

STRESS CORROSION CRACKING OF 7020 ALUMINIUM ALLOY JOINTED BY DIFFERENT WELDING METHODS

Krzysztof Dudzik

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

Abstract

The results of stress corrosion cracking (SCC) of aluminum alloy AW 7020 [AlZn5Mg1] welded by friction stir welding FSW and MIG were presented. 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 was presented as well as parameters for MIG. Metallographic analysis of bonds showed a proper structural construction of both, the FSW and MIG welded 7020 aluminum alloys. Stress corrosion cracking was examined via the slow-strain-rate-testing (SSRT) 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/m³]; relative elongation of the specimen – A_{10} [%]; max. tensile stress – R [MPa] and contraction – Z [%]. The tests were carried out on cylindrical notch-free specimens in the air and 3.5% water solution NaCl. Good resistance to stress corrosion was found of friction stir welded 7020 aluminum alloys. The tested samples cracked during SSRT test in the native material in case of FSW and in the joint in case of MIG.

Original value are received results of the stress corrosion resistance of new method friction stir welded AlZn5Mg1 alloy compared with traditional MIG method.

Keywords: aluminium alloys, friction stir welding (FSW), MIG welding, stress corrosion cracking, mechanical properties, slow-strain-rate-testing

1. Introduction

Aluminium alloys are getting more and more interest in the shipbuilding industry as these alloys allow a significant reduction in ship structure weight compared with the weight of steel structures. The use of aluminium reduces the weight by about half, thereby increasing the displacement of the vessel and maintaining the displacement for load or speed increase and stability improvement. Of weldable aluminium alloys for plastic processing, the most popular is still the group of Al-Mg (5xxx series) alloys, with good weldability and relatively good operating properties. The advantage of these alloys is their relative insensitivity to layer corrosion and stress corrosion, the disadvantage – low strength of welded joints, below 300 MPa. An alternative to these alloys could be the Al-Zn-Mg (7xxx series) alloys. They exhibit higher strength properties than the mechanical properties of Al-Mg alloys. The disadvantage of the 7xxx series alloys is that they are prone to stress and layer corrosion. Many years of research have shown that the resistance of these alloys to stress corrosion is influenced among other things by heat processing, chemical composition and welding technology (welding method, type of fillers, type of connector) [1-7]. Virtually all joints welded using conventional MIG or TIG methods in this group of alloys possess insufficient resistance to stress or layer corrosion.

An alternative to traditional methods such as MIG or TIG welding may be Friction Stir Welding (FSW). In this method, the heating and plasticization of the material is effected using a tool with a rotating shaft located at the joint of clamped sheets. After the tools with the shaft

have been put in rotation, the sheet material has been heated up with the heat of friction and in its immediate vicinity, the entire system slowly moves along the line of contact (Fig. 1). Because this method consists in welding in the solid state, below the melting temperature of the material, the mechanical properties obtained using this joining method may be higher than those for arc welding techniques (MIG, TIG). The main advantage of this method is that it is easy to obtain joints with high, reproducible properties [8, 10]. Because in the FSW method, welding occurs in the solid state, much less heat is supplied to the joined materials than is the case with conventional welding. This significantly reduces the size of the heat-affected zone. Studies of Al-Zn-Mg alloys bonded using MIG and TIG methods exposed to aggressive marine environment have shown a low resistance to stress and layer corrosion occurring just in the heat-affected zone [7, 9].

The aim of the study presented was to determine the susceptibility of AlZn5Mg1 (AW-7020) joints welded using the FSW method to stress corrosion in an aqueous solution of sodium chloride as compared to joints welded using traditional MIG methods.

2. Research methodology

The testing used EN AW-7020 T6 aluminium alloy (supersaturated and artificially aged) The chemical composition of the alloy is given in Tab. 1.

Tab. 1. Chemical composition of 7020 aluminum alloy

| Chemical composition (%) | | | | | | | | | |
|--------------------------|------|------|------|------|------|------|------|------|-------|
| 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 | other |

Butt joints of AW-7020 alloy sheets made using FSW. Sheet thickness was $g = 10\text{mm}$. The sheets were welded on both sides using identical parameters.

The diagram of friction welding with the commingling of weld material (FSW) is shown in Fig. 1 and the parameters are shown in Tab. 2.

