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THE APPLICATION OF FRICTION STIR WELDING (FSW) OF ALUMINIUM ALLOYS IN SHIPBUILDING AND RAILWAY INDUSTRY

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Abstract

The article describes possibilities of application of friction stir welding (FSW) in shipbuilding and railway industry. Actually, in these sectors of industry more and more often modern construction materials are used. The biggest restriction of implementing new materials is technological possibility of joining them. One of construction materials used in the shipbuilding is aluminum, mainly its alloy of 5xxx-aluminium-magnesium series. Its application is justified by good corrosion resistance in seawater and good mechanical attributes. Thanks to susceptibility to plastic treatment, one gains good mechanical attributes with thrice-smaller density than a density of steel, what causes triple reduction of weight of aluminum construction relative to steel one. Alloys of 5xxx series are well weldable. It is generally known that welding is not a good way to joint metals, especially the aluminum. The application of FSW with mixing allows one to change approach to production of aluminum constructions. Using aluminum plates prefabricated with FSW method allows one to reduce time needed for installation of construction and considerably decreases the production costs. The article describes technology and directions of development of friction welding of aluminum alloys of 5xxx series using FSW method. There is also shown analysis of its usefulness in ship and railway industry and comparison of mechanical attributes of weld made with electric arc using MIG (135), TIG (141) method and FSW method.

Keywords: *Friction Stir Welding (FSW), aluminium alloys, welding, shipbuilding industry, mechanical properties*

1. Introduction

Friction stir welding (FSW) is a process in which a heat necessary to join the welded elements is received directly from conversion of mechanical energy to the heat by occurrence of friction. This method can be used to weld all the aluminium alloys including those considered to be difficult to weld. In FSW process, neither additional binder nor gas shield is used so there are no factors harmful to the environment.

FSW method for industrial scale was firstly used in building ships of aluminium-magnesium alloys of 5xxx series in 1995. This method was then used in prefabrication of flat sections. This has saved time and money. This method also started to be used in other industry sectors, such as railway industry, motorization and cosmonautics. The Figure 1 shows number of patents used since the beginning of industrial using of method until 2008. In the graph, you can see that this method is considerably more often used in Japan. 45% of patents belong to Hitachi Company, and 10% to Boeing, KHI and aluminium suppliers: Showa and NLM.

In FSW method, the heat necessary to weld materials is released between rotary tool and material of welded elements. Pin rotating at high speed as a result of friction gets hot, plasticize the material, and is moved along the line of welding. Along with the plasticization, the materials of both welded elements are mixed with each other on the entire width of weld. The scheme of this method for the butt welds is shown in the Fig. 2a) and for the overlay welds in the Fig. 2b). This method can be used to make butt welds, overlay welds, angular welds and T-joints.

