

Susceptibility to corrosion of welded AlMgSi alloy EN AW 6060

In this paper electrochemical studies on welding joints of commercial extruded Al-alloy EN AW 6060 have been performed in order to evaluate corrosion behavior in solution of 3.5 mass.% NaCl. Potentiodynamic techniques like Tafel polarization and cyclic anodic polarization were employed in order to monitor the general corrosion resistance and pitting susceptibility.

Results have shown that weld zone has cathodic character compared to the base alloy, so that passive corrosion current is higher, while pitting potential E_{pit} and repassivation potential E_{rp} are lower for specimens made from welded AlMgSi coupons.

Key words: Corrosion of welded AlMgSi alloy EN AW-6060; Chloride medium

1. INTRODUCTION

In constructions of Al-alloys welding is the most frequently used joining technique, and the heat input required to weld aluminium alloys is larger than the heat input required to weld steels [1,2]. The larger heat input is caused by the substantially higher thermal conductivity of the aluminium alloys. When welding aluminium alloys, it should be realised that the commercial alloys often show large differences in thermal conductivity. Generally speaking, the thermal conductivity of a lower Mg concentration alloy, e.g. the AA6060 alloy, is much better than the thermal conductivity of a higher Mg concentration alloy, e.g. the AA5083 alloy. Welded alloys of the 6xxx series are more sensitive to hot cracking than the alloys of the 5xxx series. The tendency of solidification cracking can be minimised by using a proper composition of the filler metal. For this reason the Al-Mg alloys are frequently welded with the filler metal ER5356 (AlMg5) [1].

The alloy EN AW-6060 (AlMgSi0.5) is heat treatable corrosion resistant alloy, especially in atmospheric conditions. It is suitable for wrought and extrusion processing, with the possibility of making very complex shapes [3]. The alloy is available in several versions with different amounts of silicon and magnesium added in order to optimize different properties such as mechanical characteristics, surface appearance, suitability for anodizing, etc. Aluminium alloy 6060 is commonly used for architectural sections for

windows, doors, curtain walls, interior fittings, lighting, furniture and office equipment, and structural applications where surface finish is important. Average hardness and strength can be further improved by adding copper and silicon to aluminium matrix. By heat treatment (whether artificial or natural aging), further improvements of hardness and strength can be achieved [4,5]. Good weldability and deformability in cold rolled state make it an excellent choice for application in vehicles. However, like other aluminum alloys, in aggressive media it is susceptible to general and pitting corrosion [6].

2. EXPERIMENT

2.1 Material

From commercial semi-finished extruded aluminium profiles rectangular in cross section and 2mm thick, test specimens measuring 30 mm x 80 mm x 2 mm were machined and welded with filler metal AlMg5 [4].

Chemical composition of EN AW-6060 identified by optical emission spectrometer [7] was as follow (mass %): Al-98.72, Si-0.49, Mg-0.45, Fe-0.21, Mn-0.02 while mechanical properties were in accordance with the 6xxx series.

Welding procedure used in this experiment was TIG AlMg5.

2.2 Electrochemical testing

Electrochemical measurements were performed in electrochemical cell consisting of three electrodes. Platinum is used as counter electrode, while the referent electrode was saturated calomel electrode (SCE). Rectangular specimens made from basic material and those with weld bead placed in the center of the coupons served as working electrodes, with exposed circular area of 3.14 cm². Before each measurement specimens were mechanically and chemically treated. They were sanded with grit sandpaper

Author's address: ¹⁾University of Split; Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, Split, Croatia, ²⁾University of Zagreb; Faculty of Metallurgy, Aleja narodnih heroja 3, Sisak, Croatia, ³⁾Head of Environmental protection office at Šibensko – Kninska county, Šibenik, Croatia

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400, 500, 600 and 1000. In order to remove the surface oxide layer and eventually incorporated impurities, the specimens were cleaned for 1 minute in alkaline solution (0.1 M NaOH at 40 °C), then rinsed in distilled water, and as quickly as possible placed in the electrochemical cell.

