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Fatigue life of friction stir welded Al-Mg alloys

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Abstract: The following alloys EN- AW 5058 H321 and EN-AW 5059 H321 (Alustar) were welded by FSW (friction stir welding) method. The FSW welds showed better properties in comparison to the joints welded by the MIG method. The low-cycle fatigue life test was carried out in the symmetric cycle: in air and in 3.5% NaCl. Fatigue life of 5083 alloy welded by FSW method, exposed in 3.5% NaCl solution was lower than that of the specimens tested in air. The Alustar alloy welded by the new FSW method demonstrated higher fatigue life in comparison to the same alloy welded by the traditional MIG method. The fatigue zone shoved cleavage fracture, changing into a plastic cracking were observed on the fracture faces of the tested specimens. The fatigue cracks crossed the weld nugget.

Keywords: Al-Mg alloy; FSW; Low-cycle fatigue;

1. INTRODUCTION

In industry the aluminium alloys welding is the most often performed in pure argon shield by GTA or MIG methods. In recent years new technologies have appeared such as friction stir welding (FSW).

The friction stir welding process, invented and patented [1] in 1991, found its application in maritime industry to join aluminium alloys [2,3,4,5]. By means of that method all the aluminium alloys may be welded without sheet beveling.

The low-cycle fatigue tests are carried out at comparatively high stresses and low frequency of stress change. Such test results reflect the conditions of exploitation of the constructions which are influenced by high loads as far as the value is concerned, yet not often repeatable, e.g. deep-sea floating units' hulls. During the low-cycle tests the material is damaged in the conditions of elastic–plastic strain.

2. EXPERIMENTAL

The following alloys used in marine constructions were tested: EN AW-5083 [AlMg4,5Mn] H321 and AW 5059 [AlMg5MnZn] H321 (Alustar). The chemical composition of the alloys and mechanical properties were given in literature [8].

The low-cycle fatigue tests of the welded alloys relied on tensile – compression cycle in constant temperature (21°C) until specimen damaged. The tests were performed in the symmetric stretching- squeezing cycle (stress ratio R = -1). The low-cycle fatigue tests were carried out on polished cylindrical specimens, with a diameter of d = 6 mm and length L_0 = 20 mm, cut off perpendicularity to the weld's axle. The length L_0 included the weld's nugget and both HAZ. The test was performed under stress control (δ_a = const), constant shift rate 5 mm/min and frequency ranged between 0.08 and 0.2 Hz. The values of the stress amplitude δ_a were chosen depending on the plastic strain imposed in the 'zero' cycle from the following series: 0.08; 0.02; 0.01; 0.008; 0.005 of the measured value L_0. During the tests number of cycles until the specimen's destruction, border upper and lower values of the strength and strains for selected cycles, test duration and frequency, were recorded.

3. RESULTS AND DISCUSSION

The welding process by FSW method causes appearance of microstructures that are not observed in other welding processes. Figure 1 show characteristic microstructure of the weld's nugget and thermo-mechanically affected zone.

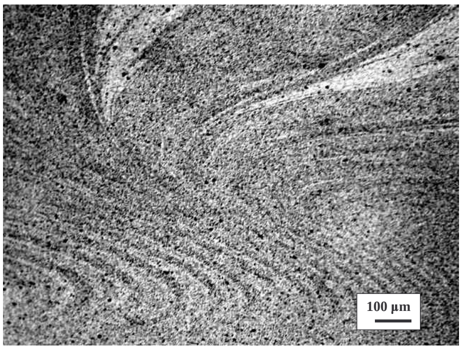

Figure 1. Microstructure of the weld's nugget of 5083 alloy

Overall strain amplitude falls initially along with the number of cycles N until the stable strain (saturation) is fixed. Cyclic hardening of the material takes place. The stable strains get fixed after 100–150 cycles. After the period of cyclic stability the strain increases, which proves development of cracking. Figure 2 presents diagrams of low-cycle fatigue life of the joints welded by FSW method of the 5058 alloy, determined in dry air (air) and 3.5% NaCl solution.

