Journal of KONES Powertrain and Transport, Vol. 21, No. 3 2014

ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1133154
DOI: 10.5604/12314005.1133154

STRESS CORROSION CRACKING OF WELDED JOINTS OF Al-Mg ALLOYS

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Abstract

Slow strain rate testing (SSRT) was used to test the stress corrosion cracking (SCC) of aluminium alloys AW 5083 and AW 5059 (Alustar) jointed by friction stir welding (FSW). The test was carried out in the air and 3.5% water solution NaCl. Cylindrical notch-free specimens and cylindrical notched specimens (R = 5 mm) were used. The following parameters were measured: time-to-failure – T [h], obtained max. load – F [N]; strain energy (the diagram surface under the stress-elongation curve) – E [MAJ/m^3]; relative elongation of the specimen – $A_{11.3}$ [%]; max. tensile stress – R [MPa] and narrowing – Z [%]. On the basis of obtained results, it was noted that FSW-welded joints show superior strength and resistance to stress corrosion, compared to MIG-welded joints. The fractions after SSRT testing were cleaved with some ductile areas. This article also gives the mechanical features of friction stir welded Al-Mg alloys. Tests have shown that the 5059 alloy, welded by FSW, has superior strength properties compared to the FSW 5083 alloy, along with comparable, good resistance to stress corrosion. FSW 5083 alloy joints have very good resistance to stress corrosion - better than those made using traditional welding methods (MUG).

Original value are received results of the stress corrosion resistance of new method friction stir welded Al-Mg alloy compared with traditional MIG method.

Keywords: *stress corrosion cracking, welding, aluminium alloy, friction stir welding (FSW)*

1. Introduction

Al-Mg alloys, especially their welded joints, may be subject to various forms of damage during use, depending on external factors. The most common form of damage taken from the environment, and the most discussed in literature, often leading to destruction (cracking) of the material, is stress corrosion. Resistance of alloys from the Al-Mg group to corrosion depends on their chemical composition and on the production technology of these alloys [1, 2, 8]. The solubility of magnesium in aluminium in solid state, at ambient temperature is around 1.4%. At higher magnesium content in the alloy, intermetallic phase Al_3Mg_2 (or Al_8Mg_5) appears which makes a strong anode for the solid solution's grains. The paper [8] shows a clearly visible effect of magnesium content in Al-Mg alloys on the tendency towards intercrystalline corrosion. Alloys containing up to 3% Mg are considered as resistant to this kind of damage. At higher magnesium content, Al-Mg alloys may – following improper heat treatment – contain concentrated deposits of the Al_3Mg_2 phase and undergo intercrystalline or stress corrosion. This however, ultimately depends on the production technology, the final temperature and the duration of annealing. The 5083 alloy (AlMg4.5Mn) is regarded as fully resistant to corrosion.

Susceptibility to damage by the environment clearly increases in the area of the joint and the adjacent area. Degradation of welded joints depends on the type of additional material and welding technology. Results of stress corrosion resistance, fatigue strength as well as fatigue-and-corrosion resistance tests for Al-Mg alloys welded using traditional MIG and TIG methods, can be found in literature. There is, however, no information regarding damage to Al-Mg alloys welded using modern methods, such as friction stir welding (FSW). Available literature offers a few elaborations on resistance to corrosion in a water solution of NaCl for Al-Cu alloys (from the 2xxx group) or

Al-Zn alloys (from the 7xxx group) welded using the FSW method [5, 6]. There are no elaborations comparing the stress corrodibility of FSW-welded Al-Mg joints (from the 5xxx group) with joints obtained using traditional welding methods (MIG). The purpose of this paper is to compare the stress corrodibility of the 5083 alloy with that of the new 5059 (Alustar) alloy, MIG and FSW welded. This will allow us to find an optimal welding method, which will ensure high strength and resistance to stress corrosion.

2. The research methodology

Material for research

The following alloys used in marine constructions were tested: 5083 H321 and AW 5059 H321 (Alustar). The chemical composition of the alloys in % of weights is given in Tab. 1.

