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Slow-strain-rate stress corrosion testing of friction stir welded joints of Al-Mg alloys*

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The specimens of friction stir welding AlMg4,5Mn and ALUSTAR alloys were tensed at slow strain rate (10^{-6} s^{-1}) in air and seawater. The tensile strength, elongation, time-to-failure, reduction-in-area and fracture energy were measured. Low susceptibility of the bonds examined to stress corrosion cracking was observed.

1. INTRODUCTION

The technology of friction stir welding (FSW) was produced and patented in 1991 in the Welding Institute (TWI) in Cambridge, Great Britain [1]. A special tool with a rotary mandrel placed in the joining place of the sheets was used to heat and soften the material. After putting the mandrel into motion, heating it with friction heat and softening the sheets in the mandrel's direct neighborhood the whole system is moving slowly along the joint line. (Fig. 1).

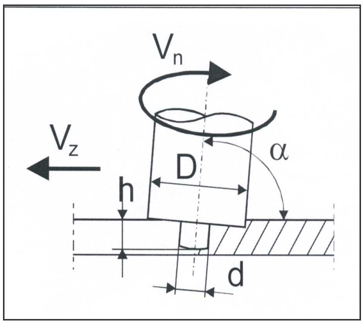

Fig. 1. Diagram of friction stir welding FSW [3]

FSW represents a method of welding in the solid state, in particular, aluminum and copper. The main advantage of FSW method is the easiness to obtain joints of high repeatable properties [2, 3]. In comparison to traditional welding, the welding line energy in FSW is very low which results in little deformations and reduction of thermal tensions [2].

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The resistance properties of the tested Al-Mg alloys welded by FSW method are higher ($R_m$of weld/$R_m$native material = 0.92) than those of the joints welded by the traditional method MIG [4]. This technology may be applied to join aluminum alloys in shipping industry where group of 5xxx series alloys still remains the most popular one. The friction stir welding may be applied provided that the FSW welded joints have a good resistance to stress corrosion in sea water. The objective of this study is to test the susceptibility of FSW welded 5xxx series aluminum alloys joints to stress corrosion in sodium chloride.

2. EXPERIMENTAL PROCEDURE

The following alloys used in marine constructions were tested: 5083 [AlMg4,5Mn] H321 (R_m = 346 MPa; $R_{0.2}$ = 270 MPa; A_{10} = 19.7%) and the new alloy (ALUSTAR) 5059 H321 [AlMg5MnZn] (R_m = 401 MPa; $R_{0.2}$ = 280 MPa; A_{10} = 16.2%). The sheets were welded front on both sides [5]. The welding parameters (Fig. 1) are presented in table 1.

Table 1
Welding parameters of FSW technology of Al-Mg aluminum alloy sheets [4,5]

Alloy	Passage number	Mandrel's dimensions			Mandrel's rotary speed V_n [rev./min]	Welding speed V_z [mm/min]
		D [mm]	D [mm]	H [mm]		
AlMg4,5Mn	I	20,0	6,0	6,0	900	140
	II	20,0	6,0	3,0	900	180
ALUSTAR	I	20,0	6,0	6,0	560	180
	II	20,0	6,0	3,0	560	180

The surface of the resistance ring of the material softening tool was inclined towards the sheet's surface under the angle of 2°. The test proved that the weld's structure was correct – with the nuclei overlapping one another (double welding operation) and with no breaks in the material that was plastically deformed [4].

The stress corrosion tests were carried out by means of the slow strain rate test - SSRT (10^{-6} s^{-1}) according to PN-EN ISO 7539-7. The following parameters were measured during the tests: time-to-failure – T [h], obtained max. load – F [N]; fracture energy (the diagram surface under the tension-elongation curve) – E [MJ/m^3]; relative elongation of the sample – A_{10} [%]; max. tensile stress – R [MPa] and reduction-in-area – Z [%]. The tests were carried out on smooth cylindrical samples in the air and artificial sea water. The fractures were analyzed by electron scanning microscope of Philips XL 30 type.

3. RESULTS AND CONCLUSIONS

The tensile test results carried out in the air (marked – air) and NaCl solution (marked - NaCl) were presented for particular measured parameters in figures 2 – 3 showing their mean values from 4 - 5 measurements and standard deviations. The examples of the samples' characteristic fractures after the corrosion stress tests are presented in figures 4 – 5.

