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PROPERTIES OF ADVANCING SIDE OF WELD IN JOINT WELDED BY FSW

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Abstract

The results of mechanical and corrosion properties research of chosen part of joint bonded by Friction Stir Welding – advancing side of the weld, were presented. AW-7020 aluminium alloy was used for research.
Research included the following methods:
- *mechanical properties were carried out using static tensile test in accordance with PN-EN ISO 4136:2011 and PN-EN ISO 6892-1:2010,*
- *Hardness testing in the cross-sections of joints was carried out using Vickers HV5 method in accordance with PN-EN ISO 6507-1:2006,*
- *microscopic examination was performed by optical microscope ZEISS Axiovert 25,*
- *the corrosion resistance research was carried out using electrochemical impedance spectroscopy (EIS) method in 3.5% water solution NaCl.*

During the study obtained higher strength properties for the FSW joint compared to the native material – all samples cracked in the native material.
The hardness test shown, that the advanced side of the weld has the highest value of hardness of completely joint.
Better resistance to electrochemical corrosion was found for the native material then joint welded by FSW of 7020 aluminum alloy, including the advancing side of the weld.
Original value is received results of the mechanical and corrosion properties of advancing side of the weld of FSW welded AW-7020 aluminium alloy.

Keywords: *Friction Stir Welding (FSW), welding, aluminium alloys, advancing side of weld*

1. Introduction

Aluminum alloys have several advantages that allow applying them in shipbuilding. The main advantages are better resistance to corrosion in seawater environment and the possibility of reducing the weight of the structure compared to the steel [4, 6].

Joining aluminium and its alloys with welding methods is difficult due to its specific properties. The main problems that can occur during welding result from the following factors: high similarity of aluminium to oxygen, the creation of high-melting (2060 °C) oxide Al_2O_3, high thermal conductivity, high thermal expansion of aluminium alloys, big casting shrinkage (being the reason of welding strains and stresses), considerable decrease of resistance at welding temperatures, the loss of alloying elements such as magnesium, zinc, or lithium during welding. The above-mentioned main drawbacks related to aluminium alloys welding provoke searching other joining methods for these materials [1, 2, 4]. An alternative to butt-welding is a method known as friction stir welding FSW [1, 6, 10].

The method of friction stir welding with weld displacement FSW (Friction Stir Welding) was worked out and patented in 1991 in Welding Institute (TWI) at Cambridge University in Great Britain. For this method of heating and plasticizing a material, a special tool with rotating pin placed in the joining point of pressed down sheets was used. After setting the tool in rotating motion, heating with friction heat and plasticizing sheets material in the direct contiguity – a slow displacement of the whole system alongside the contact line takes place [1, 4, 7, 10]. FSW is a method of welding in a solid state of mainly aluminium alloys, copper alloys and stainless steel. The main advantage of this method is the fact that it is easy to obtain welds of high, repeatable properties [3, 4].

The aim of this article is to determine the mechanical and corrosion properties of the advancing side of weld in joint made by FSW, compared to the native material and the weld.

2. The 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	the rest

Technology development of Friction Stir Welding (FSW) method for joining AW-7020 aluminium alloy elements was carried out using a conventional vertical milling machine FYF32JU2, adapted for FSW. Typical diagrammatic representation of FSW process showing the terminology associated with the way in which material is displaced from the tool, is shown in Fig. 1.

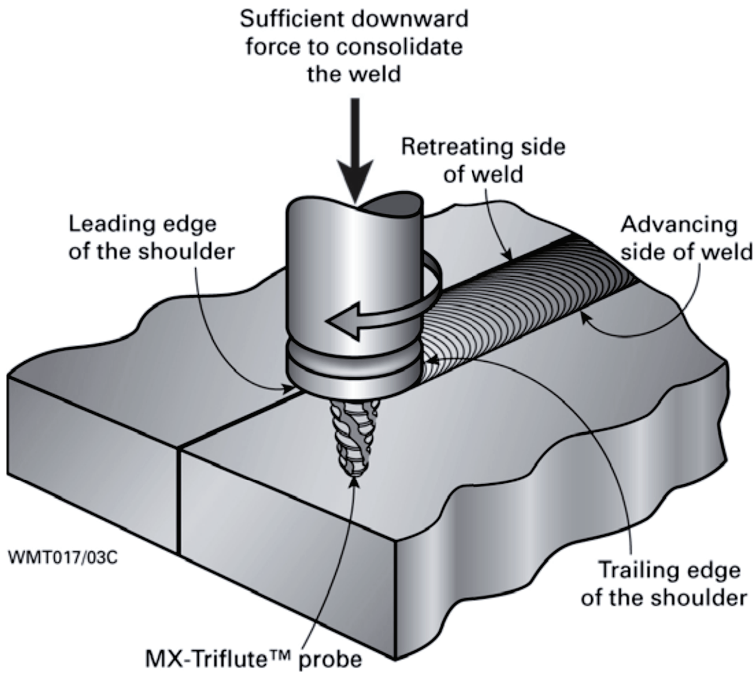


Fig. 1. The principle of Friction Stir Welding with characteristic areas [12]