Corrosion properties were studied in 3.5 mas % NaCl solution at room temperature (22 °C ± 2 °C). Solution was deaerated by blowing purified nitrogen (5N) into the reactor for 15 minutes before the start of testing, and above the solution during the experiments. Electrochemical measurements were carried out using a computer controlled Potentiostat/Galvanostat (PARSTAT 2273), managed with appropriate software PowerSuite. To study the corrosion behavior of alloy EN AW 6060 and for the determination of electrochemical parameters the following methods are used:

- open circuit potential (E_{ocp}) monitoring
- linear potentiodynamic polarization (Tafel polarization) in the potential range ± 250 mV vs E_{ocp} , scan rate 2 mV/s
- anodic cyclic polarization starting from -1.0 V to -0.2 V in the anodic direction and back again, scan rate 10 mV/s

2.3 Metallography

Surface morphology was observed by optical microscope Olympus GX 51 with digital camera Olympus DP70. Etching was done according to procedure outlined in [8].

3. RESULTS AND DISCUSSION

3.1. Open Circuit potential (E_{ocp})

Time dependence of the open circuit potential (E_{ocp}) in deaerated 3.5 % NaCl at room temperature was monitored for a period of 1 h and 1/2 h. It was found that E_{ocp} was stabilized after 15 min at a potential of -800 mV and -778 mV for unwelded and welded EN AW 6060, respectively, Figure 1.

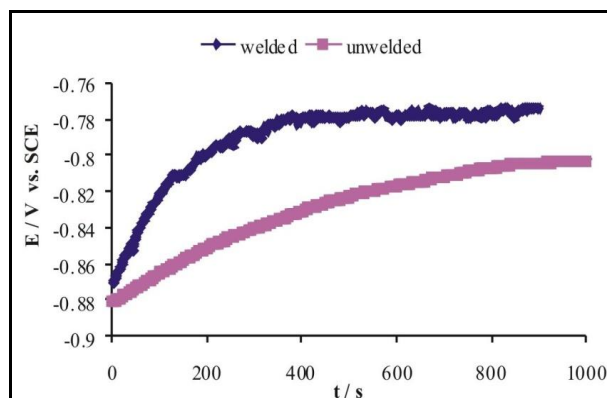


Figure 1 - Variation of open circuit potential (E_{ocp}) of EN AW 6060 in deaerated 3.5% NaCl as a function of time

This curves show that after a significant evolution of the free potential towards higher values, it stabilizes around a value of -800 mV and -778 mV for unwelded and welded specimens, respectively. More noble E_{ocp} for specimen with weld bead impose the conclusion that weld material behaves more cathodic when compared to base metal. The indicated values were taken for further experiments, and time for the stabilization of system is set at 30 min. Testing time lasted for couple of hours, therefore it was found that system stabilises after fifteen minutes.

3.2. Linear polarization

Characteristic polarization curves recorded in Tafel region can be observed in Figure 2 while characteristic electrochemical parameters obtained from these polarization curves are shown in Table 1.

Specimens with weld bead have shown the positive shift of E_{corr} , suggesting cathodic character of weldment. However, higher j_{corr} and v_{corr} were determined for the welded specimen relative to nonwelded one. Characteristic values of E_{corr} from Table 1 served as a starting point for the next testing.

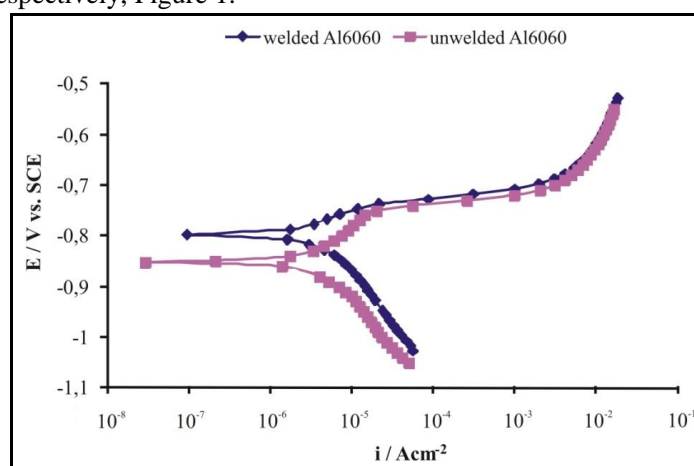


Figure 2 - Potentiodynamic polarization curves of alloy EN AW 6060 in deaerated 3.5% NaCl