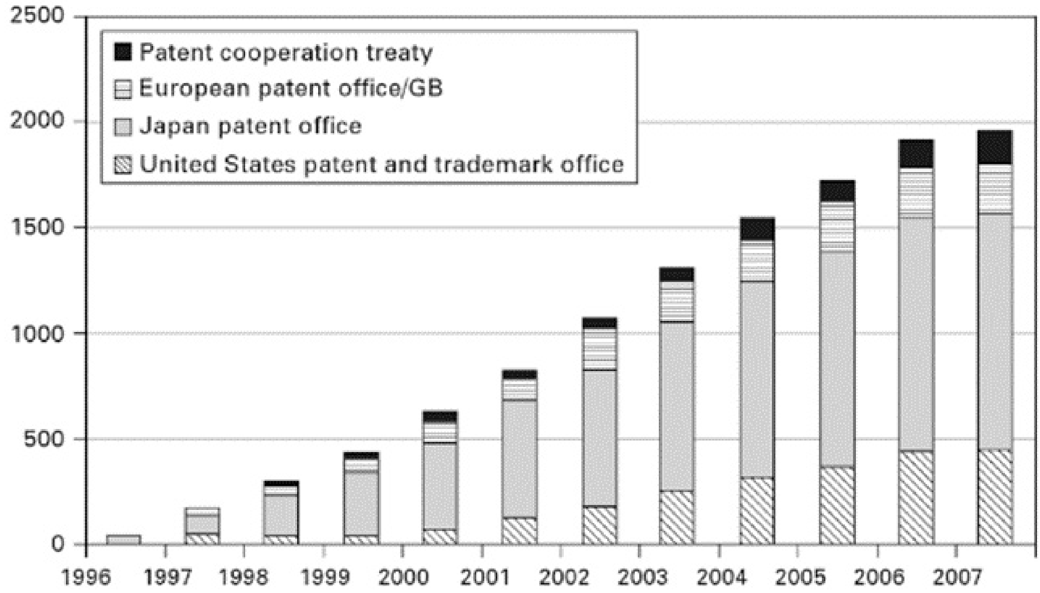

Fig. 1. The number of patents for SFW used in 1996-2008 [1]

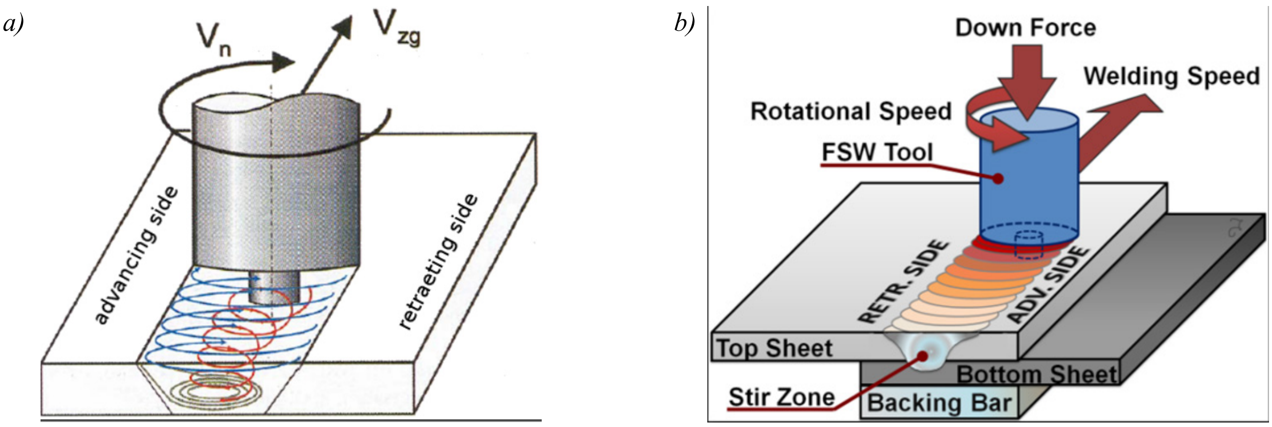

Fig. 2. Diagram of friction stir welding: a) for butt welding [2], b) for overlay welding [3]

The FSW process is shown in Fig. 3. The process starts with the fixed attachment of the work pieces and the start of the pin rotation. Then the pin is immersing into the entire thickness of the material (Fig. 3a). When the plasticity of the material (Fig. 3b) is achieved, below the melting point, the pin starts to move along the joining edge (Fig. 3c). After welding the whole length of the joint, the pin is retired from material (Fig. 3d). Fig. 4 shows the correct weld of 5083 alloy.

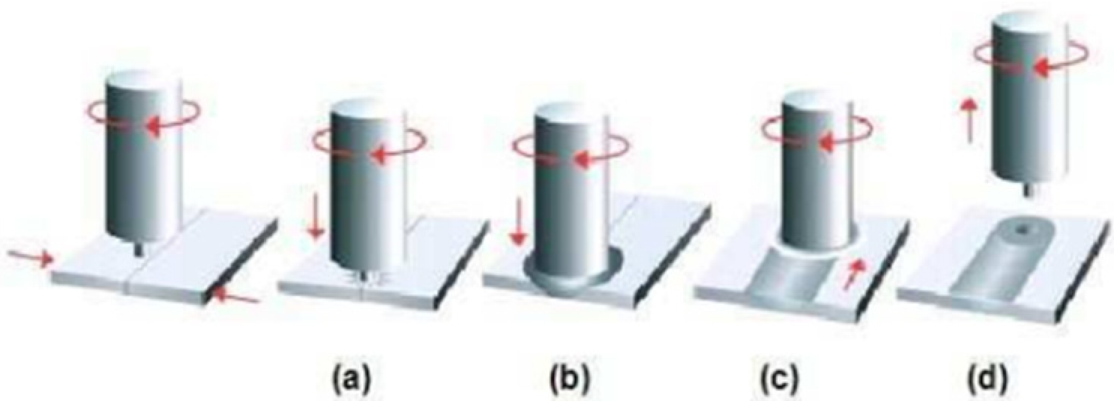

Fig. 3. Friction stir welding phases [3]