During research tool with a „TRI-FLUTE” pin, made of high speed steel HS6-5-2 (SW7M) was used. As shown by preliminary tests, the tool made of such steel is equivalent to the welding tools designed for the friction stir welding of aluminium alloys 5xxx and 7xxx series. This means that it is capable of withstanding temperatures in which the plastic deformation process occurs, mixing and forcing the metal around the mandrel, and there is no excess bonding material to the tool shoulder.

Joints were both sides welded, using the same parameters on both sides of the joined elements.

The thickness of the joining sheets was g = 12 mm. The sheets were one side milled to a thickness of 10 mm in the contact portion. Accordingly, rigid mounting plate was ensured by welding machine equipment. Except to providing general cleanliness of the sheets there was not used any degreasing agent interfaces connected elements. Plates were joined on both sides with the same parameters.

Static tensile test

In order to determine the mechanical properties was carried out static tensile test. Tensile test was carried out in accordance with PN-EN ISO 4136:2011 and PN-EN ISO 6892-1:2010. Used flat samples cut perpendicular to the direction of rolling. The study was performed at ambient temperature, i.e. + 20°C ± 2. Tensile testing was carried out on samples with flat-type testing machine EU-40 on the strength of 200 kN ± 1. During the study determined parameters such as ultimate tensile strength UTS, yield stress YS, and elongation EL.

Hardness testing

Hardness testing in the cross-sections of joints was carried out using Vickers HV5 method in accordance with the Polish Standard PN-EN ISO 6507-1:2006. The test was performed using HPO-10 hardness testing machine. The indenter load was 49 N.

Microscopic examination

The study was performed on microstructures of joints bonded by FSW method. An optical microscope ZEISS Axiovert 25 was used in research. The study of microstructure of cuts prepared mechanically and digested Keller reagent to reveal the grain boundaries and the flow lines [9, 10]. Thus, it became possible to identify areas of particular characteristic of bonded joints.

Electrochemical corrosion research

The corrosion resistance research was carried out using electrochemical impedance spectroscopy (ELIS) method. EIS measurement was performed in three-electrode system in an artificial seawater (3.5% water solution NaCl).

Before the measurements, the samples were exposed in the electrolyte to stabilize the corrosion potential. During measuring, the electrolyte was continuously mixed using a magnetic stirrer [5, 8, 11]. The samples were degreased before the test.

Atlas 0531EU & IA potentiostat was used for studies.

Electrochemical impedance spectroscopy measurements were conducted at the corrosion potential. The amplitude of the voltage signal varied in the range ± 10 mV, and the extent of the changes was the signal frequency: 100 kHz – 0.1 Hz.

Determination of the corrosion process parameters was performed by computer programs: AtlasLab 2.0 and EIS Spectrum Analyser.

3. The research results

Static tensile test

The mechanical properties of 7020 alloy and its joints welded by FSW, obtained in the static tensile test, are shown in Tab. 2.

Tab. 2. Mechanical properties of 7020 alloy and its joints welded by FSW

Specimen	UTS [MPa]	YS [MPa]	EL [%]
Native material	373	317	14.2
FSW	367	314	13.8

Where UTS – ultimate tensile strength, YS – yield stress, EL – elongation.

The mechanical properties of joints welded by FSW are practically the same as the native material. This is confirmed by the crack place that in all the FSW welded specimens was found in the native material at a distance of about 20 mm from the weld. The crack place indicated that the whole joint – the weld, advancing side of the weld, retreating side of the weld and even heat affected zone, are more durable than the native material. Heat affected zone (HAZ) in the case of Friction Stir Welding, is minimal, concluded that the cracks was in the native material – unchanged by the heat of welding. An exemplary view of FSW welded specimen subjected to the static tensile test is shown in Fig. 2.