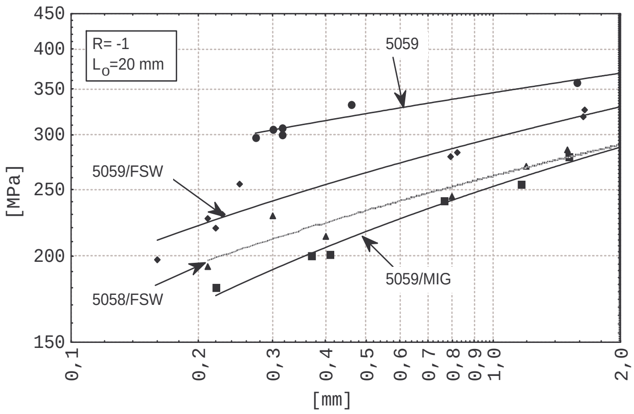

Figure 2. Diagrams of cyclic strain for the following: Alustar alloy (5059), Alustar alloy welded by FSW method (5059/FSW) and welded by MIG (5059/MIG) and AlMg4,5Mn welded by FSW (5083/FSW)

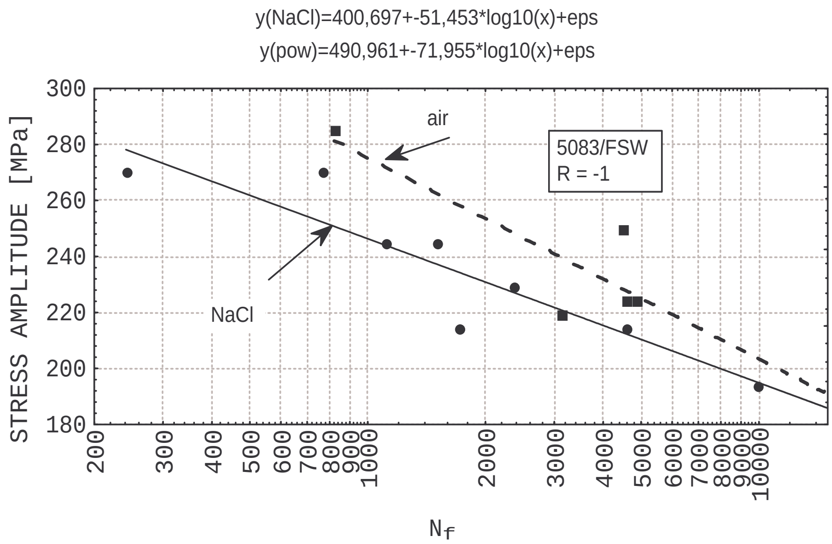

Figure 3. Low-cycle fatigue life for AlMg4,5Mn [5083] welded by FSW

The low-cycle fatigue life of the welds tested in the environments of 3.5% NaCl (Fig 3) is much lower than the fatigue life obtained in air. The corrosive environment is connected with increase in number potential points of crack initiations such as corrosion pits. The presence of aggressive environment also affects crack propagation, usually increasing the propagation by electrochemical dissolution or destruction caused by hydrogen.

Figure 4 presents collective setting-up of the low-cycle fatigue life of Alustar [5059] alloy (tested in the air), 5059 alloy welded by MIG method and 5059 alloy welded by FSW (tested in 3.5% NaCl).

