

## **MECHANICAL PROPERTIES AND STRESS CORROSION OF ELECTRON BEAM MELTING THROUGH JOINT OF AlMg3 ALLOY**

### **ABSTRACT**

This paper presents the test results on selection of parameters of electron beam welding of 12 mm thickness sheets of AlMg3 aluminum alloy. The influence of electron beam melting through of sheets on their mechanical properties was tested as well as resistance to stress corrosion cracking and resistance to corrosion in fast sea water flow (10 m/s). The slow strain rate stress corrosion tests in the air and artificial sea water were performed. It was found that electron beam melting through of the AlMg3 alloy does not decrease the mechanical properties in comparison to the native material. AlMg3 alloy melting with electron beam shows a very good stress corrosion resistance.

*Key words:* electron beam welding, aluminium alloy, stress corrosion

### **INTRODUCTION**

Electron beam welding, called electron welding consists in penetrating the elements being welded with heat obtained from the elements' bombardment in vacuum with concentrated electron beam of high energy up to  $1.5 \times 10^5$  W/mm<sup>2</sup> [1]. Concentration of the electron beam of high kinetic energy in a very small space results in generating the heat of high concentration causing melting of material in high depth. During the metal melting the electron beam makes a narrow weld of little heat affected zone (HAZ). A very large density of electron beam power and the possibility to adjust it accurately and flexibly allow for making welds in one passage up to 250 mm thick in case of steel and up to 450 mm thick in case of aluminum; the relation between the weld's height to its width ranges from 1:1 to 50:1 [1]. High heat conduction of aluminum alloys does not affect the welding process since high concentration of electron beam power heats the welded element quasi-adiabatically. Oxidation is liquidated and hydrogen porosity limited in the welding process due to application of vacuum. Electron welding is in principle the welding process with no additional material. All the aluminum alloys welded in arc welding may undergo electron welding [1]. The welds made by the electron beam joint are cleaner than the native material because during the melting process the gases coming from the welding pool are continuously released.

### **SELECTION OF WELDING PARAMETERS**

The sheets of 5754 H111 [AlMg3] alloy of 12 mm thickness were used in the tests. Before the joints were made for further tests, preliminary tests were carried out to determine optimal parameters of welding. As electron welding most often consists in melting through the alloy

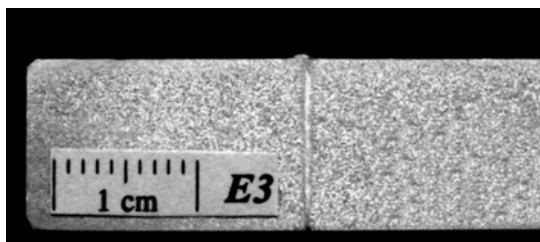
without any additional material it has been assumed that the root of the weld should be placed in solid material which to some extent corresponds to the so called insert welding [3]. In that case the possible defects of the bottom and the root of the weld do not affect the joint's qualities. Therefore the defects were not subject of research. The welding conditions were selected taking into account the quality of the weld assessed on the grounds of the course of the melting through process, shape of the weld's face, depth of melting and structure of the weld.

The beam electron melting through was carried out in vacuum by means of the welding machine WS-15 KW/100 KV (Przemyslowy Instytut Elektroniki) [3]. Before melting the sheets were degreased in tetrachloroethylene and oxides were removed with 15% solution  $\text{Na}_2\text{CO}_3$ . The applied parameters during the tests are presented in Table 1, while the selected structures after macroscopic tests are presented in Figure 1÷6. The samples, for macroscopic tests, were etched with the following reagents:  $\text{Ma6Al}$  and  $\text{Ma1Al}$  pursuant to PN-75/H-04512.

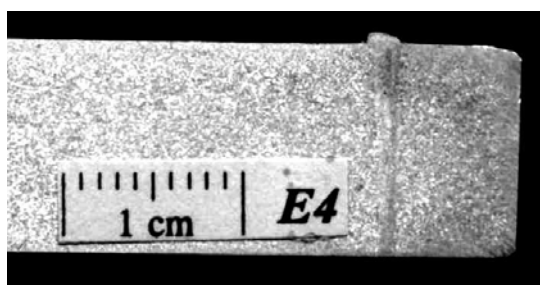
**Table 1.** Parameters of electron beam welding of AlMg3 alloy