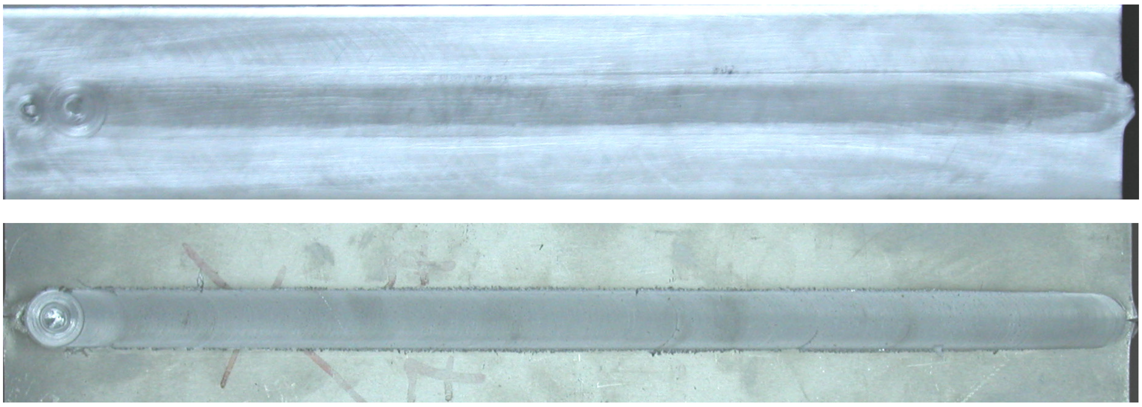

Fig. 4. The appearance of the 5083 alloy weld made by the FSW method (upper – face side, lower – root side)

The advantage of the FSW method is ease to control the parameters such as:

– rotational speed (rang from 180 to 300 rpm) depends on material thickness,
– longitudinal feed, (from 9 to 13 cm per min),
– the pressure exerted by the tool (from 35 to 70 MPa).

In the FSW method, it is necessary to obtain the correct correlation between the tool speed and the longitudinal feed rate. The temperature around the tool must be large enough to make mixing of the material possible and minimizing the forces acting on the tool at the same time. When the temperature is too high, the weld will have the undercuts. On the other hand, when the temperature is too low, the forces acting on the tool can lead to its destruction and the weld will not be obtained [6]. Currently, the researchers are conducted to improve the FSW method in terms of process efficiency and quality of the connections [9].

The microstructure of the material obtained after the FSW is shown in Fig. 5. The microstructure is classified as:

a) Native material,
b) Heat Active Zone (HAZ),
c) Thermo Mechanically Affected Zone (TMAZ),
d) Weld nugget.

In the properly FSW welding process, weld nugget should be in the middle of the joint and its size should be slightly larger than the welding tool pin.

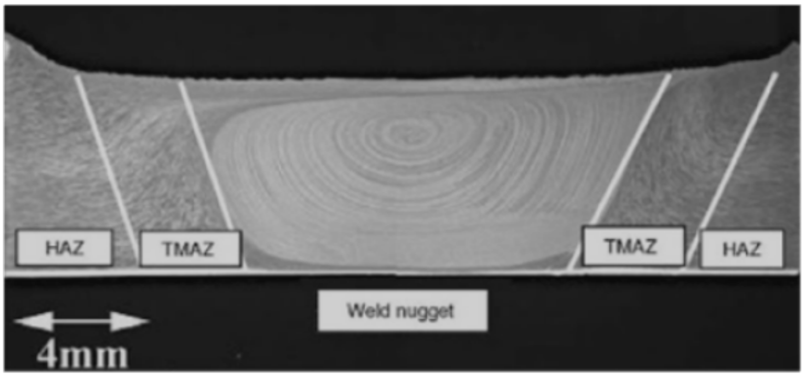

Fig. 5. Microstructure of FSW weld [4]

2. The research methodology

The 5083 aluminium alloy was analysed during the researches. The chemical composition of this material was presented in Tab. 1. The researches consisted of compare the mechanical properties of welds obtained by MIG (135), TIG (141) and FSW.