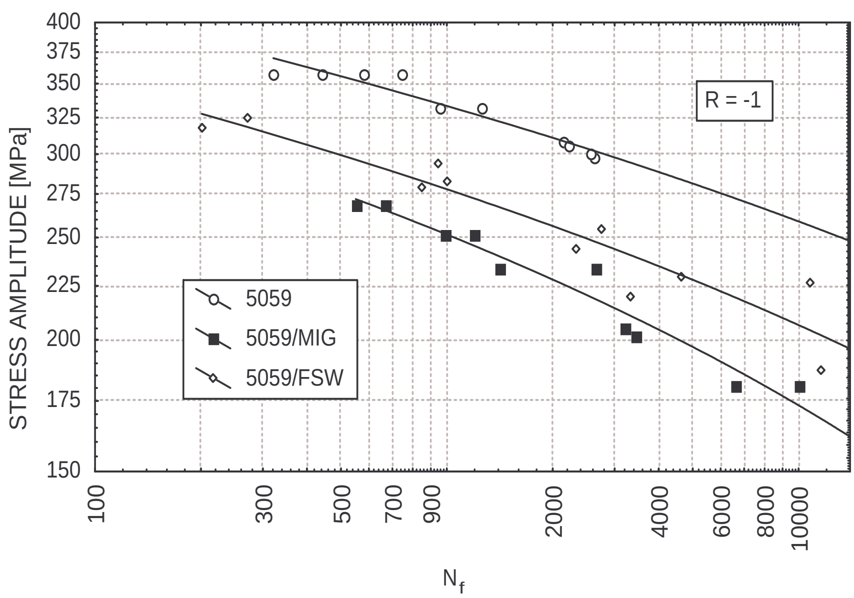

Figure 4. Low-cycle fatigue life of Alustar alloy, 5059 alloy welded by MIG and by FSW

Alustar alloy welded by the new friction stir welding method shows greater low-cycle fatigue life in comparison to the same alloy welded by MIG method.

The surface analysis of the obtained fractures was carried out on the scanning electron microscope (SEM) Philips XL30. The characteristic surfaces of the fractures of 5083 alloys and 5059 (Alustar) alloy welded with friction and stirring the weld's material (FSW), after the fatigue tests (R = -1), are presented in Figure 5 .

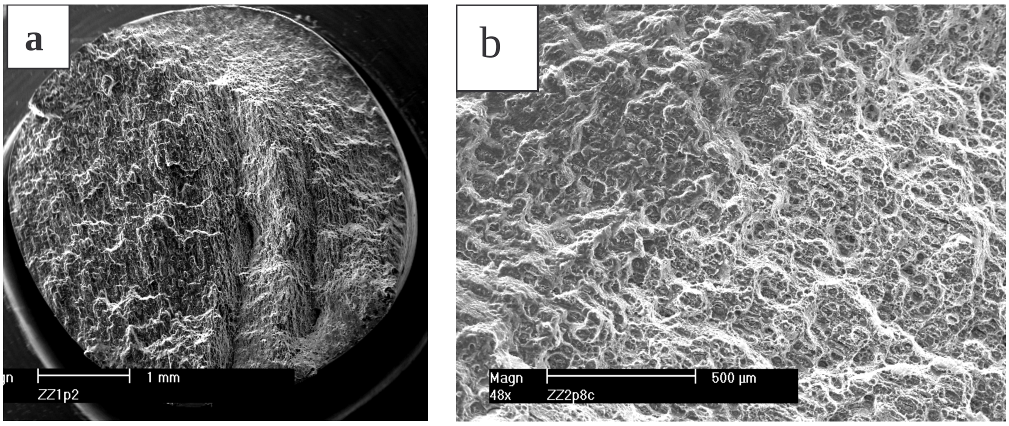

Figure 5. a) Fatigue fractures. The 5083 alloy welded by FSW method, tested in the air.
b) Border of the surface of the fatigue zone and plastic zone. The Alustar alloy welded by FSW method is damaged in the air.

The zone of fatigue has demonstrates cleavage fracture, which is turning into a plastic cracking in the fracture zone (Fig. 5), that can be easily observed on the fracture faces of tested specimens. Fatigue strips are visible on the surface of the fatigue zone. In the fracture zone, in some points, some discontinuities caused by the welding process are visible. Some cracks, which start through decohesion of interphase borders – matrix/molecule - can be seen on the surface of the specimen. The cracks are initiated by the observed microvoids which arise around particles of the fragile intermetallic phases through their cracking. Fatigue cracking most often spreads in the weld's nugget (Fig. 5).

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