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INFLUENCE OF WELDING PARAMETERS OF FSW ON HARDNESS DISTRIBUTION IN JOINTS OF AW-5083 ALLOY

Krzysztof Dudzik, Jarosław Januszkiewicz

Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 5586 549, fax: +4858 5586 399
e-mail: k.dudzik@wm.am.gdynia.pl

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 and native material. Hardness testing in across researched joints showed that the change of welding parameters in the range proposed in the research does not impact on the hardness distribution 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 [3, 5, 7, 15]. 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, welding parameters) resulted in significant improvements in the properties of welds but their strength is still less than the base material [1-5, 9, 11, 14].

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, 13]. 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 [8, 10].

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 [5, 6].

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).

2. The research methodology

The study used EN AW-5083 H321 aluminium alloy. Analysis of the chemical composition of the sample material was carried out on a Solaris-ccd plus spectrometer (Fig. 1a). It is an optical emission spectrometer with spark excitation by GNR. It performs the analysis of solid samples and metal alloys of different matrices [12]. Percentage contents of selected elements in tested aluminium alloy were presented for sample after four-spark test (Fig. 1b).

a) *b)*

Fig. 1. Solaris-ccd plus optical spectrometer (a) and the sample used for the chemical composition testing (b)

Butt joints of AW-5083 alloy sheets were made using FSW. The diagram of friction welding (FSW) and view of stand used in research are shown in Fig. 2. The stand was built on the basis of universal milling machine FWA-31.

a) *b)*

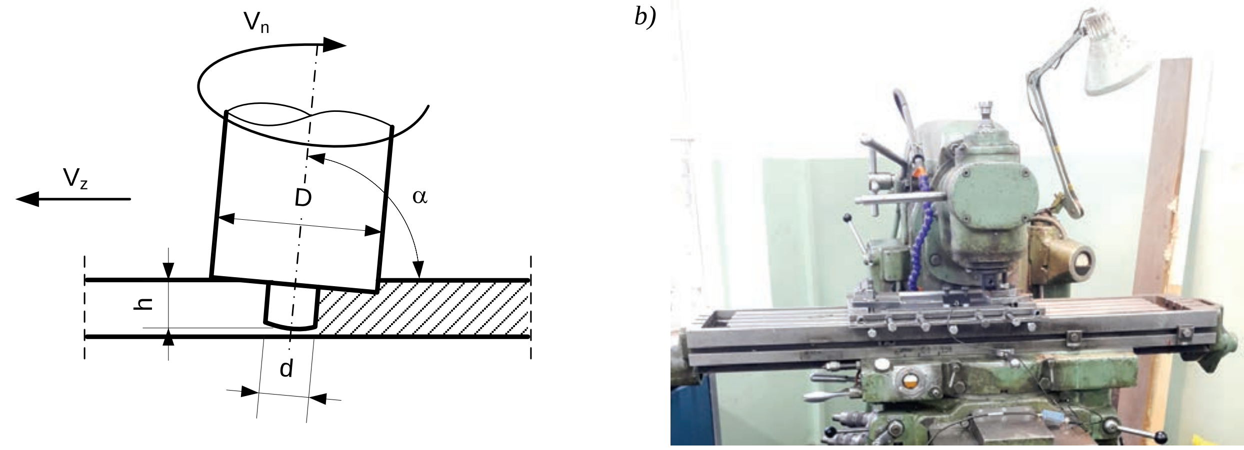

Fig. 2. The diagram of FSW (a) and view of stand used in research (b)

Sheet thickness was g = 12 mm. The sheets were welded on both sides using identical parameters. The welding parameters are shown in Tab. 1.