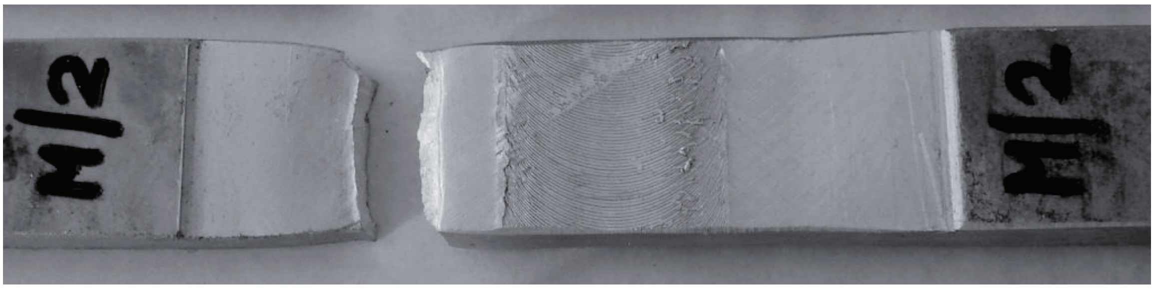


Fig. 2. Sample view of 7020 alloy welded by FSW subjected to the static tensile test – a crack in the native material

Hardness testing

The results of hardness tests in the FSW welded joint are shown graphically in Fig. 3. Advancing side of weld was indicated by a circle.

Hardness tests in the cross-section of FSW welded joints showed that the weld has a higher hardness compared to the native metal. A noticeable increase of hardness is in the weld fusion lines, both sides – advancing side and retreating side of weld. A little bit higher hardness is in the advancing side of weld. Hardness in the advancing side of the weld is about 5% higher than the weld and about 22% higher than the native material.

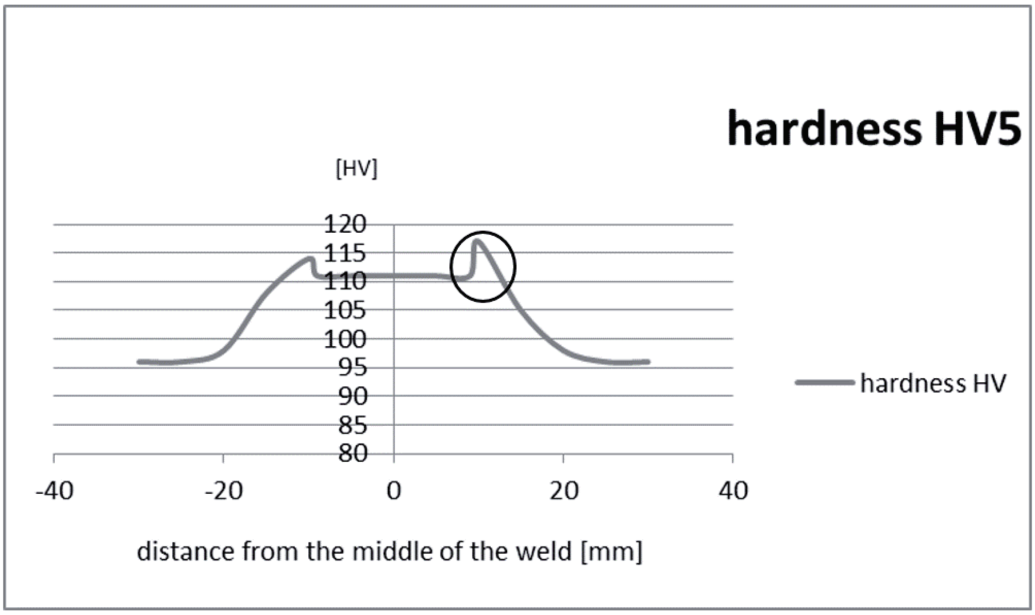
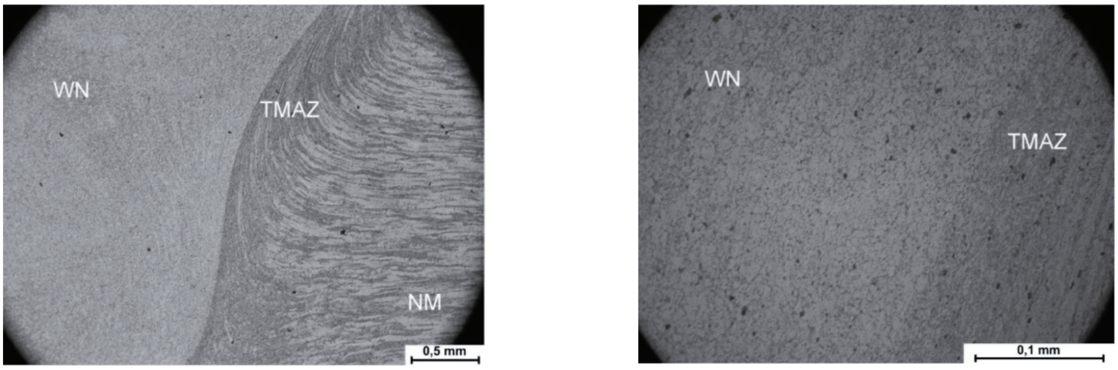