Tab. 1. Chemical composition of tested aluminum alloy (wt.%)

Chemical composition (%)										
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
AW-5059	0.037	0.092	0.011	0.767	5.411	0.003	0.57	0.024	0.114	rest
AW-5083	0.195	0.18	0.09	0.66	4.74	0.11	0.042	0.02	0.003	rest

Some plates made from 5059 (Alustar) alloy were butt-welded in an inert (argon) gas shield using MIG method, while others were butt-welded using friction stir welding (FSW) method. The welding technologies and parameters have been presented in earlier publications [4].The test proved that the joint's structure was correct – with the nuclei overlapping one another (double welding operation) and with no breaks in the material that was plastically deformed (Fig. 1).

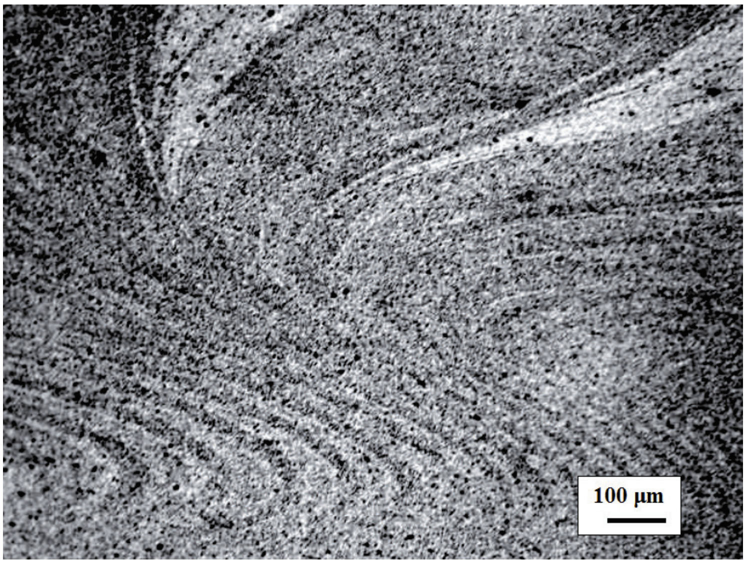

Fig. 1. Microstructure of the weld's nugget of 5083 alloy [4]

Slow-strain rate testing (SSRT)

Stress corrosion cracking was examined via the slow-strain-rate-testing (10^{-6} s^{-1}) according to EN ISO 7539-7. The following parameters were measured: time-to-failure – T [h], obtained max. load – F [N]; strain energy (the diagram surface under the stress-elongation curve) – E [MJ/m^3]; relative elongation of the specimen – $A_{11.3}$ [%]; max. tensile stress – R [MPa] and narrowing – Z [%]. The tests were carried out on cylindrical notch-free specimens with diameter d = 5 mm and measured length of L_0 = 50 mm. Before testing, the specimens were deoiled. The fractures were analysed by electron scanning microscope of Philips XL 30 type.

3. The research results

Tensile properties

The test results of mechanical properties of the native material and welded joints carried out in flat samples (according to EN 895:1995) are presented in Tab. 2.

Tab. 2. Mechanical properties of the native material and welded joints Al-Mg (average value from two-four specimens) [4]

Material	UTS [MPa]	YS [MPa]	EL [%]
5083/native material	346	270	19.7
5083/FSW	322.2	238.3	10.4
5083/MIG	282	206	15.1
5059/native material	401	280	16.2
5059/FSW	367.3	278.4	12.7
5059/MIG	296.0	192.7	7.6

where: UTS – ultimate tensile strength, YS – yield stress, EL – elongation.

The resistance properties of the tested Al-Mg alloys welded by FSW are higher ($UTS_{weld}/UTS_{native\ material}$ = 0.92) than those of the joints welded by traditional MIG method.

Results of SSRT

Table 3 presents results of evaluations of stress corrodibility for Al-Mg alloys and their MIG- and FSW-welded joints, defined as average percentage of decrease in the values measured when examining parameter values obtained in a corrosive environment, and compared to those obtained in air. Susceptibility to damage caused by stress corrosion has been determined according to the relation [4]:

$$K_x = (1 - X_{scc}/X_{pow}) \text{ x } 100\%,$$

where:
K_x – stress corrodibility [%],
X – value of the measured parameter during tests in a sea water equivalent (SCC) or in air (air).

