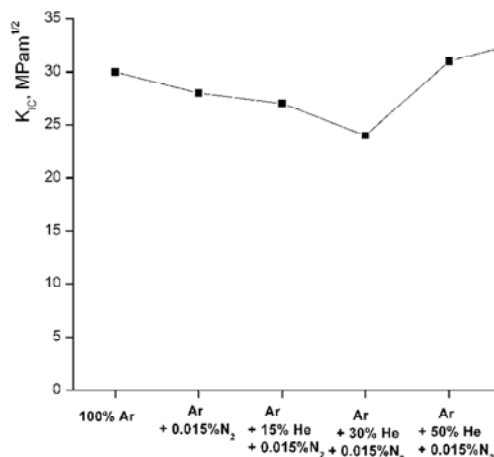


Figure 3. Shielding gas vs. fracture toughness K_{Ic} .
Slika 3. Zaštitni gas i žilavost loma K_{Ic}

The highest value of K_{Ic} is observed for the shielding atmosphere Ar + 50%He + 0.015%N₂ (31 MPa√m). Addition of nitrogen to pure argon affects the mild decrease of K_{Ic} (30 MPa√m for 100%Ar and 28 MPa√m for Ar + 0.015%N₂), Fig. 3.

The estimation of fatigue crack growth rate dependency, da/dN , requires defining the coefficient C and exponent m in Paris' equation. Based on testing results, dependencies $da/dN-\Delta K$ are calculated and presented in Table 7. In this table, the values of the fatigue threshold ΔK_{th} are also given, next to the crack growth rate da/dN , for all the zones of the stable crack growth on the Paris curve, /5/. The diagrams in Fig. 4 show the dependence between the crack growth rate, da/dN -strain intensity range ΔK .

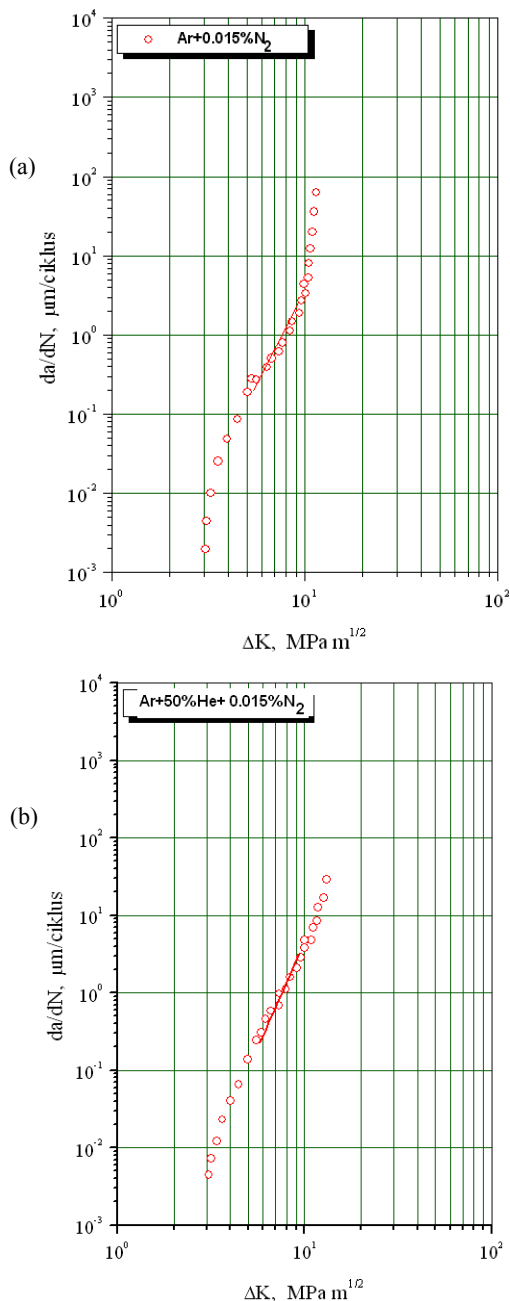


Figure 4. Diagrams $da/dN-\Delta K$ for weld metal: (a) Ar + 0.015%N₂ and (b) Ar + 50%He + 0.015%N₂.

Slika 4. Dijagrami zavisnosti $da/dN-\Delta K$ za metal šava: (a) Ar + 0.015%N₂ i (b) Ar + 50%He + 0.015%N₂

Analyzing the results, it becomes obvious that the lowest fatigue crack growth rate, da/dN , e.g. the highest resistance to the crack growth of the existing crack is found in the

weld metal with the shielding atmosphere Ar + 50%He + 0.015%N₂. In practice this means that the initiated crack will propagate three to four times faster, which will lead to weld failure in the other two samples, /6/. In other words, the shielding atmosphere Ar + 50%He + 0.015%N₂ provides the highest resistance to crack growth.

Table 7. Coefficients in the Paris equation for sample welds.

Tabela 7. Parametri relacije Parisa za zavarene epruvete

Shielding atmosphere	ΔK_{th} (MPa $\sqrt{\text{m}}$)	Coef. C	Expon. m	da/dN (m/cycle) $\Delta K = 7 \text{ MPa}\sqrt{\text{m}}$
Ar + 0.015%N ₂	3.06	$1.79 \cdot 10^{-11}$	4.96	$2.78 \cdot 10^{-7}$
Ar + 50%He + 0.015%N ₂	3.09	$2.13 \cdot 10^{-11}$	4.74	$2.16 \cdot 10^{-7}$

CONCLUSIONS

Based on the results presented and discussed, one can conclude the following:

Pre-heating above 100°C is necessary, even for a relatively small thickness (12 mm) in order to reduce porosity.

Adding only N₂ does not influence significantly the weld quality, but further addition of He reduces porosity and improves weld shape, leading to better mechanical properties, as well. The best results are obtained by using the gas mixture Ar + 50%He + 0.015%N₂.

The worst mechanical properties are obtained for gas mixture Ar + 30%He + 0.015%N₂, requiring further investigation.

The crack initiation energy is not influenced by welding procedure, neither by testing temperature, nor the composition of shielding atmosphere. These parameters only affect the total impact energy and crack propagation energy.

The highest value of the critical stress intensity factor K_{Ic} , i.e. the maximal allowed critical crack length has the weld metal in Ar + 50%He + 0.015%N₂ (31 MPa $\sqrt{\text{m}}$).

The testing temperature and the shielding atmosphere composition affect the total impact energy and crack growth energy. The crack initiation energy does not depend significantly on the testing temperature nor on the shielding atmosphere composition. The highest toughness and crack growth energy at all testing temperatures are found for the shielding atmosphere Ar + 50%He + 0.015%N₂.

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