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LOW-CYCLE FATIGUE OF Al-Mg ALLOY JOINTS

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Abstract

This article presents the results of the low-cycle fatigue tests of AW-5059 Alustar alloy. Gas metallic welding in argon arc shield was used. Metallographic analysis of bonds showed a proper structural construction MIG welded 5059 aluminum alloy.

The low-cycle fatigue tests were carried out in the air and artificial seawater (3.5% water solution NaCl), with stable amplitude of stress value. The stresses were changed in the symmetric cycle (the stress ratio was R = -1) with constant strain rate of 5mm/min and the frequencies oscillating between 0.08-0.2 Hz. During the tests the following parameters was observed: number of cycles until the specimen's destruction, upper and lower extreme values of force and strain for the selected cycles, duration-time of the test and frequency. Analysis of specimens fracture surfaces was performed with scanning electron microscope (SEM) Philips XL30.

In case of the specimens exposed in 3,5% water solution NaCl the fatigue durability is lower than the durability of specimens tested in the air. The article depicts the changes in total strain amplitude ε_{ac} [mm] depending on number of cycles [N] obtained in the tests with σ_a=const and the low-cycle fatigue resistance for the welded Alustar alloy. Original value are received results of the low-cycle fatigue tests of AW-5059 Alustar alloy welded by MIG.

Keywords: *corrosion fatigue, Al-Mg alloy, MIG welding*

1. Introduction

The argon arc shielded GTA welding and GMA welding are most frequently used methods of welding Al-Mg alloys. The susceptibility of Al-Mg alloys to hot cracking when welding decreases when the content of Mg > 2% increases [1, 10]. The joints of the welded reinforced Al-Mg alloys have got non-homogenous mechanical properties. The bigger their heterogeneity is, the bigger is the degree of cold work [1]. The joint has got worse mechanical properties since in result of the welding process it obtains the coarse-grained structure. In the heat affected zone (HAZ) the resistant properties and hardness are smaller than the properties of the native material reinforced by the cold work. This is the consequence of re-crystallization during the welding process [1, 11].

A major part of the constructions made of aluminum alloys is subject to changeable loads. During exploitation of ship hulls made of Al-Mg alloy, which are subject to dynamic changeable loads, some cracks appeared. The cracking was caused by huge technological stresses as well as considerable changeable exploitation stresses. The stresses' frequency was 0.2 Hz. They occurred in the range of limited fatigue resistance.

The technical literature often describes the results of fatigue tests made with rotary bending and elongation-stress activity, usually with high frequencies oscillating between 30–40 Hz. [1]. When the frequency of loads increases from 0.2 Hz to 40 Hz, the fatigue resistance distinctly increases, as well. [1].

During the low-cycle fatigue tests the applied stress exceed the yield point what causes substantial deformation of the material. Such deformations or stresses may occur in many industrial appliances under service conditions. For instance, such difficult conditions take place during utilizing of airplanes, pressure tanks, turbine parts, pipelines, or hulls of sea-going ships.

Aluminium alloys of 5xxx series and their welded joints show good resistance to stress corrosion cracking in seawater [3, 7, 8, 11]. Tests performed in rapid sea water flow have shown better anticorrosion resistance of Al-Mg alloys welded by the MIG method as compared to joints welded by the TIG method [4].

2. The research methodology

The tests carried out in a symmetric tension-compression cycle (R = –1) were performed on the testing machine INSTRON 1195 with a corresponding software. Low-cycle fatigue tests were performed on round cross-section specimens of diameter d = 6 mm and gauge length L_0 = 20 and cut out perpendicular to the axis of welding. The gauge was situated in the weld zone. The test was carried out with controlled stress (δ_a = const), at a constant strain rate $8*10^{-2}$ s^{-1} and frequencies in the 0.08-0.2 Hz range. Values of stress amplitude σ_a were selected in dependence on plastic strain set in the „zero" cycle from the following series: 0.08, 0.02, 0.01, 0.008, 0.005 [5, 6]. The following quantities were recorded during the tests: number of cycles to fracture, upper and lower boundary values of stress and strain for the selected cycles, time of tests duration and frequency. The tests were performed at constant temperature t = 21ºC in the air and in 3.5% NaCl solution.
To tests, a novel aluminium alloy 5059 (Alustar) [AlMg5MnZn] H321 was used. Chemical composition of the alloy is given in Tab. 1.