Tab. 3. Stress corrodibility of welded Al-Mg alloys [4]

Alloy/Welding method	K_R [%]	K_E [%]	K_T [%]	K_A [%]	K_Z [%]
5059	0.43	13.0	6.6	11.55	0
5059/MIG	1.5	4.75	3.3	2.66	1.0
5059/FSW	1.33	3.2	1.38	1.5	2.0
5083	0.23	2.5	3.3	0.4	0.43
5083/MIG	2.23	4.6	0.4	0.7	0
5083/FSW	0.55	0	0.6	0	0

where: K_R – average% of maximum load decrease at the instant of specimen failure, K_E – average% of strain energy decrease, K_T – average% of time-to-failure decrease, K_A – average% of elongation decrease at the instant of specimen failure, K_Z – average% of narrowing width decrease.

The results of SSRT tests carried out in the air (marked – air) and NaCl solution (marked – NaCl) were shown in graphical form on Fig. 2.

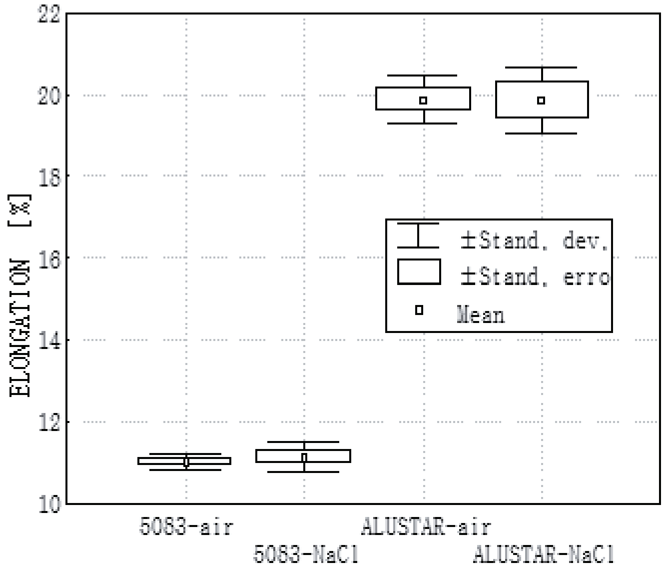

Fig. 2. Elongation of Al-Mg alloys by FSW obtained in the slow-strain testing in the air (air) and artificial seawater (NaCl)

During the SSRT tests, FSW-welded joints cracked between crystals, shearing along the welding line, between the native material and the welded joint (Fig. 3). Specimens made from MIG-welded joints cracked along the joint with a ductile fracture (Fig. 4).

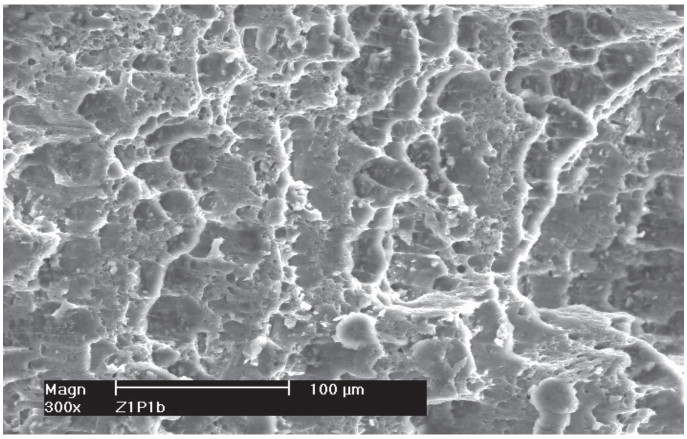

Fig. 3. Fracture of 5083 alloy by FSW, after being exposed in the air, of mixed character

