INFLUENCE OF THE NOTCH FOR MECHANICAL PROPERTIES OF 7020 ALUMINIUM ALLOY JOINTED BY FSW

Krzysztof Dudzik, Mirosław Czechowski

Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 6901549, +48 58 6901346, fax: +48 58 6901399
e-mail: kdudzik@am.gdynia.pl, czecho@am.gdynia.pl

Abstract

The article presents the results of the mechanical properties of aluminum alloy AW 7020 [AlZn5Mg1] welded by friction stir welding FSW. Friction Stir Welding (FSW) – a new technology can be successfully used for butt welding of different types of aluminum alloy sheets. In the article the parameters for friction stir welding of sheets made of AlZn5Mg1 [7020] alloy were presented. Analysis of bonds showed a proper structural construction of the FSW welded 7020 aluminum alloy. The test was examined via the slow-strain-rate-testing (SSRT) according to EN ISO 7539-7. The following parameters were measured: time-to-failure – T [min], obtained max. load – F [N]; strain energy (the diagram surface under the stress-elongation curve) – E [MJ/m^3]; relative elongation of the specimen – A10 [%]; max. tensile stress – R [MPa] and contraction – Z [%]. The tests were carried out on cylindrical notch-free specimens and on specimens with “U”- notch in the air.

Despite the use of “U” - notch cut in the joint, the specimens cracked in the native material. On the basis of test results were high strength properties of aluminum alloy 7020 joints welded by FSW.

Original values are received results of the mechanical properties of new method friction stir welded AW-7020 [AlZn5Mg1] alloy.

Keywords: *aluminium alloys, friction stir welding (FSW), mechanical properties, slow-strain-rate-testing, U-notch*

1. Introduction

The application of aluminum alloys for the construction of ship and vessel hulls has increased, as these alloys allow considerable reduction of the weight of the vessel weight compared to using a steel structure. Use of aluminum alloys enables this weight to be reduced by half, increasing the ship’s displacement, or, keeping the displacement, increases the load capacity, speed and stability. For this purpose, the designers prefer aluminum alloys to build superstructures, tanks or even entire hulls. Owing to its relatively good endurance properties and weldability, currently, the most popular group of alloys are those of the Al-Mg system (5xxx series). An advantage of these alloys is their relative insensitivity to layer and stress corrosion. A disadvantage is the weakness of welded joints, not exceeding 300 MPa. In the 1990s, great interest was paid to the alloys of the Al-Zn-Mg system (7xxx series). They are characterized by higher resistance properties than the strength properties of Al-Mg alloys. The disadvantage of Al-Zn-Mg alloys is a tendency for stress and layer corrosion. Long-term tests have indicated that the resistance of these alloys to stress corrosion is affected, among other things, by heat treatment, chemical composition and technology of welding (welding method, type of additional materials and joint type) [1-7]. Practically all joints in alloys of this group, welded using traditional methods MIG or TIG, have insufficient resistance to stress or layer corrosion e and for this reason, alloys of the 5xxx Al-Mg group remain the only materials suitable for the hulls of light watercraft.

To prevent welding defects that are practically unavoidable during the use of traditional arc methods (MIG, TIG), one has prepared a friction welding method, Friction Stir Welding. This method, for heating and plasticizing the materials, uses a tool with a rotary mandrel placed instead of combining the clamped metal sheets. After putting the rotary tool with a mandrel in motion, warming up with the heat of friction and plasticizing the material of metal sheets in its immediate vicinity, there is slow movement of the whole system along the contact line (Fig. 1). Since this is the method of welding in a solid condition, below the material melting point, the endurance properties, obtained by this method of making joints may be higher than those obtained with arc welding (MIG, TIG). The main advantage of this method is the ease of making joints with high repeating properties [7, 9]. Since with the FSW method the welding is present in a solid state, the welded materials are subject to much lower heat than in traditional welding. This significantly reduces the size of the heat impact zone. Tests of Al-Zn-Mg alloys, welded by means of MIG and TIG methods, exposed to an aggressive sea environment showed low stress and layer corrosion resistance, occurring in the very zone of heat impact [6, 8].

A potential application of a 7xxx series alloy (which is tougher than the commonly used alloys of the 5xxx series) in the marine industry, is determined by finding a method of welding which will improve the properties of the whole structure, including the welded joints as well as the alloy itself. One of the tests performed in order to determine the mechanical properties of welded connections using the FSW method with metal sheets of a 7xxx series alloy, is a test of deformation with a slow speed of deformation SSRT.

The purpose of the presented paper is to identify the impact of the presence of a notch, namely stress swelling, on the mechanical properties of the friction welded connector with the FSW method, defined in a test of deformation with low speed. One has tested the joints made of AlZn5Mg1 (AW-7020) alloy.

2. Methodology of research

In research, one has used aluminum alloy EN AW-7020 T6. The chemical composition of the alloy is specified in Tab. 1.

