THE INFLUENCE OF WELDING PARAMETERS ON THE QUALITY OF JOINTS MADE BY FSW OF AW-5083 ALUMINIUM ALLOY

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Abstract

The article presents the research results on the mechanical properties of aluminium alloy 5083 - the most currently used in shipbuilding aluminium alloy and its friction stir welded (FSW) joints. Influence of different welding parameters and kinds of welding tools used for the connection of the sheets made of 5083 alloy on quality of the joint were presented. During the study used two types of tools: with cylindrical pin and with conical pin. Metallographic analysis of chosen joints showed the correct construction of structural bonded joints.

Friction Stir Welding (FSW) - a new technology can be successfully used for butt welding of different types of aluminium alloy sheets. FSW method can be an alternative to traditional arc welding methods i.e. MIG or TIG. The research was carried out using a static tensile test in accordance with the requirements of the Standards PN-EN ISO 4136:2011 and PN-EN ISO 6892-1:2010. Flat samples cut perpendicular to the direction of rolling were used. The research was conducted at the temperature of + 20 ºC.

The shape of the welding tool pin does not affect the strength properties of the FSW welded joint. In the case of joints welded by FSW method, achieved reduction of ultimate tensile strength (UTS) approx. 7 % and yield strength (YS) approx. 12 % compared to the native material. When considering plastic properties of FSW welded joint observed almost 2 times lower elongation comparing to the native material, but meet the requirements of classification societies, including the PRS (Polish Register of Shipping).

Keywords: Friction stir welding (FSW), aluminium alloys, joining, welding parameters, mechanical properties

1. INTRODUCTION

The interest growth of the ship designers in aluminium alloys used for hull and whole vessels construction gives an opportunity of a considerable reduction of its mass. This allows to increase the ship displacement with simultaneous increase of her dead-weight tonnage or her speed. Weld-able aluminium alloys for plastic processing, the most popular in shipbuilding industry 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. Nowadays the most common aluminium alloy used in shipbuilding is AW-5083 (AlMg4.5Mn0.7) alloy [1, 2, 3].

Joining aluminium and its alloys by 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. An alternative to traditional arc welding is a method known as friction stir welding (FSW) [4].

The method of friction stir welding 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 [4, 5, 6]. FSW is a method of welding in a solid state of mainly aluminium alloys, copper alloys and stainless steel. Compared to traditional arc welding methods used in the shipbuilding industry (MIG, TIG), this method does not require such time-consuming preparation of joined plates and the use of additional materials, such as filler material and shielding gases. The main advantage of this method is the fact that it is easy to obtain welds of high, repeatable properties [5, 7]. Constant development of this method resulting in, among others, the development of new shapes of welding tools enforces carrying out the work related to the optimization of welding parameters selection in order to obtain joints with the best possible quality.

The aim of this study was to determine the effect of the tool shapes and welding parameters on joints quality determined on the basis of the appearance of the weld, structure and mechanical properties. Investigated joints of AW-5083 aluminium alloy were welded by FSW using two kinds of tool - 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**.

Table 1 Chemical composition of 5083 aluminium alloy (wt. %)

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

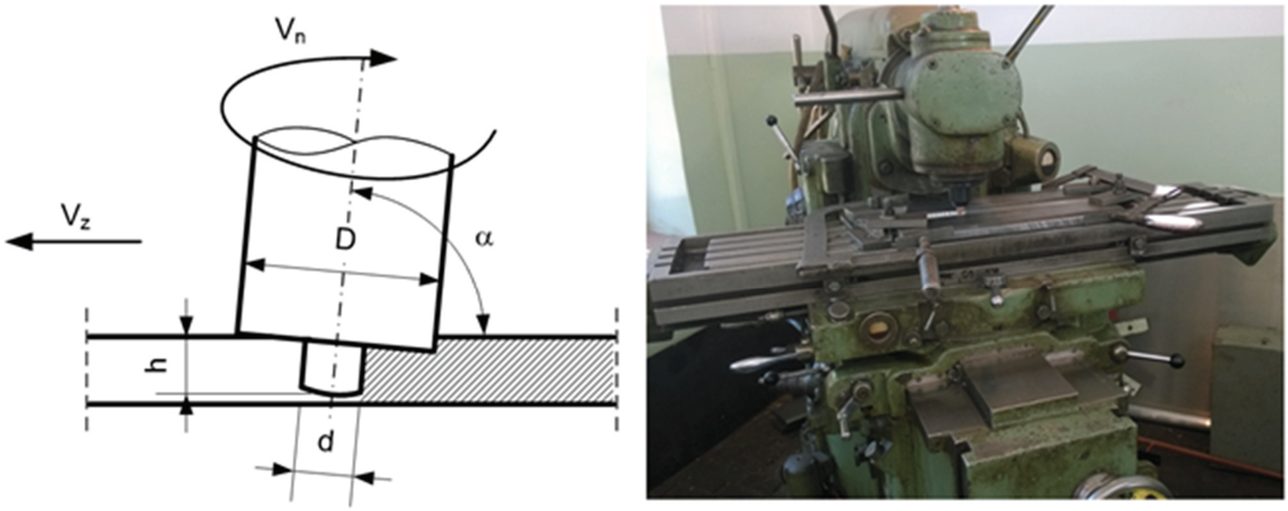
Butt joints of AW-5083 alloy sheets were made using FSW. Sheet thickness was g = 12 mm. With exception of provided general cleanliness of the sheets there wasn't used any degreasing agent interfaces connected elements.