Sample marking	$U_a$ [KV]	$J_a$ [mA]	$J_o$ [mA]	$V_s$ [cm/min]	Beam oscillation		K [KW]	Fig. No
					F [Hz]	A [mm]		
E3	72,5	60	12,3	100	812	0,2	4,35	Fig. 1
E4	72,5	60	12,3	100	812	0,5	4,35	Fig. 2
E5	72,5	60	12,6	100	812	0,5	4,35	Fig. 3
E6	72,5	55	12,3	100	812	0,5	3,99	Fig. 4
E7	72,5	55	12,45	100	812	0,5	3,99	Fig. 5
E3(404)	72,5	52	10,85	100	812	0,5	3,77	Fig. 6

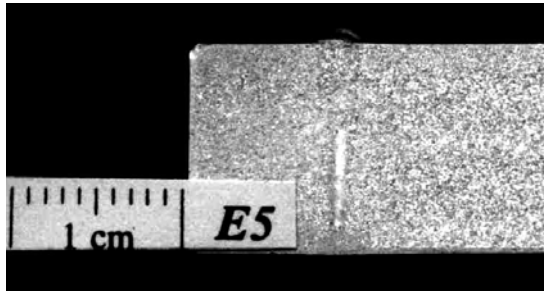
$U_a$  – anode voltage,  $J_a$  – beam current,  $J_o$  – focusing current,  $V_s$  – welding speed, F – frequency, A – amplitude, K – beam's power



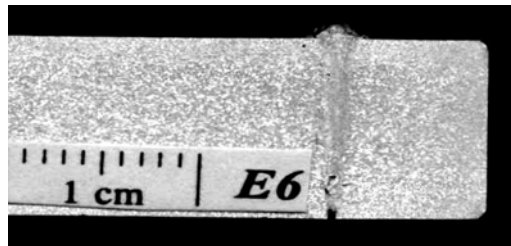
**Fig. 1.** AlMg3 alloy melting with electron beam through the sheet. The face of the weld is concave, up to 2,2 mm wide. Narrow weld of equal width. The root effluent all over the melting length.



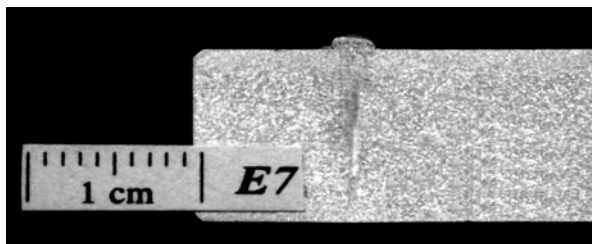
**Fig. 2.** Melting all over the thick sheet. The weld's face is convex, 2,9 mm wide. The concave face with numerous effluents.



**Fig. 3.** Not-complete melting, 11 mm deep. The weld's face of 3,5 mm width is flat-convex alternating. The weld is becoming narrow towards the root which is found in the solid material.



**Fig. 4.** Throughout melting. The weld's face is 3,3 mm wide. The face is melting in points with effluents.



**Fig. 5.** Not-complete melting up to 9,6 mm thick. The face is 2,4 mm wide, convex.



**Fig. 6.** The melting depth approximately 8 mm. The face is 3,5 mm wide. There are two little ball-like air sacs  $\phi$  0,2 mm (2011) pursuant to PN-EN 30042:1994.

The sheets made of AlMg3 alloy were melting through for further tests, according to the assumptions, so that the weld's root was placed in the solid material, applying the same parameters which were used for E5 sample – according to Table 1.

The tests to welding the AlMg4,5Mn alloy, of larger content of magnesium, with electron beam failed. The welds were porous with many air sacs. It was also difficult to obtain vacuum in the welding machine. The alloy components of high vapor pressure - Mg, Zn, Mn - might have been the reasons for such difficulties. Low pressure results in degassing of chemical elements of high vapor pressure causing porosity of the weld and unstable operation of the welding machine.

