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INFLUENCE OF FRICTION STIR WELDING ON HARDNESS DISTRIBUTION IN JOINTS OF AW-5083 ALLOY

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Abstract

The article presents the research results of hardness distribution of friction stir welded joint (FSW) of AW-5083 aluminium alloy. During the study used two types of tools: with cylindrical pin and with conical pin. FSW is a method of welding in the solid state, mechanical properties of joints welded by that method can be higher than that for arc welding techniques (MIG, TIG). The parameters of friction stir welding (FSW) used for joining 5083 alloy sheets were presented. Metallographic analysis of chosen joints showed the correct construction of structural bonded joints.

The study was carried out using Vickers hardness HV1 in accordance with the requirements of the Polish Standard PN-EN 6507 using a hardness and microhardness-testing machine FM-800. The location of measurement points in the butt joint was determined in accordance with PN-EN 1043-1:2000. The indenter load was 9.8 N.

In order to identify areas of particular characteristic of bonded joints macroscopic examination was performed using an optical microscope ZAISS AxioVert A1 MAT. The test specimens were polished and then etched with KELLER reagent. This enabled the precise identification of zones present in the joint, such as weld nugget, thermo-mechanically affected zone, native material.

Hardness testing in across researched joints showed that the shape of the welding tool pin does not affect the mean value of hardness in the weld.

Keywords: *FSW, welding, hardness distribution, 5xxx aluminium alloy, shipbuilding*

1. Introduction

Aluminium alloys are materials, which are widely used in the global industry, including shipbuilding. Aluminium alloys are used more and more widely for building ship and vessel hulls as these alloys allow a significant reduction in ship structure weight compared with the weight of steel structures. The use of aluminium can reduce the weight by approx. 50%, thereby increasing the displacement of the vessel and maintaining the displacement for load or speed increase and stability improvement. For these reasons, aluminium alloys are used, among other things for the construction of hulls and superstructures. 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 [5, 7, 8]. The advantage of these alloys is their relative insensitivity to layer corrosion and stress corrosion, the disadvantage – relatively low strength of welded joints, below 300 MPa.

Continuous development of welding technology (welding method, type of fillers, and type of connector) resulted in significant improvements in the properties of welds but their strength is still less than the base material [1, 2, 3, 5].

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 tool has 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. 1a). 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 simplicity of obtaining joints with high, reproducible properties [1, 3, 5, 6, 8]. 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. Supply of large amounts of heat causes structural changes in the material causing the heterogeneity of construction and thus differentiation of the mechanical properties of cross-section of the joint.

The industrial applicability of the most popular in shipbuilding industry 5xxx series alloy shall be subject to finding a method of bonding, which will improve the properties of the whole structure, i.e. also bonded joints and not just the alloy itself. One of the tests performed to determine the mechanical properties of 5xxx series alloy joints, bonded using various methods, is the hardness test in the joint's cross-section [4].

The aim of this study was to determine the hardness distribution in the cross-section of joints welded by FSW. Joints used for the tests were made of an alloy (AW-5083). For joining, were used two types of tools: with cylindrical and conical pin.

2. The research methodology

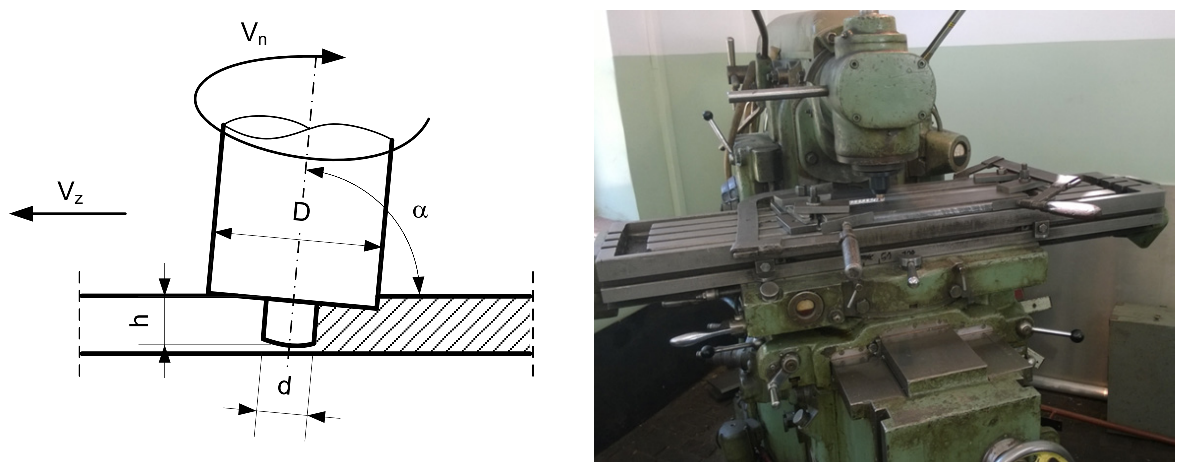
The study used EN AW-5083 H321 aluminium alloy. The chemical composition of the alloy is given in table 1.