Tab. 1. FSW parameters of 5083 aluminium alloy sheets

Tool dimensions			Angle of tool deflection α [°]	Tool's rotary speed V_n [rpm]	Welding speed V_z [mm/min]	Specimen
D [mm]	d [mm]	h [mm]				
20	10 – in the top 6 – in the bottom	7.5	89	500	138	1
					84	2
					52	3
					104	4

For joining sheets made of 5083 alloy was used tool with conical pin. View of that tool is shown in Fig. 3. 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 identical parameters – chosen in optimization process.

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

Fig. 3. View of tool used for joining by FSW

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

The results of the chemical composition of tested EN AW-5083 alloy after four-spark test are presented in Tab. 2.

Tab. 2. Results of chemical composition of AW-5083 alloy after four-spark test

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Sn
mean	0.171	0.288	0.018	0.393	4.035	0.096	0.011	0.030	0.002
max	0.174	0.295	0.019	0.403	4.130	0.098	0.012	0.032	0.002
min	0.167	0.277	0.017	0.379	3.894	0.093	0.011	0.027	0.002
	P	Pb	V	Ag	Sb	Ca	Ga	Zr	Al
mean	0.005	0.001	0.015	0.005	0.006	0.004	0.025	0.005	94.905
max	0.005	0.001	0.015	0.005	0.006	0.005	0.027	0.005	95.072
min	0.005	0.001	0.014	0.005	0.005	0.003	0.024	0.005	94.787

Location of measurement points are shown in Fig. 3. In Fig. 4 overview of the sample cross-section of FSW double-side welded 5083 aluminium alloy were shown (with characteristic zones). Macrostructure examination confirmed the correctness of structures of chosen joints.

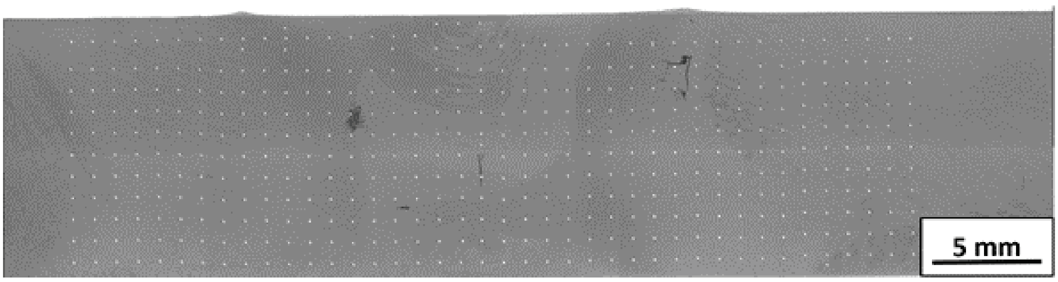

Fig. 3. The view of FSW welded specimen after hardness testing with visible measurement points

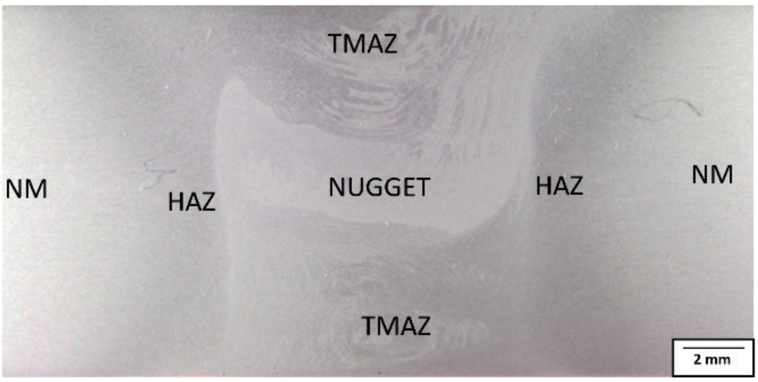

Fig. 4. Macrostructure of FSW welded joint: NUGGET – weld nugget, HAZ – heat affected zone TMAZ – thermo-mechanically affected zone, NM – native material

The results of hardness tests in the FSW welded joints are shown graphically in Fig. 5-8.