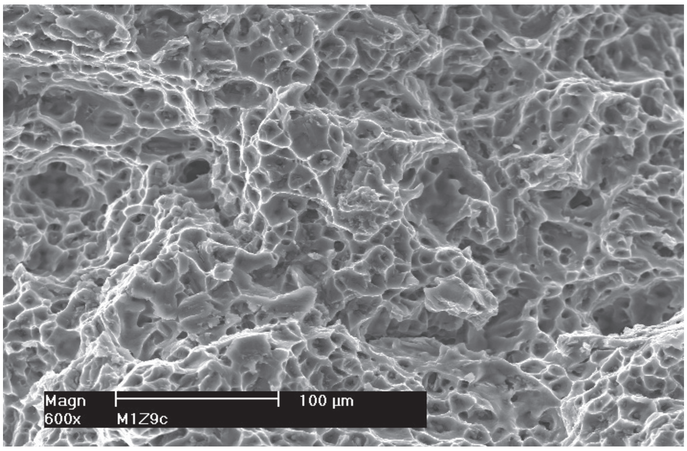

Fig. 4. Fracture of 5083 alloy welded by MIG

4. Summary

On the basis of obtained test results, it can be said that FSW-welded 5083 (AlMg4.5Mn) alloys and 5059 (Alustar) alloys are resistant to stress corrosion in seawater. The values of particular parameters, measured in air and in artificial seawater for each of the tested alloys, do not differ. Tests in slow-strain-rate-testing 10^{-6} s^{-1} and corrosive conditions have shown that the 5059 (Alustar) alloy, welded by FSW method, has superior strength properties compared to the FSW-welded AlMg4.5Mn alloy, along with comparable, good resistance to stress corrosion.

Among the tested 5058 and 5059 alloy joints, FSW-welded joints show the best resistance to stress corrosion. Elongation of specimens made from 5059 (Alustar) alloy, welded by FSW method, pulled in equivalent sea water, decreased only by 1.5% compared to specimens tested in air. Decrease of elongation value for MIG-welded joints was 2.66%. Similarly, FSW-welded AW 5083 alloy joints have very good resistance to stress corrosion – better than those made using traditional welding methods (MIG).

An important parameter of constant strain rate testing is duration of exposure (time to specimen failure). Average times to failure, for the 5059 (Alustar) alloy and welded joints, obtained in stress corrosion tests, are presented in Tab. 4. Considering this parameter of evaluation, the optimal method of welding for the 5059 alloy is, again, FSW welding, where average times to failure are the most similar to exposure times of the native material.

Tab. 4. Average time-to-failure of specimens, obtained during SSRT tests [4]

Alloy	time-to-failure [h]	
	Air	NaCl
Alustar	33	30.8
Alustar/FSW	28.9	28.5
Alustar/MIG	24	23.2

References

[1] Thomas, W. M., *Friction stir welding. GB patent 9125978*, 6.12.1991, International patent application PCT/GB92/02203.

[2] Eriksson, L. G., Larsson, R., *Friction Stir Welding – progress in R&D and new applications*, Svetsaren, Vol. 57, No. 2, 11-13, 2002.

[3] Eriksson, L. G., *Friction stir welding*, Svetsaren, Vol. 56, No. 2-3, 3-6, 2001.

[4] Czechowski, M., *Podatność na niszczenie środowiskowe złączy stopów Al-Mg spajanych wybranymi metodami,* Prace Naukowe Akademii Morskiej w Gdyni, Gdynia 2009.

[5] Dudzik, K., Czechowski, M., *Analysis of possible shipbuilding application of Friction Stir Welding (FSW) method to joining elements made of AlZn5Mg1 alloy*, Polish Maritime Research No. 4, 2009.

[6] Dudzik, K., *The influence of joining method of AW-7020 aluminium alloy on corrosion properties,* Journal of KONES Powertrain and Transport, Vol. 18, No. 4, Krakow 2011.

[7] Squillace, A., Fenzo, A., Giorleo, G., Bellucci, F., *A comparison between FSW and TIG welding techniques: modifications of microstructure and pitting corrosion resistance in AA 2024-T3 butt joints*, Materials Processing Technology, 152, 97-105, 2004.

[8] Davis, J. R., *Corrosion of Aluminium and Aluminium Alloys*, ASM International, Materials Park, OH, 1999.