Tab. 1. Chemical composition of researched aluminium alloy

Chemical composition (%)									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
0.195	0.18	0.09	0.662	4.745	0.111	0.042	0.025	0.037	The rest

Butt joints of AW-5083 alloy sheets were made using FSW. Sheet thickness was g = 12 mm. The sheets were welded on both sides using identical parameters.

The stand was built based on universal milling machine FWA-31. The diagram of friction welding (FSW) and view of stand used in research are shown in figure 1. The welding parameters are shown in table 2.



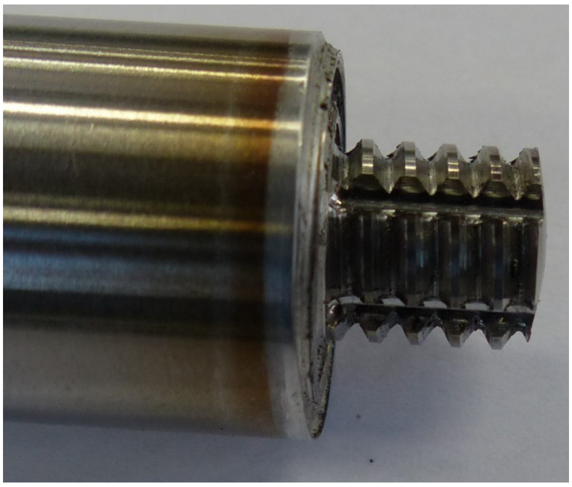
a) b)

Fig. 1. The diagram of FSW (a) and view of stand used in research (b)

For joining sheets made of 5083 alloy were used two kind of tools – with cylindrical pin and with conical pin. Views of those tools are shown in figure 2. For optimizing quality of joints were used different parameters: angle of tool deflection, tool's rotary speed and welding speed. The sheets chosen for research were welded on both sides using two kinds of tools and identical parameters – chosen in optimization process.

Tab. 2. FSW parameters of 5083 aluminium alloy sheets

Kind of tool	Tool dimensions			Angle of tool deflection α [°]	Tool's rotary speed V_n [rpm]	Welding speed V_z [mm/min]
	D [mm]	d [mm]	h [mm]			
With cylindrical pin	20	10	7.5	88.5 – 89.5	150 - 750	52 - 180
With conical pin	20	10 - in the top 6 - in the bottom	7.5	88.5 – 89.5	150 - 750	52 - 180



a)

b)

Fig. 2. View of tools used for joining by FSW: a) with cylindrical pin, b) with conical pin

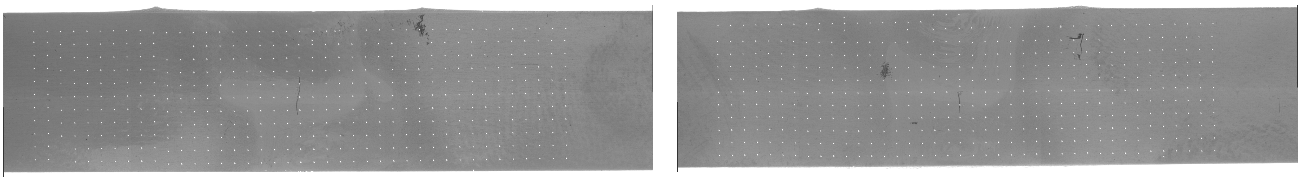
Studies of the weld have shown its correct structure without visible discontinuities in the area of the plastically deformed material.

Hardness testing was carried out using Vickers HV1 as required by the Polish Standard PN-EN 1043-1:2000. The indenter load was 9.8 N. The hardness was measured in parallel rows, from the centre of the weld through the thermo-mechanically affected zone (TMAZ) to the native material. The distance between measured points was 1 mm.

Samples for testing were polished and etched using Keller reagent. This allowed precisely determining zones occurring in the welded joint, such as: weld, heat affected zone or unchanged material – native, and then to make precise measurements exactly in the aforementioned areas.