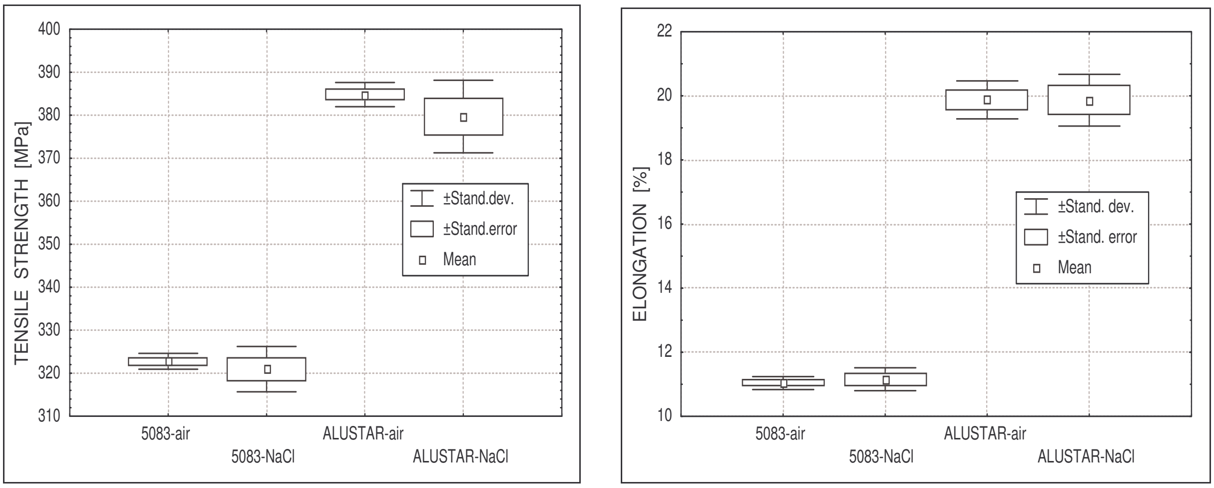

Fig. 2. Tensile strength and elongation of Al-Mg alloys welded by FSW method obtained in the slow strain rate test in the air (air) and artificial sea water (NaCl).

On the grounds of the obtained test results it is found that AlMg4,5Mn alloys and ALUSTAR alloy friction stir welded (FSW) are resistant to stress corrosion in sea water. The values of particular measured parameters obtained in the air and artificial sea water for every tested alloy do not vary (Fig. 2 and 3). The tests in the conditions of free stable deviation (10^{-6} s^{-1}) and corrosion environment showed that the sheets made of ALUSTAR alloy welded by FSW method have got better resistance properties in comparison to AlMg4,5Mn alloy welded by FSW method with comparable, good resistance to stress corrosion.

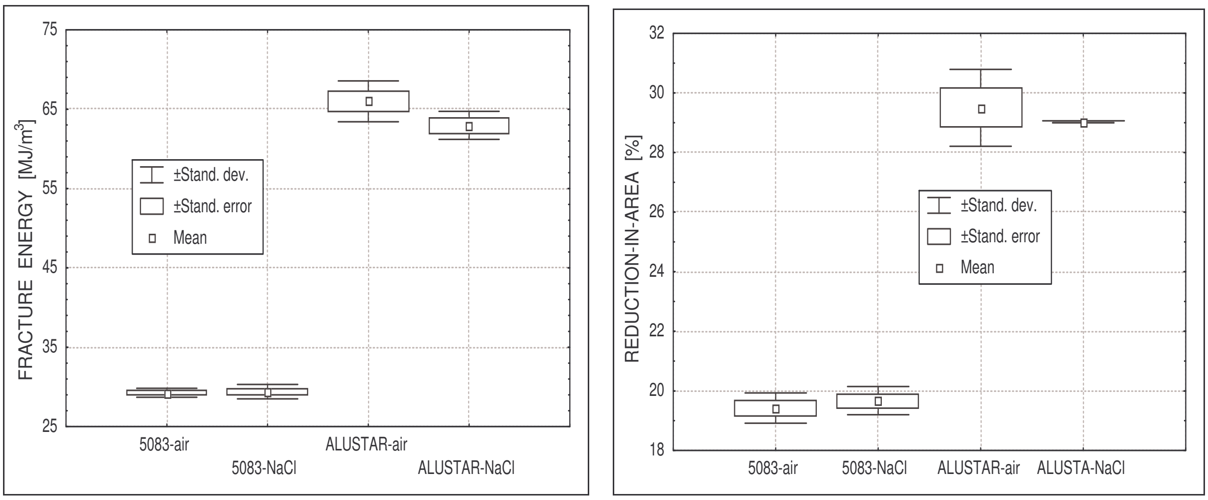

Fig. 3. Strain energy and reduction-in-area obtained in SSRT test of Al-Mg alloys welded by FSW method.