### TESTS OF MECHANICAL PROPERTIES

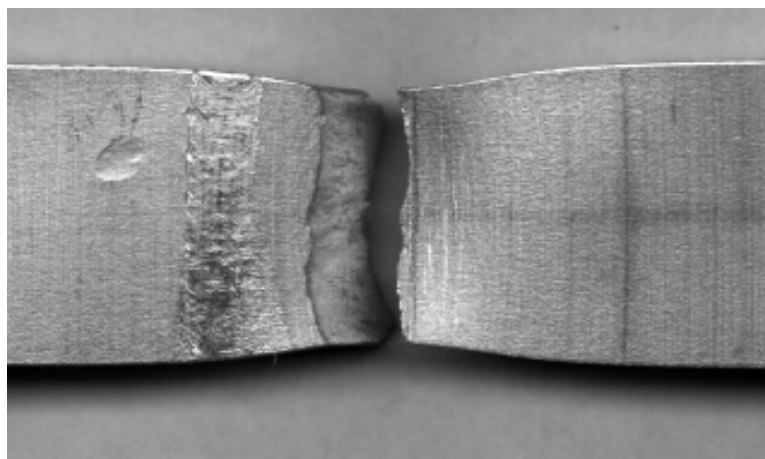
Tests of mechanical properties of the native material were carried out on flat samples,  $g = 12$  mm thick, according to PN-91/H-04310. The results are presented in Table 2.

Tests of mechanical properties of the welded joints were performed pursuant to the standard PN-EN 895:1995 and PN-EN 10002-1+ACI:1998. The ambient temperature during the test was 21.5 °C. The sample's dimensions were set up according to PN. The mechanical properties of the tested materials are presented in Table 2.

**Table 2.** Mechanical properties of the native material and the alloy melting through with electron beam (average values from four samples).

Material	Tensile strength	Yield strength	Elongation
	[MPa]	[MPa]	[%]
AlMg3 / native material	201	110	26.8
AlMg3 / melting with electron beam	200.2	116.5	26.7

Melting through with electron beam of AlMg3 alloy in vacuum did not affect the mechanical properties in any way in comparison to the native material. The crack during the static tension test had ductile character and proceeded in the native material (Fig. 7).



**Fig. 7.** The sample after the static tension test with a visible place of electron beam melting.

## TESTS OF CORROSION RESISTANCE

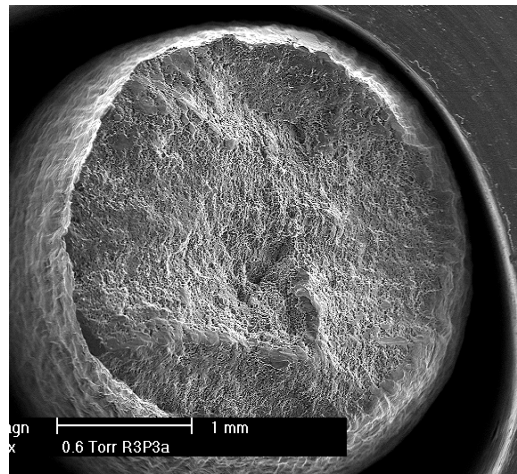
The stress corrosion tests were carried out with the slow strain rate test ( $10^{-6} \text{ s}^{-1}$ ), pursuant to PN-EN ISO 7539-7. The parameters measured during the tests included : time to failure – T [h], obtained maximum load – F [N], fracture energy (the surface of the diagram under strain-elongation curve) – E [ $\text{MJ/m}^3$ ], the sample's relative elongation -  $A_{10}$  [%], max. tensile stress – R [MPa] and reduction-in-area – Z [%]. The tests were performed on smooth cylindrical samples in air (air) and artificial sea water (NaCl). The fracture area was analyzed by means of electron scanning microscope. The objective of the tests was to determine the influence of electron melting through of AlMg3 alloy sheet to corrosion stress resistance in artificial sea water.

The test results of resistance to stress corrosion cracking in the native material and the samples melting with electron beam (Ele) are presented in Table 3 which provides the average values of four measurements.

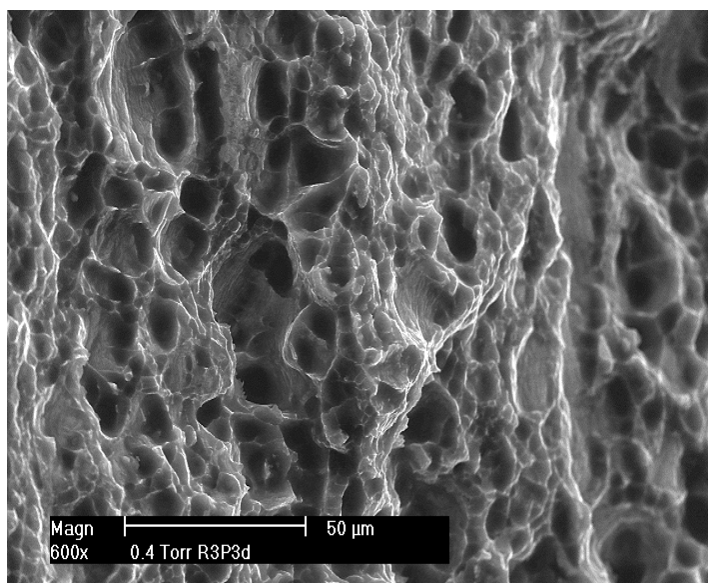
**Table 3.** Results of slow strain rate tests of AlMg3 alloy and AlMg3 alloy melting through with electron beam (Ele) in the air (air) and sea water (NaCl).