Tab. 1. Chemical composition of 7020 aluminum alloy

Chemical composition (% of weight)									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
0.30	0.35	0.10	0.24	1.30	0.14	4.70	0.08	0.07	the rest

Butt joints of sheets with thickness g = 10 mm were made by the FSW method. The sheets were welded on both sides with the same parameters.

The scheme of friction welding with the mix of the welding material (FSW) is shown in Fig. 1; on the other hand, the parameters are presented in Tab. 2.

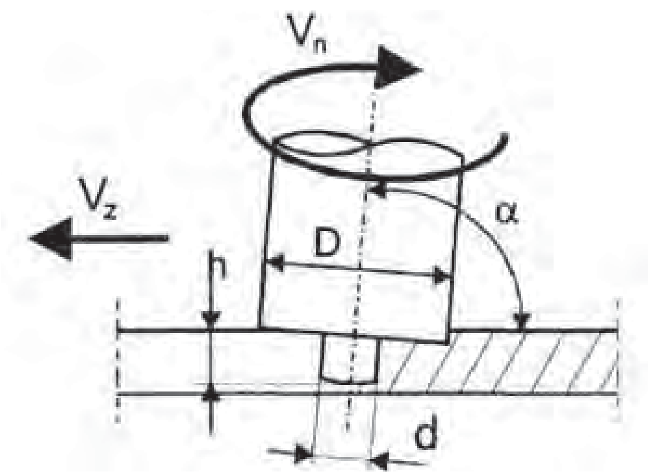


Fig. 1. The diagram of FSW

Tab. 2. FSW parameters of 7020 aluminum alloy sheets

Mandrel dimensions			Tool inclination angle, α [°]	Mandrel rotational speed, V_n [rpm]	Welding linear speed, V_z [mm/min]
D [mm]	d [mm]	h [mm]			
25	10	5.8	88.5	450	180

The tests of the welded structure proved its correct construction without visible discontinuities in the field of the material plastically deformed.

The tests of mechanical properties were conducted using Slow Strain Rate Testing - SSRT in accordance with PN-EN ISO 7539-7 [10]. The research was conducted at the specially designed measurement post allowing stretching of the samples in a corrosive environment, at a stretching speed from 10^{-3} to 10^{-7} s^{-1}.

During the tests, recorded with a computer, or measured after the end of the testing, the following parameters were measured: relative extension at the time of the sample's destruction A_{10} [%], maximum strength F_{max} [kN], maximum stress R_{max} [MPa], proper energy of destruction E [MJ/m^3] (graph surface for the stress – extension curve), narrowing at the time of the sample's destruction Z [%], duration of the test to the sample's destruction T [min.].

The test was conducted on smooth, cylindrical samples with a diameter of 5mm without a notch as well as on cylindrical samples with a diameter of $\Phi = 6$ mm with a ring notch cut in a weld ($\Phi_1 = 5$ mm). The endurance tests were performed in a neutral environment - dry air, at low speeds of deformation $\acute{\varepsilon} = 1.6 \times 10^{-6}$ s^{-1} until the total sample's destruction. Before exposure, the samples were polished and degreased.

3. Test results

The average values of test results of mechanical properties, obtained by performance of the test with a low speed of deformation, on smooth samples and with a ring notch, welded with the FSW method, are presented in Tab. 3.

Tab. 3. Slow strain rate test results

Type of samples	Force, F_{max} [kN]	Stress, R_{max} [MPa]	Energy [J]	Fracture energy, E [MJ/m^3]	Elongation, A_{10} [%]	Narrowing, Z [%]	Time to failure, T [min]
Without a notch	5.96	303.9	19.17	19.53	7.31	48,65	593
With "U" notch	9.40	478.9*	30.44	31,02	5.52	40.19	604
* - calculated for sample diameter in a notch Φ = 5 mm							

The sample graph, registered by a computer during the performance of the SSRT test for a sample with a notch, is presented in Fig. 2.

The obtained results confirm the high endurance properties of the joints welded with the FSW method of alloy AW-7020. Significantly higher values obtained in samples with a notch, indicate high insensitivity to operation of stress swelling in a weld. Despite that, at the site of a U-shaped indent with a diameter of 5mm, they burst beyond the notch, where the diameter amounted to $\Phi = 6$ mm. Similarly, like the samples with a notch, the smooth samples also burst beyond the weld in a native material. These results indicate that the joints made using friction welding FSW has greater endurance properties than the native material itself.

The view of the samples after the tests of deformation at low speed has been presented in Fig. 3.