Tab. 1. Chemical composition of tested aluminium alloy (wt. %) [8]

Chemical composition [%]										
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
AW-5083	0.195	0.18	0.09	0.66	4.74	0.11	0.042	0.02	0.003	rest

The mechanical properties of samples were carried out in accordance with PN-EN ISO 6892-1:2016-09 and PN-EN ISO 4136:2013-05 in ambient temperature. Hardness HV5 was carried out in accordance with PN-EN ISO 6507-1:2007 with load of 49 N. Hardness measurements covered the whole width of the welded specimens to the effect of reveal the hardness distributions of the material depending on the distance from the weld axis. The location of these points in butt welds is determined by the PN-EN ISO 9015-1:2011.

3. The research results

The mechanical properties of the native material (5083 aluminium alloy) and its properties after FSW, MIG and TIG welding are shown in Tab. 2 and also presented in the chart (Fig. 6). The line chart (Fig. 6) presents YS/UTS factor.

The mechanical, strength and plastic properties of the FSW welded specimens are considerably higher than those of other welding methods. They are also much closer to the native material properties than in case of MIG and TIG welding.

It should also be mentioned that during the tensile test, the MIG and TIG welded specimens cracked in the weld, while for FSW welded specimens the fracture occurred in a line that separates the native material from the plastic deformed material.

Tab. 2 Chemical composition of tested aluminium alloy (wt. %)

Material	YS [MPa]	UTS [MPa]	EL [%]
5083/native material	268	343	18.9
5083/FSW	232.0	321.7	10.8
5083/MIG	212.6	285.8	6.7
5083/TIG	159.5	279.2	14.7
where: YS – yield stress, UTS – ultimate tensile strength, EL – elongation			

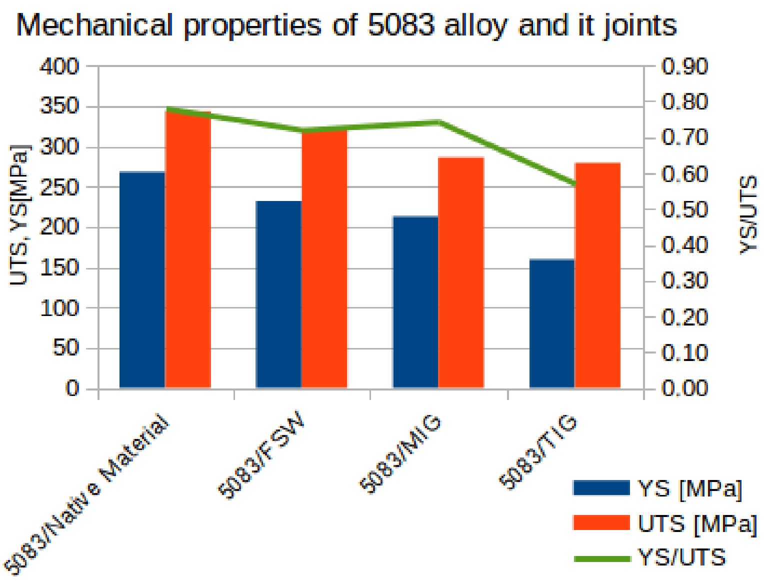

Fig. 6. Graphical interpretation of mechanical properties of 5083 alloy and its FSW, MIG and TIG welded joints

The hardness measurements of FSW, MIG and TIG welds from face side are sown in the linear chart (Fig. 7) and from root side in Fig. 8.