Tab. 1. Chemical composition of the AW-5059 [AlMg5Mn0,7] H321 alloy

Alloying components content [%] (weight)									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	B	Zr
0.037	0.092	0.011	0.767	5.411	0.003	0.571	0.025	0.001	0.114

Sheets made of ALUSTAR were welded by GMA (Gas metal-arc), popularly known as MIG welding. Both sides GMA welding was performed with application of filler material 5183 alloy. Sheets of 12 mm thickness were bevelled to X by an angle of 110^0 and 60^0 before welding.

The mechanical properties of the welded joint carried out in flat specimens (pursuant to PN – EN 895:1995) obtain the value UTS = 296 MPa, YS = 192.7 MPa, El. = 7.6 % [2].

3. The tests results and conclusions

Examples force - strain F = f(ε) diagrams acquired in tests at σ_a = const, are shown in Fig. 1 and 2. The diagrams show the static strain curve A and recorded boundary values of hysteresis loop in selected cycles N.

Amplitude of the total strain ε_{ac}, corresponding to tops of the hysteresis loop changes during tests at σ_a=const, in dependence on the cycle number N. These changes, for the selected representative test samples, are shown in Fig. 3.

Amplitude of the total strain ε_{ac} decreases at first with number of cycles N, until a stable strain (saturation) is reached. So there occurs a cyclic hardening effect [5]. The stable strains are reached after 100 to 150 cycles. After period of cyclic stability there occurs a growth of strain what indicates the initiation and propagation of the crack.

From the presented diagram for different but constant values of cyclic stress σ_a = const different values of stable strain ε_{as} are obtained. These data are used to plot a graph $\sigma_a = f(\varepsilon_{as})$, called the curve of cyclic strain [5, 6, 8]. The cyclic strain curve for the tested alloys, in logarithmic coordinates system, is shown in Fig. 4.

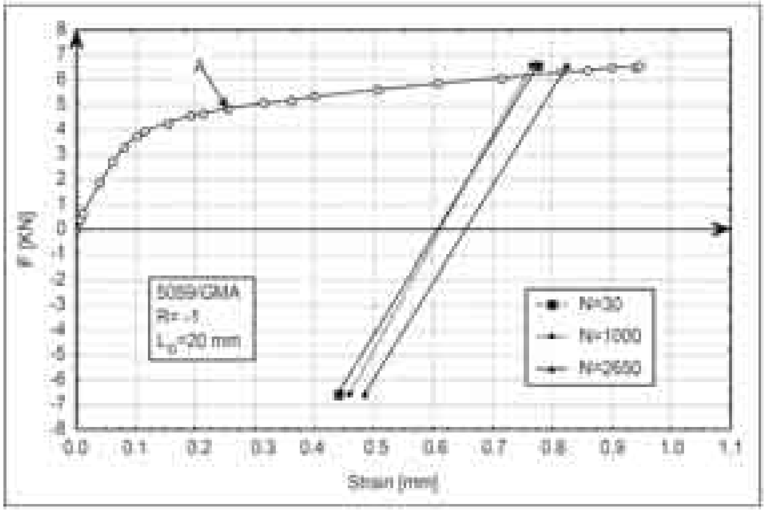

Fig. 1. Boundary points (upper and lower) of hysteresis loop for cycles N=30, 1000 and 2650 against the background of static force curve A. Tests at σ_a = const. Initial plastic strain ε_p = 0.04 (0.8mm), total ε_c = 0.948 mm

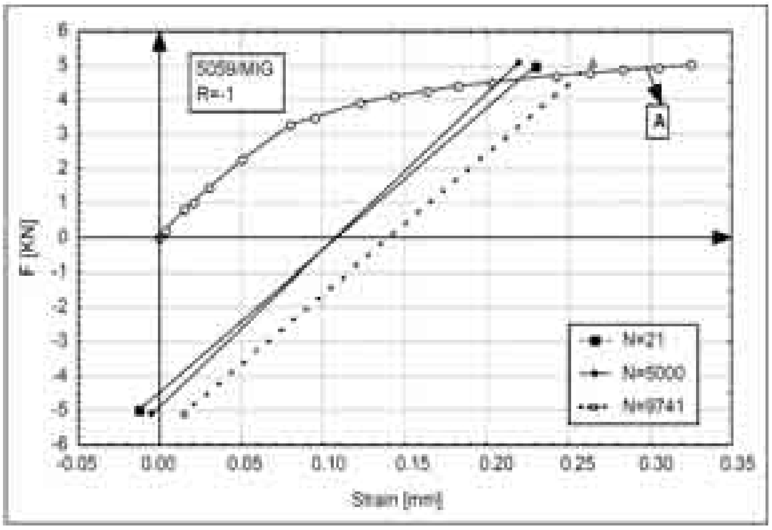

Fig.2. Boundary points (upper and lower) of hysteresis loop for cycles N=21, 5000 and 9741 against the background of static force curve A. Tests at σ_a = const. Initial plastic strain ε_p = 0.01 (0.2mm), total ε_c = 0.33 mm