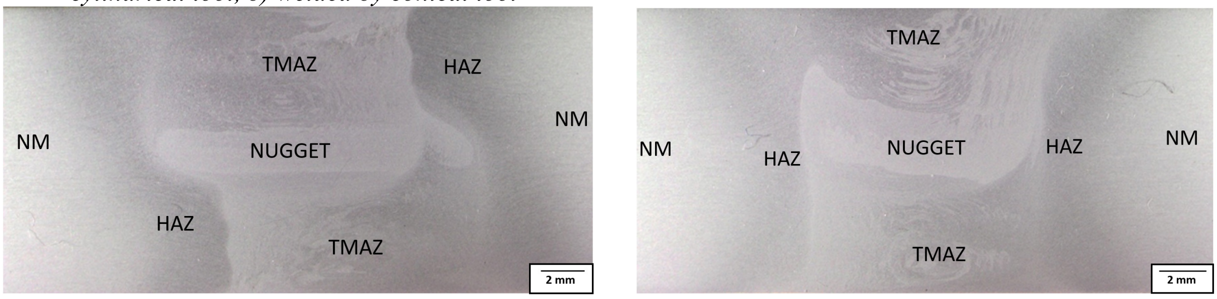
3. The research results

Location of measurement points are shown in Figures 2a and 2b. In Figures 3a and 3b overviews of the samples cross-section of FSW double-side welded 5083 aluminium alloy by different tools were shown (with characteristic zones). Macrostructure examination confirmed the correctness of structures of chosen joints.



a) b)

Fig. 2. The view of FSW welded specimens after hardness testing with visible measurement points: a) welded by cylindrical tool, b) welded by conical tool



a) b)

Fig. 3. Macrostructures of FSW welded joints: a) by cylindrical tool, b) by conical tool

The results of hardness tests in the FSW welded joint are shown graphically in Fig. 3 and 4.

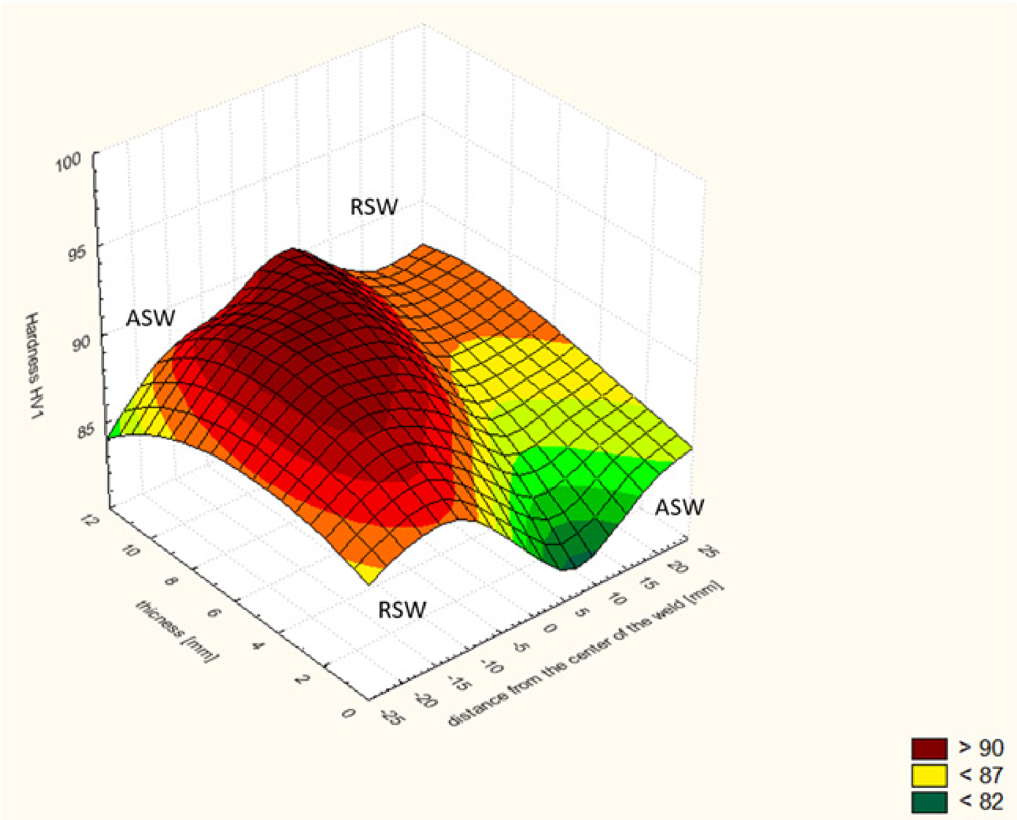


Fig. 3. Hardness distribution in joint welded by tool with cylindrical pin, ASW – Advancing Side of the Weld, RSW – Retreating Side of the Weld

The maximum hardness value occurs in the welded joint opposite the impact zone of pin tool after second pass of it. The differences in the maximum values in the joints welded by two kinds of tools: with cylindrical pin and conical are small. In the case of joints welded by cylindrical pin tool, maximum value was 95.6 HV while the conical pin was 97.5 HV. The shapes of the diagrams of hardness distributions in the investigated joints are very similar and the differences are due to the shape of the welding tools. In both considered joints, lowest hardness values observed in the advancing side of the weld on that side, which was welded in second pass of the tool. On that side of the weld, which was welded in the first pass, there is the same hardness distribution but due to the high downforce of tool to jointed sheets final hardness is slightly higher. On the retreating side of the weld was observed noticeably higher hardness relative to the advancing side of the weld.

