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Low-cycle fatigue 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 test of microstructure proved the proper structure of the weld which consisted of following: welded nugget, thermo-mechanically affected zone (TMAZ), heat affected zone (HAZ) and unaffected material.

The surface microanalysis (EDS) showed particles containing Fe and Mn and particles containing Si and Mg in the weld nugget of 5083 alloy. These are likely to be the phases: $(Mn,Fe)Al_7$ and Mg_2Si. Particles containing Fe and Mn were visible in the weld nugget of the Alustar alloy. 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 showed cleavage fracture, changing into a ductile cracking on the fracture faces of the tested specimens. The fatigue cracks crossed the weld nugget.

Keywords: Al–Mg alloy; Friction stir welded; Low-cycle fatigue

1. Introduction

At present, Al–Mg alloys are aluminium alloys the most frequently used in shipbuilding. The mechanical properties of the Al–Mg plastically processed alloys depend on the content of magnesium in the alloy. With an increase of magnesium from 0.5 to 5% the properties increase; this rise – especially at the $R_{p0.2}$ border of plasticity – is greater when magnesium increases from 3 to 6% [1]. Al–Mg alloys with 4.5% Mg are the most common alloys used for constructing maritime structures, e.g. EN-AW 5083. Recently [2,5] a new Al–Mg Alustar alloy was made with more magnesium and better strength properties.

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 [3] in 1991, found its application in maritime industry to join aluminium alloys [4,6,7]. By means of that method all the aluminium alloys may be welded without sheet beveling.

Al–Mg alloys welded by FSW method and used in shipbuilding should have high mechanical and technological properties. Apart from the guaranteed mechanical properties, cold cracking resistance, good weldability, capability for plastic processing in cold, resistance to corrosion in the sea environment, the materials must have appropriate fatigue-corrosive durability, in particular in the scope of low-cycle regime, where the stresses exceed the yield strength.

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, yet not often repeatable, e.g. for deep-sea floating units' hulls. During the low-cycle tests the material is damaged in the conditions of elastic–plastic strain.

2. Experimental

2.1. Material

The following alloys used in marine constructions were tested: EN-AW 5083 [AlMg4,5Mn] H321 and AW 5059

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Table 1
Chemical composition of the tested aluminium alloys (wt.%)

	AW 5059	AW 5083
Si	0.037	0.195
Fe	0.092	0.18
Cu	0.011	0.09
Mn	0.767	0.66
Mg	5.411	4.74
Cr	0.003	0.11
Zn	0.57	0.042
Ti	0.024	0.02
Zr	0.114	0.003
Ni	0.004	0.005
Al	Rest	Rest

[AlMg5MnZn] H321 (Alustar). The chemical composition of the alloys is given in Table 1.

The 5059 alloy in comparison to the 5058 alloy has got increased contents of magnesium and zirconium with decreased content of silicon and iron. The tested sheets of Al–Mg alloys were welded by FSW method: double butt welding [8].

2.2. Tensile properties

The test results regarding mechanical properties of 5083 and 5059 alloys and the joins welded by FSW method carried out on flat specimens (according to EN 895:1995) are included in Table 2. Table 2 shows also mechanical properties of the 5059 alloy (Alustar) joints welded by MIG method using filler material: AA 5183 (Mg = 4.86%, Zn = 0.001%, Cu = 0.001%, Si = 0.04%, Fe = 0.12%, Mn = 0.64%, Cr = 0.07%, Ti = 0.06%, Be = 0.0002%, Al = remainder).

2.3. Low-cycle fatigue testing

The low-cycle fatigue tests of the welded alloys relied on tensile–compression cycle in constant temperature (21 °C) until the 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. Fig. 1 shows a fatigue specimens' schematic. The length L_0 included the weld's nugget and both HAZ. The test was performed under stress control ($\delta_a = \text{const}$), constant shift rate 5 mm/min and frequency ranged between 0.08 and 0.2 Hz.

Table 2
Mechanical properties of the native material and welded joints of Al–Mg alloys (average value from two to four replicates)

Material	UTS (MPa)	YS (MPa)	El. (%)
5083/native material	346	270	19.7
5083/FSW	322.2	238.3	10.4
5059/native material	401	280	16.2
5059/FSW	367.3	278.4	12.7
5059/MIG	296.6	192.7	7.6

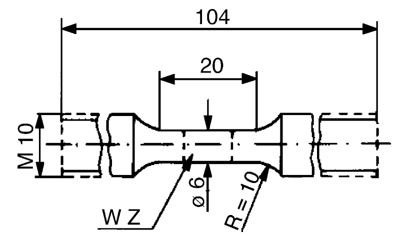

Fig. 1. Schematic of low-cycle fatigue specimen. WZ: welded zone.

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 failure, border upper and lower values of the strength and strains for selected cycles, test duration and frequency, were recorded. The tests were carried out in the air and artificial sea water (3.5% NaCl).

3. Results and discussion

3.1. Structure of FSW welded joints

The welding process by FSW method causes appearance of microstructures that are not observed in other welding processes. They are visible while testing the welded zones by means of light microscope. There are several characteristic areas in the weld: distinct layer of mixed materials in the central part of the weld called welded nugget, thermo-mechanically affected zone (TMAZ), heat affected zone (HAZ) and unaffected material. Figs. 2–5 show characteristic microstructures of the weld's nugget and thermo-mechanically affected zone. Passage from the strained material to the native material may take place from the attacking side (Fig. 2) or from the material's flow (Fig. 5). Contribution of particular areas in the weld's formation depends on welding technology and the kind of welded material. The weld's nugget (Fig. 3) arises as result of the material squeezing around mandrel. The material squeezed around the mandrel is forced into circular movement connected to appropriately profiled mandrel's protru-

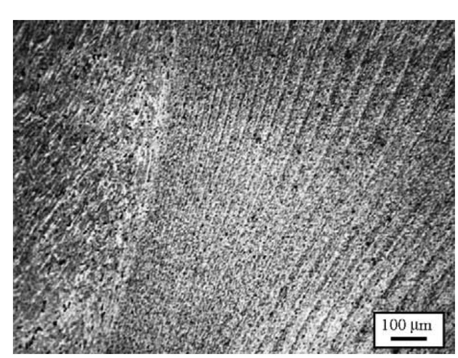

Fig. 2. Microstructure of 5083 alloy welded by FSW method. Attacking side.