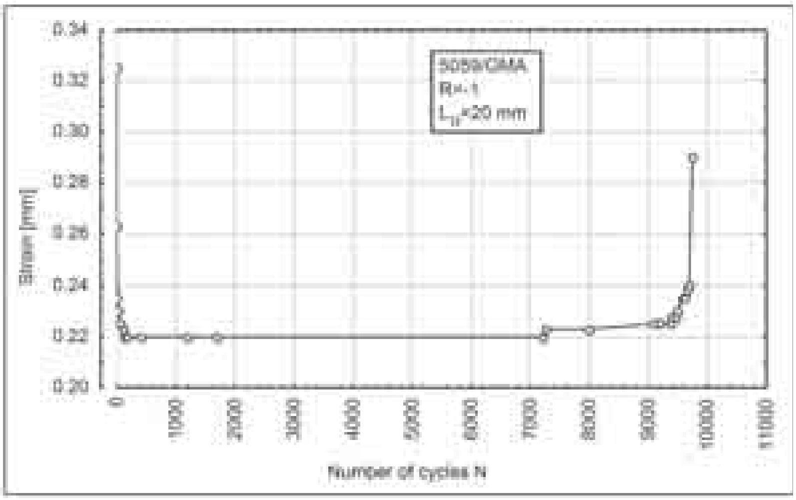

Fig. 3. Change of total strain amplitude ε_{ac} [mm] in dependence on the cycles number N obtained during the tests at σ_a=const (180.5 MPa). Initial total strain ε_c=0.33 mm. ALUSTAR alloy welded with GMA (MIG) method (see Fig. 2)

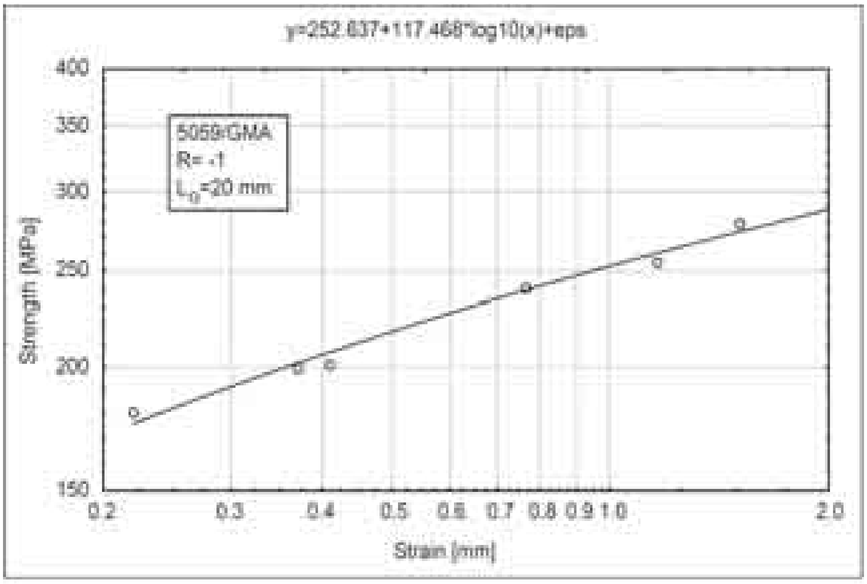

Fig. 4. Diagram of cyclic strain for ALUSTAR alloy welded with GMA method

Diagram of low-cycle fatigue life in the air and in 3.5% NaCl water solution, of the 5059 alloy welded with GMA, determined at a strain rate 0.08 s^{-1}, in symmetric tension-compression cycle at σ_a = const, is shown in Fig. 5.