The diagram of friction welding (FSW) and view of stand used in research are shown in **Figure 1**. The stand was built on the basis of universal milling machine FWA-31.The welding parameters are shown in **Table 2**.

Table 2 FSW parameters of 5083 aluminium alloy sheets

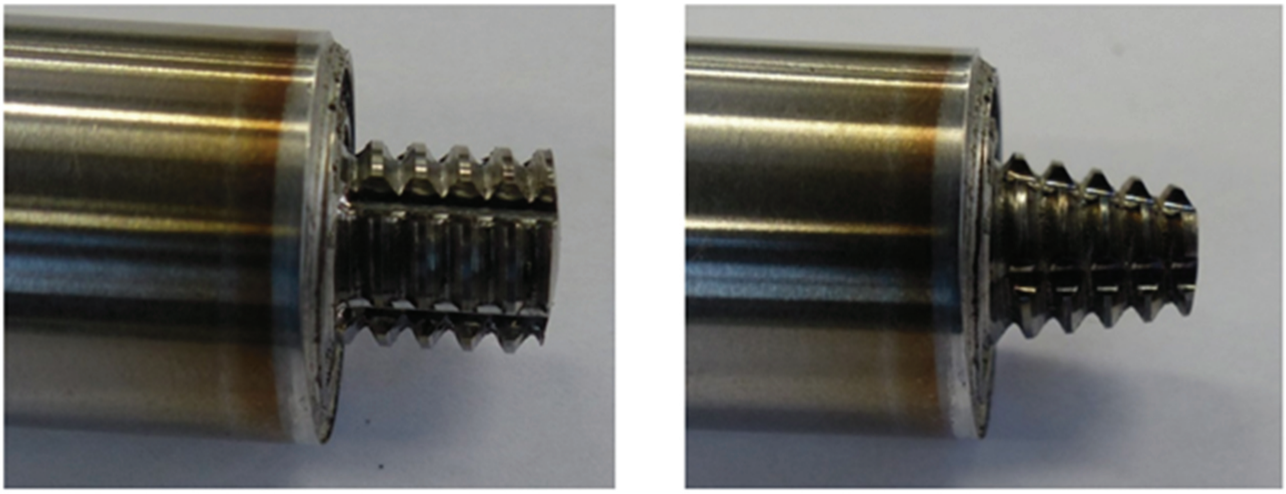
Kind of tool	**Tool dimensions**			**Angle of tool deflection** α **[°]**	**Mandrel's rotary speed** V_n **[rpm]**	**Welding speed** V_z **[mm / min]**
	D [mm]	**D [mm]**	**H [mm]**			
With cylindrical pin	20	10	7.5	88.5 - 89.5	150 - 750	52 - 180
With conical pin	20	10 - in the top 6 - in the bottom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

For joining sheets made of 5083 alloy were used for two kinds of tools - with cylindrical pin and with conical pin. Views of these tools are shown in **Figure 2**. For optimizing quality of joints were used different parameters: angle of tool deflection, mandrel'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.



a) b)

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



a) b)

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

The study was performed macrostructures of joints bonded by both kinds of tools. Stereo - microscope OLYMPUS SZX16 was used in research. The study of macrostructure of cuts prepared mechanically and digested Keller reagent to reveal the flow lines [8, 9]. Thus it became possible to identify areas of particular characteristic of bonded joints.

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 flat-type samples using 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.

3. THE RESEARCH RESULTS

Changed parameters: rotary speed (V_n), welding speed (V_z) and angle of tool deflection (α) affect the properties of the joints. Very large forces associated with the welding process, especially during the first phase of welding cause that high rigidity of the entire system is required - mainly mounting joined sheets. Insufficient downforce of joined plates results formation of the gap between them. Both the incorrect selection of welding parameters and insufficient downforce of joined plates caused the occurrence of discontinuities (welding defects) in the joints.

An example of the welded joint by different welding parameters is shown in **Figure 3**. Visible discontinuities of joint points to incorrect welding technology.

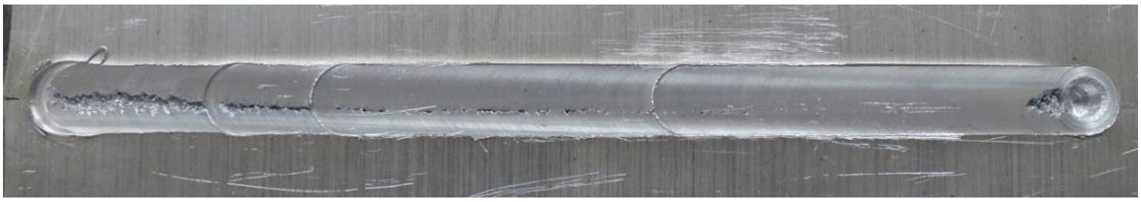


Figure 3 An example of friction stir welded joint with incorrect parameters - visible welding defects

The optimizing process of welding parameters selection enables obtaining proper joint without flaws. View of an exemplary joint without visible welding defects is shown in **Figure 4**.