Due to the larger face surface of the cylindrical tool pin compared to the conical tool pin the width of the hardened area of the joint is larger in the first case. The average value of the hardness of joints made by both types of tools is about 95 HV while the native material, this value is about 87 HV.

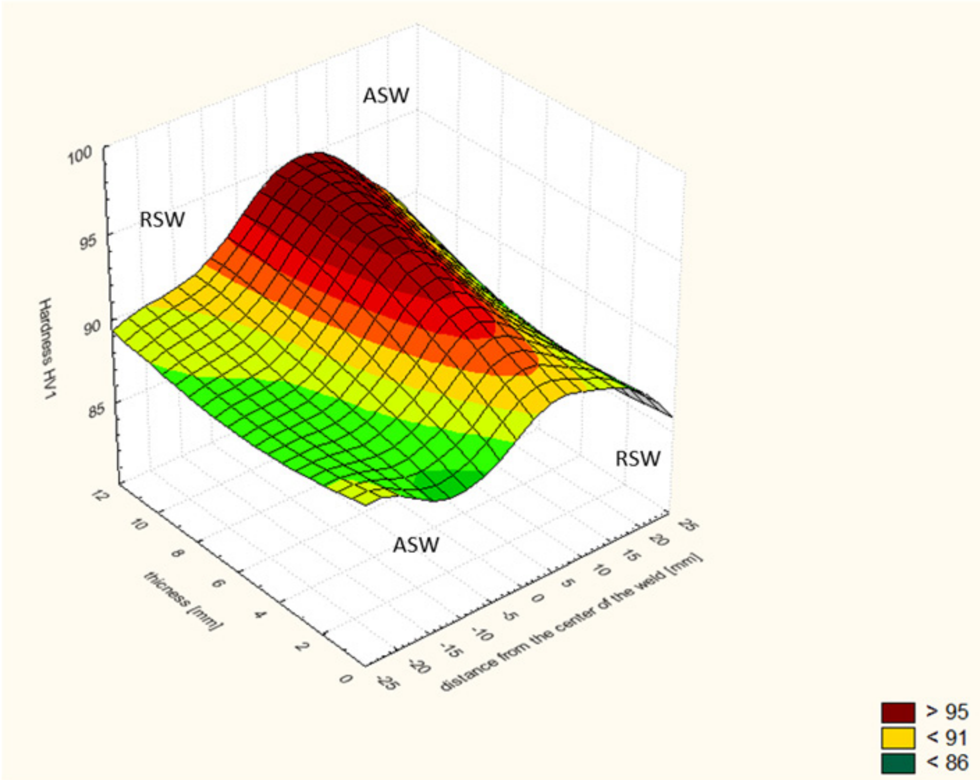


Fig. 4. Hardness distribution in joint welded by tool with conical pin, ASW – Advancing Side of the Weld, RSW – Retreating Side of the Weld

The increase of the hardness in the welded joints can be caused by fragmentation of the grains due to mechanical impact of welding tools, deformation and recrystallization in the nugget of the weld both the thermo-mechanically affected zone of the weld.

4. Summary and conclusions

Friction Stir Welding is an alternative to traditional methods of arc welding for joining aluminium alloys. Bonding occurs by mixing of the plasticized material of joined sheets at a temperature of about 450 °C, which is in the solid state. This makes it possible to obtain joints having a higher strength compared to welds obtained by traditional MIG or TIG methods. The increase in strength properties is associated with an increase in the hardness of the joints. In order to evaluate the hardness distribution on the cross section of joints welded by FSW studies were carried out by Vickers. In the research were used joints of 5083 aluminium alloy - the most commonly used in shipbuilding.

Alloy 5083 is susceptible to the strengthening of plastic processing. 5083 alloy sheet was brought in H321 that is hardened after cold working.

Hardness tests on a cross section of FSW welded joints made using two types of tools - with cylindrical and conical pin. The average value of the hardness of the joints is approximately 95 HV while the native material of about 87 HV.

Probably as a result of the thermal effect accompanying the process of welding observed decrease of hardness in the advancing side of the weld. In other zones of joints, mechanical impact was so great that despite the increase in temperature above the recrystallization achieved hardness increase relative to the native material. The increase of hardness in the nugget and thermo-mechanically affected zone of the weld is likely due to mechanical impact of pin tool, which causes fragmentation of grains and thermo-plastic processing of welded materials.

The shape of the welding tool pin does not affect the mean value of hardness in the weld, however, to influence the width of the joint with increased hardness relative to the base metal.

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