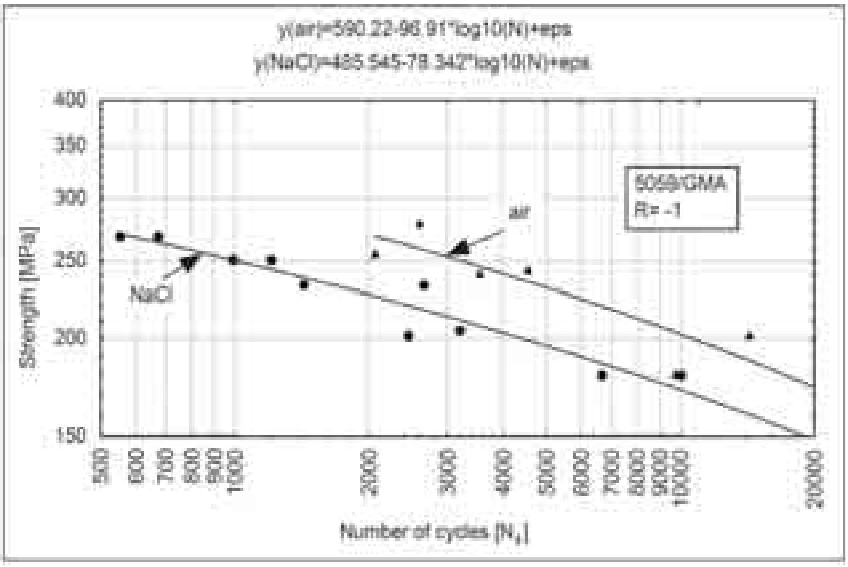

Fig. 5. Low-cycle fatigue properties of GMA-welded Alustar [5059] alloy

The time to fracture for test pieces exposed in 3.5% NaCl water solutions is lower than the time to fracture of specimens tested in the air. At greater stresses at 0.93 UTS (R_m) decrease of the time to fracture reaches up to 80%. Samples subjected to cyclic tension-compression in 3.5% NaCl solution, at stresses of 0.61 R_m, showed low-cycle strength lower by abt. 18% than specimens tested in the air at similar stresses. So the degree of the time to fracture decrease for test pieces exposed in 3.5% NaCl solution as compared to the strength of specimens tested in the air depends on the value of plastic strain. Crack initiation may occur inside cracked secretions or welding defects (Fig. 6, 7), on the surface or inside the specimen. Aggressive chloride medium inside the crack tip significantly accelerates its propagation. Fracture of test pieces occurred always in the weld.

Analysis of fracture surfaces was performed with scanning electron microscope (SEM) Philips XL 30. Typical fracture images obtained after fatigue tests are shown in Fig. 6-10.

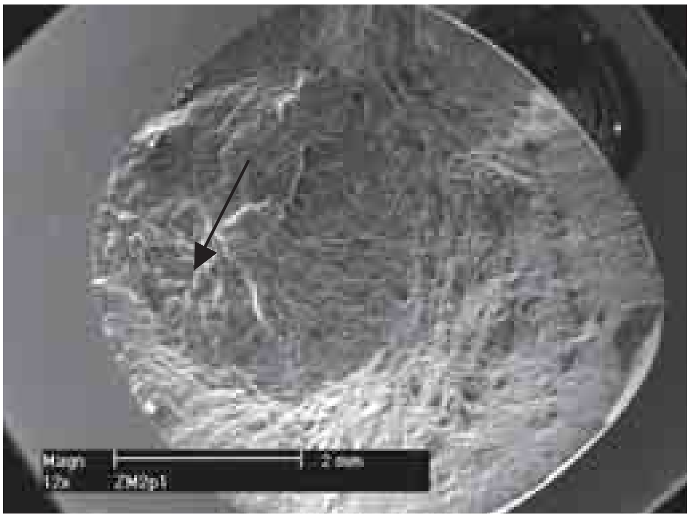

Fig. 6. *Fatigue fracture image of test specimen of 5059 alloy welded by GMA. Fatigue zone (marked with an arrow) and plastic fracture zone are visible*