Figure 4 An example of friction stir welded joint with correct parameters - lack of welding defects

Improper selection of the welding parameters, in the extreme case, may lead to breakage of the tool, as shown in **Figure 5**.

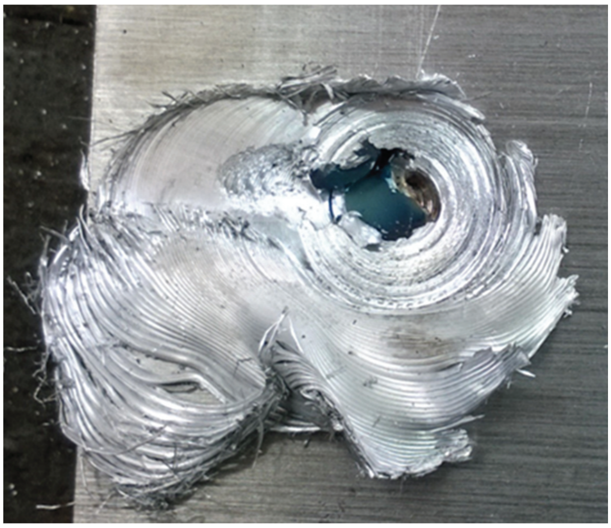


Figure 5 View of broken FSW tool into 5083 alloy sheet - result of joining with incorrect parameters

For macrostructure examination and the static tensile test were selected that joints, in which there was no welding defects, verified in the visual studies and by X-ray flaw detection.

In **Figures 6 a)** and **6 b)** 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.

Figure 6 Macrostructures of FSW welded joints: a) by cylindrical tool, b) by conical tool

In the FSW joint can be divided the following zones [10, 11]:
NM - native material,
HAZ - heat affected zone,
TMAZ - thermo-mechanically affected zone,
NUGGET - weld nugget.

The mechanical properties of 5083 alloy and its joints welded by FSW are shown in **Table 3**. Presented values are the average of the three samples, obtained in the static tensile test.

The results were compared with the mechanical properties of joints welded by traditional MIG method [12].

Table 3 Mechanical properties of 5083 alloy and its joints welded by FSW and MIG [12]

Alloy - welding method - tool type	UTS [MPa]	YS [MPa]	EL [%]
5083 - native material	349	273	19.7
5083 - FSW - cylindrical tool pin	321	235	10.5
5083 - FSW - conical tool pin	326	241	10.4
5083 - MIG	282	206	15.1

The mechanical properties of welded joints made by the FSW tool with cylindrical and conical pin are at the same level. The absence of significant differences in the results of FSW joints obtained in the static tensile test indicates that the shape of pin of welding tool does not affect the mechanical properties of the joint.

In the case of joints welded by FSW method, achieved reduction of ultimate tensile strength (UTS) approx. 7 % and yield strength (YS) approx. 12 % compared to the native material. When considering plastic properties of FSW welded joint observed almost 2 times lower elongation comparing to the native material, but meet the requirements of classification societies, including the PRS (Polish Register of Shipping). The minimum value of elongation must exceed 10 %.

In the case of joints welded by traditional arc welding method (MIG), achieved reduction of ultimate tensile strength (UTS) approx. 15 % and yield strength (YS) approx. 25 % compared to the native material. Decrease of plastic properties was approx. 23 %.

4. CONCLUSION

Application of FSW method for joining metal sheets made of 5083 aluminium alloy allows obtaining very good mechanical properties of the joints. In order to achieve high quality of joint it is necessary to precisely select the welding parameters.

The research showed that the welding parameters have a big impact on the quality of joints made by FSW. In the extreme case, incorrectly selected parameters can damage the tool. Changed parameters: rotary speed, welding speed and angle of tool deflection affect for the properties of joint as well as the stiffness of mounting the sheets. Insufficient downforce of joined plates and the incorrect selection of welding parameters caused the occurrence of welding defects (discontinuities) in the joints. Joints made both types of tools (with cylindrical and conical pin), with the appropriate parameters have the correct structure. The visual study and X-ray flaw detection of investigated joints showed no welding defects. Macroscopic tests showed the correct structure of joints.

The study of the mechanical properties obtained in the static tensile test showed higher strength of the joints welded by FSW compared to joints welded by traditional arc method - MIG. Practically the same values UTS, YS and EL were obtained for samples welded by tool with cylindrical and conical pin. There are no differences in the results of research suggests that the shape of the tool pin does not affect the strength of welded joints made by FSW. UTS and YS of welded samples decreased respectively - about 7 % and about 12 % in comparison to native material. EL decreased almost 2 times (down from about 20 % to about 10 %). Despite such a large decrease in the plastic properties of FSW joints still meet the requirements of classification societies (eg. PRS).

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