Fig. 3. Hardness distribution in the cross section of FSW welded joint

Microscopic examination

The microstructure of FSW welded joint (the same area of joint) using different magnifications is shown in Fig. 4a and 4b.



a) *b)*

Fig. 4. Microstructure of joint welded by FSW, a), b) different magnifications

Symbols used in the Fig. 4 represent the characteristic joints zones:
NM – native material,
WN – weld nugget,
TMAZ – thermo-mechanically affected zone.

For the analysis of the microstructure of FSW, welded joint, chosen the advancing side of the weld, the place where there are the greatest deformation of both mechanical and thermal properties. In the weld are slightly visible flow lines characteristic of the material by interaction of welding tool. Clear signs of tool interaction are visible in the thermo-mechanically affected zone. In the native material are visible forming signs (after rolling process) and heat treatment, in the form of horizontal stripes formed by the grains.

Homogeneous colour of the weld nugget (compared to native material) is due to a partial recrystallization and plastic deformation of the materials mixed during joining process of metal sheets [9]. Additionally, during welding were crushed and mixed oxides of the passive layer and intermetallic phases, occurring mainly at grain boundaries.

Electrochemical corrosion research

The results of the electrochemical impedance spectroscopy of samples of 7020 alloy joint welded by FSW were computer processed. As a result, set the parameters characterizing the corrosion process, where the average values of five samples are presented in Tab. 3. These parameters define the individual components of the model – a replacement circuit.

Tab. 3. Parameters of the replacement corrosive electrical circuit of 7020 joint welded by FSW

Specimen	R_s [Ω·cm^2]	Std. Dev.	R_{ct} [Ω·cm^2]	Std. Dev.	CPE_{dl} [μF /cm^2]	Std. Dev.	n_{dl} [-]	Std. Dev.
Native material	0.98	0.21	876.83	126.13	44.23	14.08	0.94	0.01
Advancing Side	1.03	0.08	601.47	64.83	70.38	13.11	0.92	0.03
Weld	1.14	0.15	558.11	85.74	79.87	18.72	0.96	0.02

Where Std. Dev. – the standard deviation, HAZ – heat affected zone

The best corrosion properties were obtained for the native material and the worst for the joint welded by FSW. The most important parameter determining the susceptibility to electrochemical corrosion R_{ct} – charge transfer resistance, reaches the highest value for the sample of native material and the lowest value for the sample from the centre of the weld. In the case of sample from the advancing side of weld, the parameters achieved during the research, are almost the same as for the sample from the weld.

The component power exponent of capacitive impedance n_{dl} (of equivalent circuit), determining the homogeneity of corrosion is the lowest for Advancing Side of weld. This indicates a greater tendency to pitting corrosion was for FSW joints. Despite the differences in values that occur n_{dl} parameter for each sample, the values are relatively high which indicates a high homogeneity of the processes of corrosion in whole joint.

Electrolyte resistance R_s, which is corrosive environment for all the samples, was the same level and to receive very low values which indicates a very high electrical conductivity of the solution. This parameter is not critical in the consideration of corrosion resistance of the samples.

4. Summary

Results of the tests showed that the strength properties of advancing side of the weld are comparable with the properties of the weld and higher than the native material. The confirmation of these studies is the occurrence of cracks samples in static tensile test – all samples were cracking at the native material.

Hardness test of the cross-section joints showed that the highest values of hardness in the whole joint is characterized by the advancing side of the weld and the smallest in the native material.

Analysis of the electrochemical impedance spectroscopy showed that the native material has more resistance to electrochemical corrosion than FSW welded joint. Charge transfer resistance value by a double layer of R_{ct} is smaller for a sample jointed by FSW, which indicates a lower resistance to withstand the charge exchange (ions, electrons) between the material and the electrolyte. R_{ct} parameter value during the test for sample of the native material, reached about 46% higher than the advancing side of weld and about 57% higher than the joint welded by FSW.

Studies on the electrochemical corrosion resistance made by the EIS method showed that the FSW welded joint and advancing side of weld are less resistant than native material AW-7020, for this type of degradation in seawater environment.

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