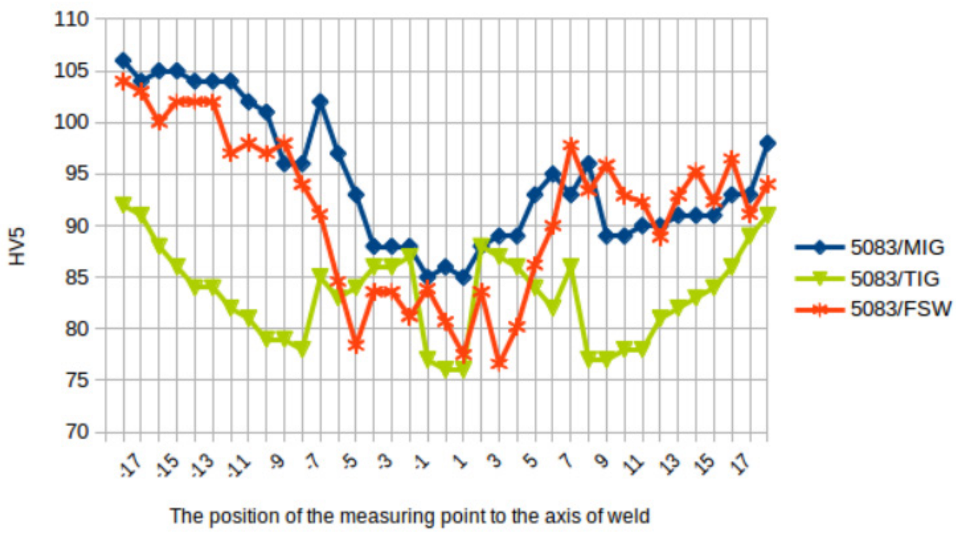

Fig. 7. Influence of the welding method on the distribution of hardness HV5 in the face of connections

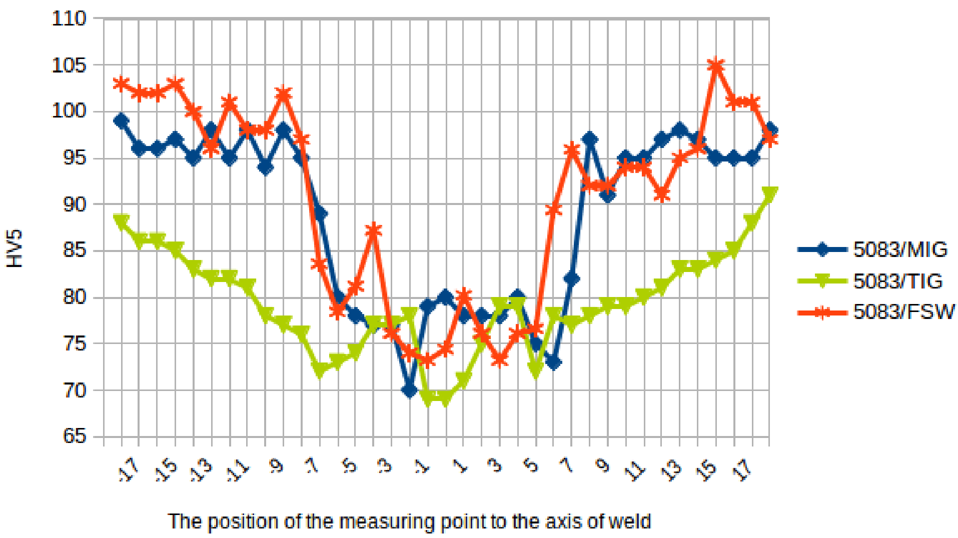

Fig. 8. Influence of the welding method on the distribution of hardness HV5 in the root of connections

4. Summary

After research and analysis of the results, we can see that the strength and plastic properties of FSW welded specimens are significantly higher than MIG and TIG welded. Also the UTS_{FSW}/ /UTS_{Native} ratio is equal 0.94 and is definitely higher than for MIG (0.83) and TIG (0.81) welding methods. It shows that the FSW welding has properties near native material. These properties in combination with advantages such as joining without material melting lower heat affection, there is no need to use the binding material and arc, cheap and simple machinery causes that the FSW method is worth using in industry.

In using FSW welding, it is not necessary to specify technology in the same way as for welding processes. This method does not require special edge preparation and the use of shielding gases, but still produces the good quality joints. There are considerably less of imperfections in FSW welds in comparing with the standard welding methods. Many imperfections such as porosity, cavity, cracks, craters, inclusions, lack of fusions, etc. do not exist in FSW welds.

The biggest disadvantage of FSW welding method is lack of possibility of welding curved elements.

This welding method is perfect to use in shipbuilding and railway industry to prefabrication of flat sections made from aluminium alloys e.g. decks, shell plating, bulkheads, shell of railway carriages etc. It allows one to reduce costs of production and time needed to realise the project.

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