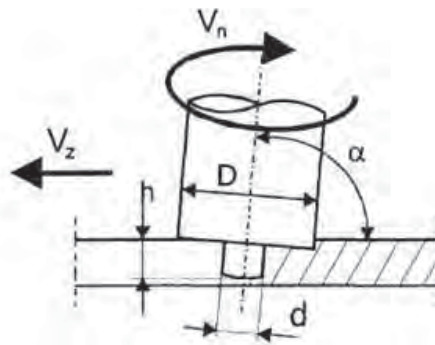


Fig. 1. The diagram of FSW

Tab. 2. FSW parameters of 7020 aluminum alloy sheets

| Tool dimensions | | | Angle of tool deflection, α [°] | Mandrel's rotary speed, V_n [rev/min] | Welding speed, V_z [mm/min] |
|-----------------|--------|--------|--|---|-------------------------------|
| D [mm] | d [mm] | h [mm] | | | |
| 25 | 10 | 5.8 | 88.5 | 450 | 180 |

The examination of structural construction of welds showed proper construction without any visible discontinuities in the area of plastically deformed material. Fig. 2 presents characteristic microstructure of weld nugget.

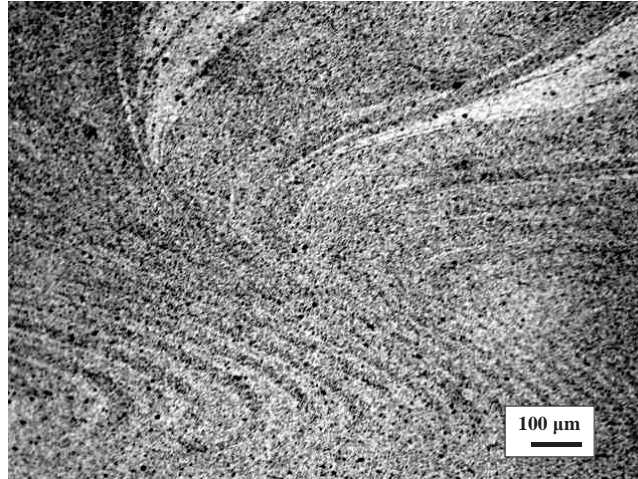


Fig. 2. Microstructure of the weld nugget

For the comparison, butt joints were used between sheets with a thickness $g = 12$ mm, made using the traditional MIG arc welding method. The preparation of welded joints was made in accordance with the procedures required by the shipbuilding industry. AlMg5 (Nertalic AG5 made by SAF) alloy wire was used for the welding. Argon was used as shielding gas with a purity of 99.99. The welding parameters used for joining sheets are shown in Tab. 3.

Tab. 3. MIG welding parameters of 7020 aluminum alloy sheets

| Welding electrode diameter [mm] | Welding current [A] | Number of layers | Argon consumption [m ³ /h] |
|---------------------------------|---------------------|------------------|---------------------------------------|
| 1.6 | 190-230 | 4 + pre-welding | 16-18 |

Welds made using both the FSW and MIG method were checked using X-ray flaw detection and showed no welding defects.

Stress corrosion tests were carried out using the Slow Strain Rate Testing – SSRT method compliant with PN-EN ISO 7539-7 [11]. The testing was conducted on a specially designed test bench allowing sample tension in a corrosive environment, at a tension velocity of 10^{-3} to 10^{-7} s⁻¹. Susceptibility to stress corrosion (K) was assessed by comparing the average values of parameters measured obtained on identical samples exposed to the effects of the corrosive environment (X_{SCC}) and neutral environment (X_{air}), according to relationship (1).

$$K_x = [1 - (X_{SCC}/X_{air})] \times 100 (\%). \quad (1)$$

During the tests, parameters were computer-recorded or measured after measurement, such as: relative elongation at the time of sample destruction A_{10} [%], maximum force F_{max} [kN], maximum stress R_{max} [MPa], proper destruction energy E [MJ/m³] (area under the stress – elongation curve), constriction at the time of destruction of sample Z [%], time of test until sample destruction T [hrs].

The test was carried out on smooth, cylindrical samples without a notch. Strength tests were performed in replacement sea water with a temperature +20°C and in an inert environment – dry air at low rate of deformation $\dot{\epsilon} = 1.6 \times 10^{-6}$ s⁻¹ until total sample destruction. Prior to exposure, the samples were polished and degreased.

3. Test results

Results of SSRT testing conducted in air and in replacement sea water are listed in Fig. 3 which shows the susceptibility to stress corrosion for native material and for joints bonded using FSW and MIG methods.