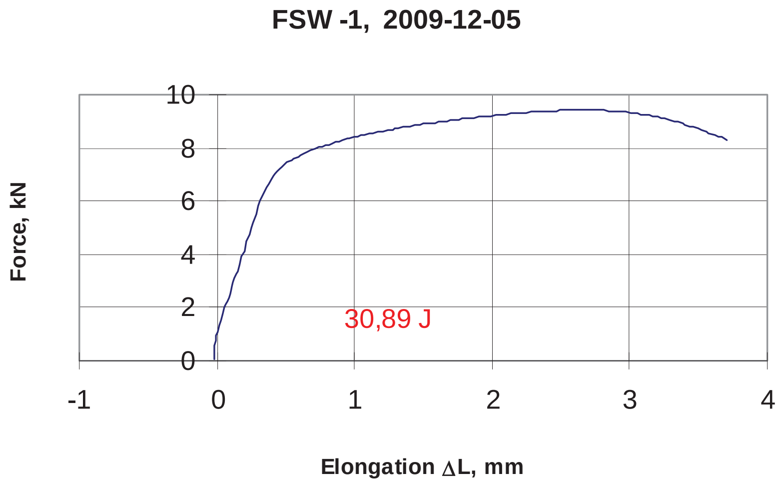
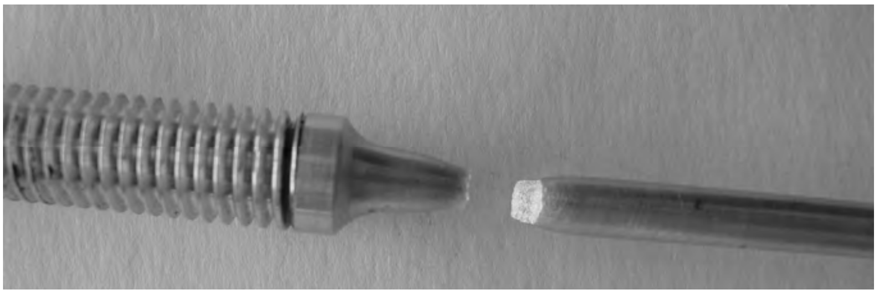


Fig. 2. The diagram of SSRT

a)



b)

Fig. 3. View of the specimens after SSRT: a) without notch, b) with "U"- notch

4.Summary and conclusions

The research was conducted in order to determine the mechanical properties of the weld made by a method of friction welding FSW. For this purpose, apart from smooth samples, one used samples with a ring notch, cut in a weld. The tests of mechanical properties at application of the deformation method at low speed indicated that the connection made using the method of friction welding FSW is characterized by greater resistance properties as compared to analogical properties of native material. Both smooth samples without a notch and with a ring notch cut in the weld during the tests burst in a native material. While in the case of smooth samples, this result was not a surprise, the crack of the sample with a notch at the place where the sample diameter was 6mm instead of 5mm in a notch indicates significantly higher strength of a joint that is friction welded. This is caused by strengthening of the weld material caused by plastic deformations that takes place during welding of alloy 7020 in a solid state. The native material is strengthened by heat processing (supersaturation and ageing).

The obtained maximum values of the sample breaking force, and hence the maximum stress, in case of samples with a notch, were higher than smooth samples by almost 58%. The parameter that remained the same in all samples, namely smooth and with a ring notch, was the time to the sample's destruction.

In order to set the strength of the weld itself, it would be necessary to give the samples a notch, greater than those indicated in the standard, that would cause the crack to occur only in this selected place.

References

[1] Anderson, T., *New developments within the Aluminium Shipbuilding Industry*, Svetsaren, pp. 3-5, Vol. 58, No. 1, 2003.

[2] Bugłacki, H., *Wpływ technologii spawania na odporność korozyjną stopów Al-Zn-Mg*, International Conference on Environmental Degradation of Engineering Materials, Politechnika Gdańska, pp. 260-267, Jurata 1999.

[3] Cudny, K., Puchaczewski, N., *Stopy metali na kadłuby okrętowe*, Politechnika Gdańska, Gdańsk 1995.

[4] Czechowski, M., *Effect of anodic polarization on stress corrosion cracking of some aluminium alloys*, Advances in Materials Science, Vol. 7, No. 1 (11), pp. 13-20, 2007.

[5] Czechowski, M., *Własności złączy doczołowych blach ze stopów Al-Mg spajanych różnymi metodami*, Materiały i Technologie, Politechnika Gdańska, Nr 1 (1), pp. 16-19, Gdańsk 2003.

[6] Czechowski, M., Chrzanowski, J., Zieliński, A., *Naprężeniowe pękanie korozyjne złączy spawanych stopów aluminium*, Materiały II Pomorskiej Konferencji Naukowej - Inżynieria Materiałowa 2001, Politechnika Gdańska, Sobieszewo 2001.

[7] Czechowski, M., Pietras, A., Zadroga, L., *Własności stopów aluminium serii 5000 zgrzewanych tarciowo nową technologią FSW*, Inżynieria Materiałowa, Nr 6, pp. 264-266, 2003,

[8] Czechowski, M., Zieliński, A., *Effect of cathodic polarization on failure and degradation of mechanical properties of some aluminium alloys*, Scripta Metallurgy Materials, Vol. 30, 1994.

[9] Lahti, K., *FSW – possibilities in shipbuilding*, Svetsaren, Vol. 58, No. 1 pp. 6-8, 2003.

[10] PN-EN ISO 7539-7: 2000. *Badania korozji naprężeniowej. Próba odkształcenia z małą prędkością.*