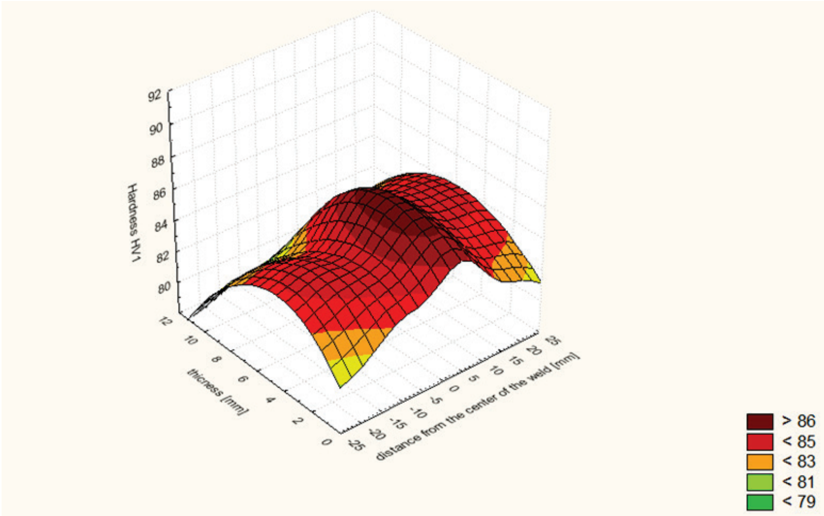

Fig. 5. Hardness distribution in joint – specimen 1

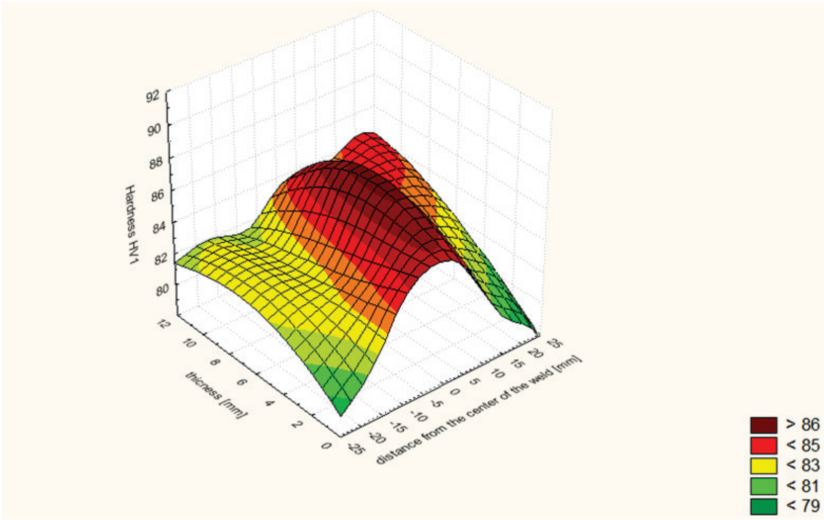

Fig. 6. Hardness distribution in joint – specimen 2

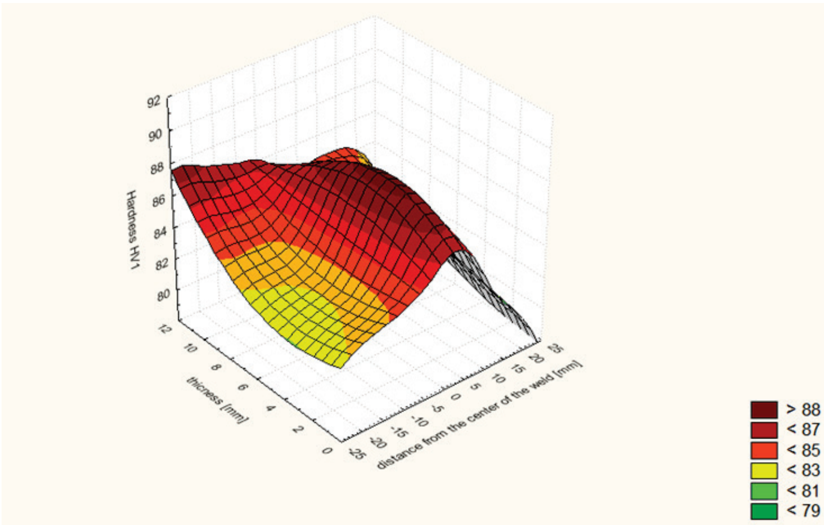

Fig. 7. Hardness distribution in joint – specimen 3

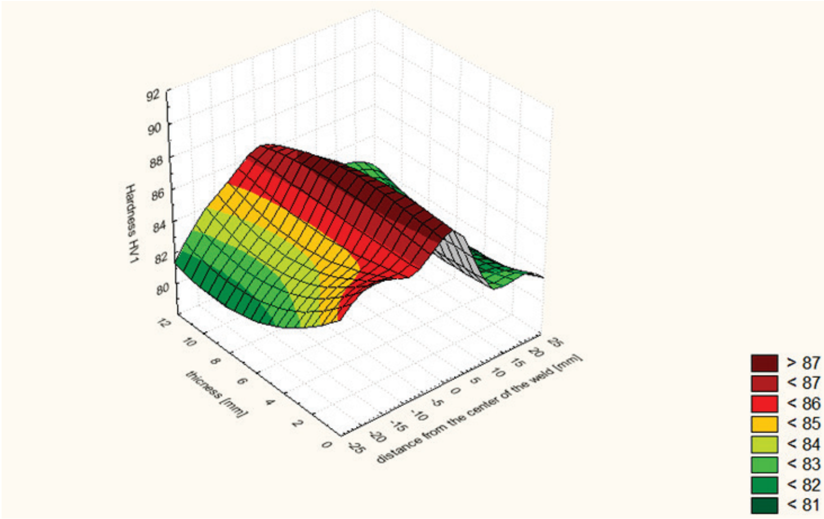

Fig. 8. Hardness distribution in joint – specimen 4

The shapes of the diagrams of hardness distributions in the investigated joints are very similar. The maximum hardness value occurs in the middle of the welded joint – in weld nugget.

The research results of hardness test obtained in characteristic zones of joints are presented in Tab. 3.

Tab. 3. Average values of hardness in characteristic joint zones

Joint zone	Specimen 1		Specimen 2		Specimen 3		Specimen 4	
	Hardness	Std. Dev.	Hardness	Std. Dev.	Hardness	Std. Dev.	Hardness	Std. Dev.
	[HV1]		[HV1]		[HV1]		[HV1]	
NUGGET	87.1	1.7	87.6	2.3	87.9	2.8	88.3	2.1
HAZ	85.7	2.3	83.0	2.1	84.7	2.8	82.6	2.3
TMAZ	86.5	2.8	86.5	2.1	87.5	2.8	87.8	3.6
Native material	83.3	1.9	82.7	1.9	83.2	1.6	83.3	1.7

The maximum average value of hardness (88.3 HV) was registered in weld nugget while the lowest value was in heat-affected zone (82.6 HV). The average HAZ hardness was on the same level as the base material.

The average value of the hardness for whole joints made with different parameters is about 86.3 HV while the native material, this value is about 83.1 HV.

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 aluminum 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 aluminum 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 with different parameters made using tool with conical pin. The average value of the hardness of the joints is approximately 86 HV while the native material of about 83 HV.

The change in hardness relative to the native material for characteristic weld zones is similar for all samples. For the weld nugget, the increase in hardness was 5.5%, for the thermo-mechanical affected zone it was 4.7%. The smallest increase in hardness relative to native material occurred in the heat-affected zone and amounted to 1.1%.

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 change of welding parameters in the range proposed in the research did not have a significant impact on the hardness distribution in the welded joints.

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