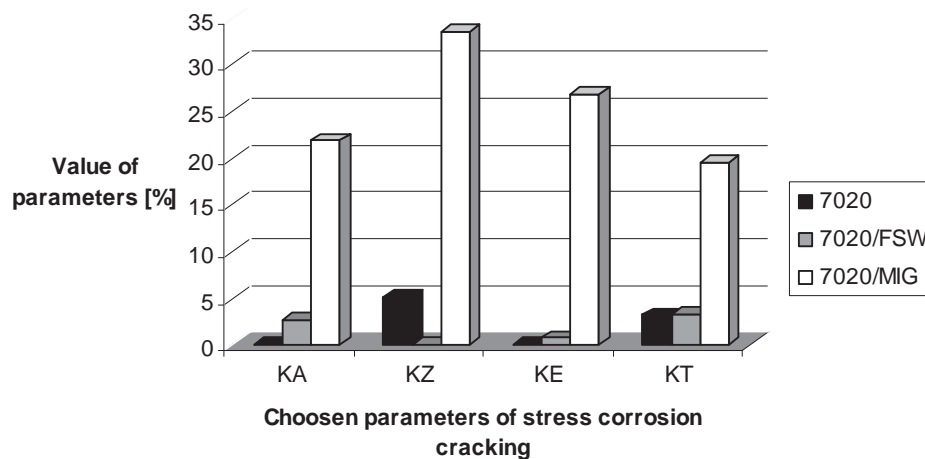


Fig. 3. Stress corrodibility of 7020 alloy and its joints

Susceptibility to stress corrosion was determined by comparing the average values measured during parameter testing:

K_E - reduction in destruction energy in percentage terms,

K_T - reduction of time to destroy the sample in percentage terms,

K_A - reduction in elongation on sample destruction in percentage terms,

K_Z - constriction reduction in percentage terms.

4. Summary and conclusions

Based on research results obtained, it can be concluded that the AW-7020 (AlZn5Mg1) alloy friction welded using the FSW method is resistant to stress corrosion in sea water. Values of the individual measured parameters obtained in air and artificial seawater for friction-welded joints do not differ significantly from each other (Fig. 3). Elongation of samples welded using FSW stretched in replacement sea water dropped on average by 2.7% only compared with those investigated in the air. An even smaller reduction in percentage terms was achieved when measuring the constriction and relative destruction energy ($K_E = 0.77\%$). The greatest discrepancy between the results obtained at two different centres was observed for time to destroy the sample where the parameter K_T for samples welded and made of native material was around 3.3%.

Different results were obtained for MIG welded samples. Here, differences between samples exposed in air and in a corrosive environment are large enough to clearly indicate low resistance to stress corrosion. This applies to all four selected parameters determining the joints' susceptibility to stress corrosion. The highest value was reached for the K_Z parameter related to constriction reduction, reaching over 33% while the lowest value was reached for the parameter specifying the reduction in time to break the sample in percentage terms ($K_T = 19.6\%$).

The high strength of joints made using the FSW method is confirmed by the location of rupture of samples tested. When tested for deformation at low speed (SSRT), they burst in the native material outside the weld. This applies both to samples exposed in air and in replacement sea water environment.

References

- [1] Anderson, T., *New developments within the Aluminium Shipbuilding Industry*, Svetsaren, Vol. 58, No. 1, pp. 3-5, 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., *Low-cycle fatigue of friction stir welded Al-Mg alloys*, *Journal of Materials Processing Technology*, 164-165, pp. 1001-1006, 2005.
- [6] Czechowski, M., *Własności złączy doczołowych blach ze stopów Al-Mg spajanych różnymi metodami*, *Materiały i Technologie*, Politechnika Gdańska, Nr 1 (1), s. 16-19, Gdańsk 2003.
- [7] Czechowski, M., Chrzanowski, J., Zieliński, A., *Naprężeniowe pękanie korozyjne złączy spawanych stopów aluminium*, *Materiały II Pomorska Konferencja Naukowa - Inżynieria Materiałowa 2001*, Politechnika Gdańska, Sobieszewo 2001.
- [8] Czechowski, M., Pietras, A., Zadroga, L., *Własności stopów aluminium serii 5000 zgrzewanych tarcioowo nową technologią FSW*, *Inżynieria Materiałowa*, Nr 6, pp. 264-266, 2003.
- [9] 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.
- [10] Lahti, K., *FSW – possibilities in shipbuilding*, *Svetsaren*, Vol. 58, No. 1, pp. 6-8, 2003.
- [11] PN-EN ISO 7539-7: 2000. *Badania korozji naprężeniowej. Próba odkształcenia z małą prędkością.*