Alloy	T.S. [MPa]	Fracture energy [ $\text{MJ/m}^3$ ]	Elongation $A_{10}$ [%]	Reduction- in-area Z [%]	Time to failure [h]
AlMg3-air	203,8	44,85	24,40	62,3	40,7
AlMg3-NaCl	203,3	42,80	24,72	63,3	40,9
AlMg3/Ele-air	201,0	41,17	23,72	62,0	39,4
AlMg3/Ele-NaCl	202,5	43,54	24,60	60,4	40,9

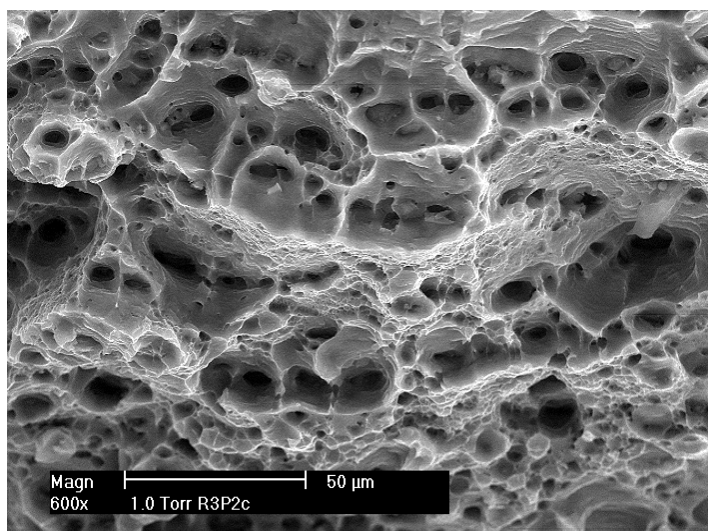
The results proved a very good resistance to stress corrosion of AlMg3 alloy. The values of the measured particular parameters obtained during exposure in the air as well as artificial sea water vary. In case of the samples strained in air the fracture area showed deformation of the solid solution, proceeding destruction of the sample. Visible numerous dimples and different stages of microvoids' coalescence are the evidence. (Fig. 8÷10). For the samples strained in the artificial sea water morphology of the observed fractures was very close to that appearing in the samples strained in the air.



**Fig. 8.** The sample strained in the air. Ductile cracking in the native material.



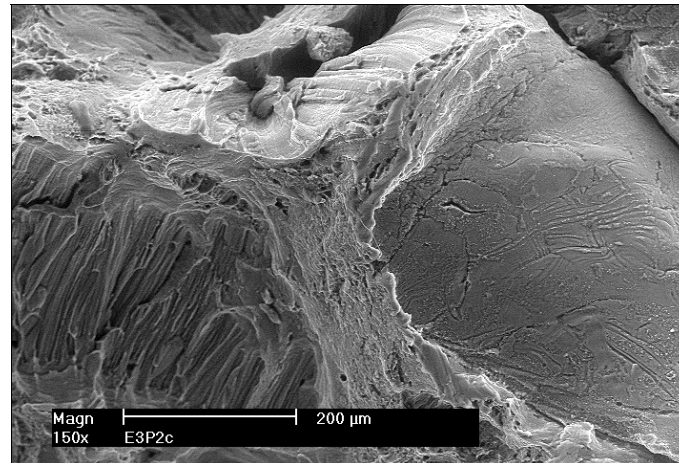
**Fig. 9.** A piece of fracture from Fig. 8. The fracture-in-area with bands of dimples in the region of solid solution.