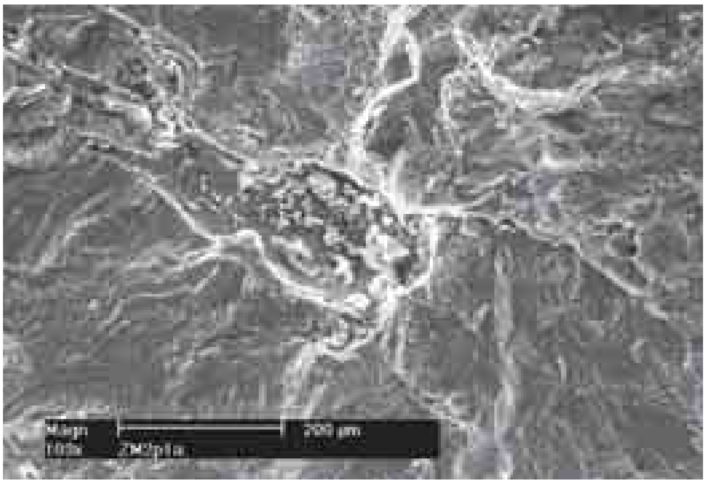

Fig. 7. Part of the fatigue fracture zone from Fig. 5. Region of fatigue crack initiation (welding defect)

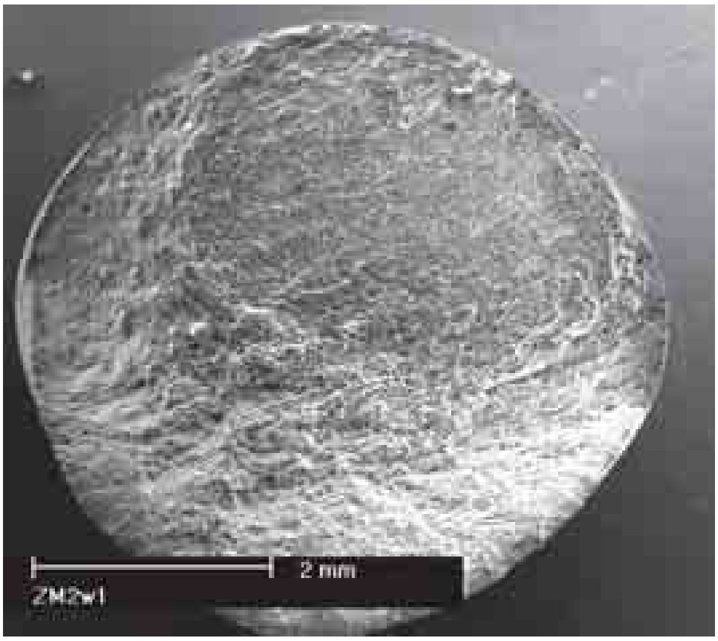

Fig. 8. Surface of fatigue crack. 5059 alloy welded with GMA method

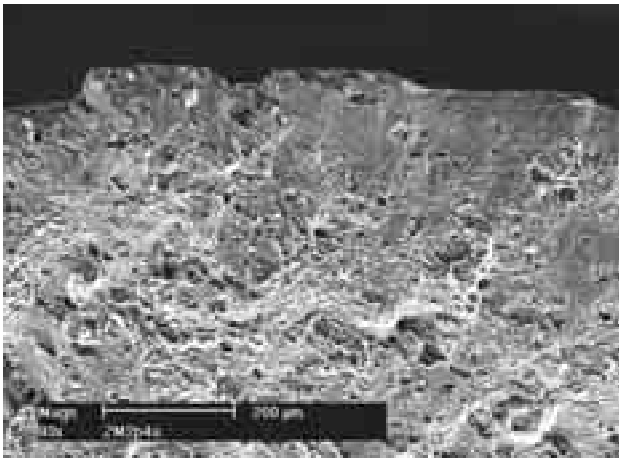

Fig. 9. Fragment of fatigue fracture at the specimen's surface

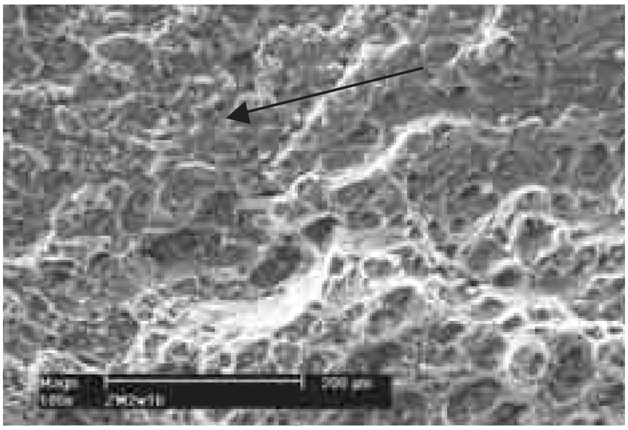

Fig. 10. Fragment of passage from the fatigue fracture (marked with an arrow) into a plastic fracture

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