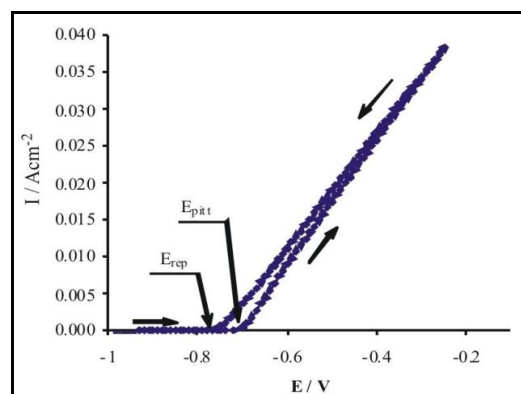
Table 1 - Electrochemical parameters of alloy EN AW 6060 in deaerated 3.5% NaCl

Specimen	E_{ocp} , V	E_{corr} , V	b_a , mV/dec.	b_c , mV/dec	j_{corr} , μAcm^{-2}	v_{corr} , mma^{-1}
EN AW 6060	-0.800	-0.853	90.2	176.3	3.91	1.385×10^{-2}
Welded EN AW 6060	-0.778	-0.802	260.2	211.9	5.21	1.847×10^{-2}

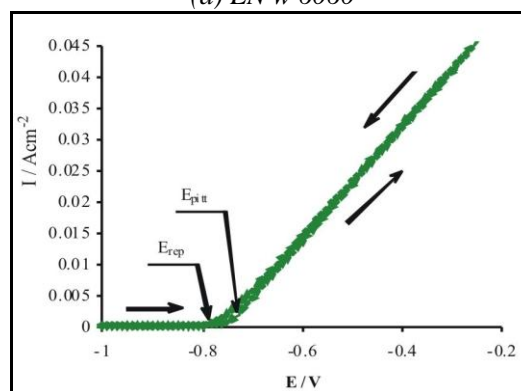
3.3 Anodic cyclic polarization

In order to accurately determine the potential area in which the sample behaves passively and an area where there is an active dissolution, the measurements were carried out with anodic cyclic polarization. From the curves in Figure 3, it is possible to determine the characteristic parameters (Table 2) of materials prone to passivation, i.e. the pitting potential (E_{pit}) at which the breakdown of passive layer starts, and repassivation potential (E_{rep}) where again a passive state is re-established. Ability of repassivation is manifested by gradual reduction of the current polarization, which is known as hysteresis loop ($E_{hys} = E_{pit} - E_{rep}$): the narrower the loop, the material is prone to repassivation (at the experimental conditions used).

It is visible in Figure 3 that the reverse polarization curves have standard cyclic behavior with area enclosed by hysteresis loop. The lower value of E_{hys} (52 mV relative to 153 mV) suggests that welded specimen repassivates more easily. However, according to E_{pit} value, its pitting susceptibility is higher. Evidently, the corrosion behaviour of welded EN AW 6060 was largely controlled not only by its nobler E_{ocp} and E_{corr} but also by the microstructural constituents present on the surface of this material.



(a) EN w 6060



(b) welded EN AW 6060

Figure 3 - Typical anodic polarization curves in deaerated 3.5% NaCl for alloy EN AW 6060

Table 2 - Electrochemical parameters determined from anodic polarization curves in deaerated 3.5% NaCl

Specimen	E_{corr} , mV	E_{pits} , V	E_{rep} , V	E_{hys} , V	I_{pass} , μA
EN AW 6060	-0.853	-0.700	-0.800	0.153	88.5
Welded EN AW 6060	-0.802	-0.750	-0.790	0.052	250.0

Comparison of electrochemical parameters in Table 1 and Table 2 enables to conclude that cathodic character of welded specimen is not the guarantee for its better corrosion resistance.

The reason for such electrochemical behaviour was revealed by metallography.

3.4. Metallography

Weld bead and corrosion pits formed on the surface of alloy EN AW 6060 are shown in Figure 4.

Metallographic analyses revealed microstructural peculiarities of base metal and welded area like surface porosity and heterogeneity, especially in heat affected zone.

Figure 4c illustrates that weld exhibits a smaller grain size than base metal while equiaxed grains in heat affected zone are characterized with numerous particles of secondary intermetallic phases. Their presence on the surface of the alloy favors the

formation microgalvanic cells resulting in pitting corrosion [9].