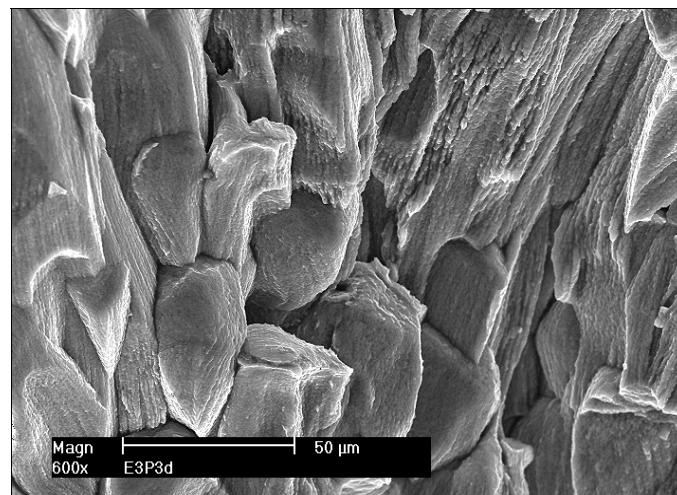
**Fig. 10.** Ductile fracture of the native material of AlMg3 alloy.

The AlMg3 alloy samples melting with electron beam plastic cracked in the native material beyond the place of melting. The samples' fractures were similar to the fractures obtained in AlMg3 alloy.

Two tested samples melting with electron beam cracked in the line of melting through. The reason for this quasi-fissile cracking were the defects (incomplete fusion) caused by the process of melting. The fractures with the defects are seen in Figures 11÷12.



**Fig. 11.** The sample broken in the place of electron beam melting with a little defect (incomplete fusion).



**Fig. 12.** The sample broken in the electron beam melting. Inter-crystal 'stony' fracture.

The tests for resistance in fast flow sea water consisted in exposure of the joints melting with electron beam in the so called centrifuge which ensures flow of water along the sample surface at a speed of 10 m/s. The objective of test was to determine the degree of corrosion (accelerated dynamic method) and its location in the joint's area.

Samples of 200 × 80 mm were tested [4]. They were cut off crosswise up to the place of melting through. The weld was in the sample's axle and went along the short side of the sample. The front surface of the sample was polished and degreased immediately before the test. The samples were fixed in a container with artificial sea water where an agitator was placed speeding the water up to 10 m/s in relation to the immobile samples. The container received fresh sea water continuously. The salinity of the sea water was approximately 0.7%. The water temperature during the test comprised between 20°C and 30°C. The test in mobile sea water took 1000 hours.

After completion of the tests the samples were dismantled, the products of corrosion removed and the depth of corrosion decrements measured with accuracy of 0.01 mm. After the test the sample looked as shown in Fig. 13.

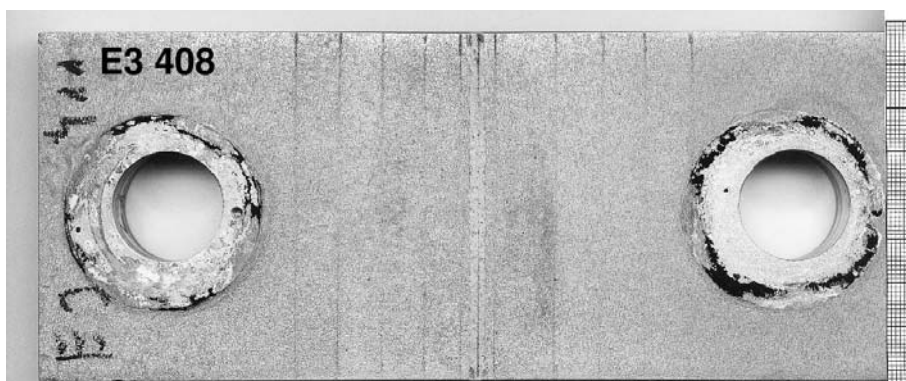


Fig. 13. The sample after corrosion tests. AlMg3 material melting through with electron beam [4]

For the samples made of AlMg3 alloys melting through with electron beam no corrosion decrements were found. This means that the resistance to corrosion in fast flow of sea water is very good.

## CONCLUSIONS

The tests allowed for drawing the following conclusions:

1. It is possible to weld AlMg3 alloy with electron beam by melting through of the material using no additional materials. The alloy melting does not affect negatively in tensile tests properties. The samples (apart from those with macrodefects) cracked in the native material beyond the place of melting.
2. The AlMg3 alloy sheets melting through with electron beam show a similar resistance to stress corrosion in the sea water as the native material and very good resistance to corrosion in fast flow sea water.

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