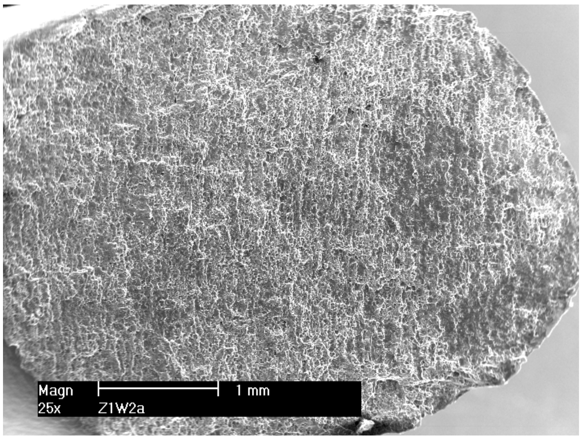

Fig. 4. 5083 alloy welded by FSW method damaged in sea water. The fracture surface with cutting area and ductile fracture zone.

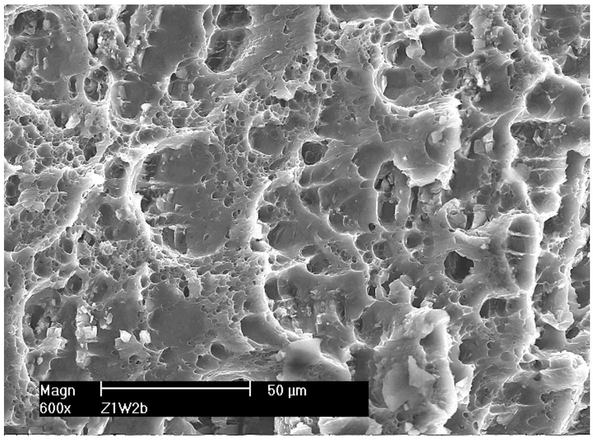

Fig. 5. Fragment of the fracture shown in Fig. 4. The fracture surface with bands of dimples parallel to the cutting direction.

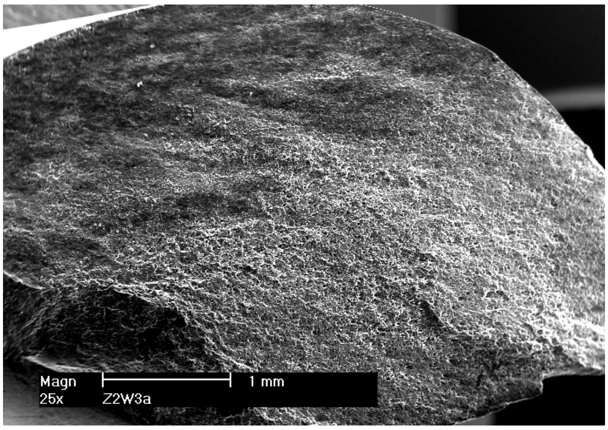

Fig. 6. ALUSTAR alloy FSW. The fracture surface was created by cutting, with bands of dimples parallel to the cutting direction.

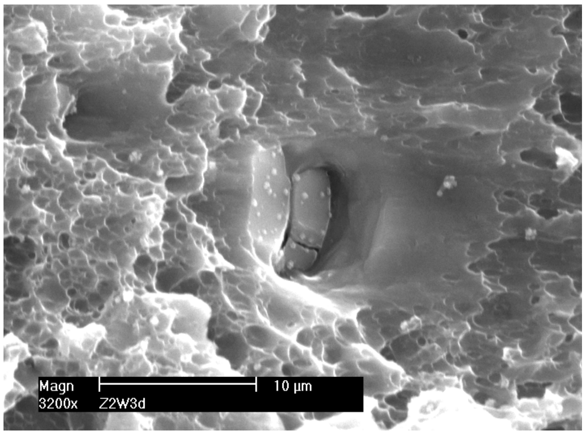

Fig. 7. Fragment of Fig. 6. The area of dimples; a large dimple around the cracked particles of inter-metallic phases is seen.

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