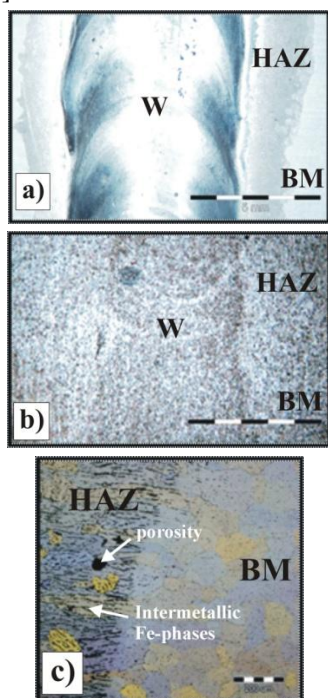


Figure 4 - Optical micrographs of alloy EN AW 6060: (a) weld bead in plain view; (b) pitting after cyclic anodic polarization in 3.5% NaCl; (c) particles of Fe-rich intermetallic phases (Barker etching, polarized light, tint-filter); W-weld metal, BM-base metal; HAZ- heat affected zone

Numerous pits are visible along the fusion line of welded zone in Figure 4b. It is obvious that welding process has led to melting and mixing of the filler metal with basic material, resulting in additional complexity in the distribution of intermetallic compounds in the microstructure. The former studies with local corrosion of AlMg alloys [8] have shown that particles containing iron, like α -Al(FeSi,Mn) as cathodes in local microcorrosion cells.

4. CONCLUSIONS

- On the basis of electrochemical and metallographic studies of EN AW 6060 alloy it was found that in 3.5% NaCl both, unwelded and welded specimens are prone to general and pitting corrosion.
- Electrochemical tests and values obtained for E_{ocp} and E_{corr} have shown that welded specimens have cathodic character compared to the base alloy. However, weld bead on the surface of alloy EN AW 6060 contributes to its heterogeneity, so that higher corrosion rate and pitting susceptibility are recorded for welded specimens.
- The results indicated that welded EN AW 6060 is more prone to pitting corrosion due to the presence of intermetallic phases in the heat affected zone of the alloy that favor the formation microgalvanic cells.

5. REFERENCES

- [1] T. Luijendijk, Journal of Materials Processing Technology 103 (2000) 29 -35.
- [2] V. Panchal, A. Patel, N. Shah, Zastita materijala 53, 1 (2012) 15-24.
- [3] C. Vargel, Corrosion of Aluminium, Elsevier Ltd., Amsterdam, 2004.
- [4] URL:http://www.sallu.me/OOO_Salume/OOO_%22Salume%22_files/Data_6060.pdf
- [5] D.Vuksanovic,D.Radonjic,D.Boricic,Z.Cvijovic,Lj.Pavlovic, Zastita materijala 49, 1 (2008) 51-57.
- [6] Z. Szklarska-Smialowska, Corrosion Science 41 (1999) 1743-1767.
- [7] R. Mimica, J. Radošević, S. Slavica-Matešić, Strojarstvo 53 (2011) 271-275.
- [8] N. Dolić, J. Malina, A. Begić Hadžipašić, J. Min. Metall.-B 47 (2011) 79-87.
- [9] A. Aballe, M. Bethencourt, F.J. Botana, M.J. Cano, M. Marcos, Corros. Sci. 45 (2003) 161–180.

IZVOD

SKLONOST KOROZIJI ZAVARENE AlMgSi LEGURE EN AW 6060

U ovom članku provedena su elektrokemijska ispitivanja na zavarenim spojevima komercijalne, ekstrudirane Al-legure EN AW-6060 u cilju procjene korozijskog ponašanja u otopini s 3.5% - tim masenim udjelom NaCl. Potenciodinamičke tehnike poput Tafel polarizacije i cikličke anodne polarizacije primijenjene su u cilju promatranja otpornosti na opću koroziju i sklonosti pojavi pitinga. Rezultati su pokazali da zona zavara ima katodni karakter u usporedbi s osnovnom legurom tako da je struja pasivacije veća, dok su piting potencijal E_{pit} i repasivacijski potencijal E_{rp} niži za uzorke izrađene iz zavarenih AlMgSi pločica.

Ključne riječi: Korozija zavarene AlMgSi legure EN AW-6060; Kloridni medij

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