MICROSCOPIC EXAMINATION OF AlZn5Mg1 ALLOY JOINTS WELDED BY FSW AND MIG

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Abstract

The article presents the research results of microscopic examination of friction stir welded joint (FSW) alloy AW 7020 (AlZn5Mg1). The joints welded by traditional MIG method of the same aluminium alloy were chosen as reference points. Friction stir welding (FSW) - a new technology can be successfully used for butt welding of sheet metal with different types of aluminium alloys. The parameters of friction stir welding (FSW) and MIG welding used to join metal alloy AlZn5Mg1 (7020) were presented. Welds made using both the FSW and MIG method were checked using X-ray flaw detection and showed no welding defects.

In order to determine the structural changes in the bonded joints, the samples were polished and then micro-etched KELLER reagent. Metallographic examination was carried out using optical microscope Axiovert ZAISS 25. To determine the grain size in the different zones of joints welded by FSW and MIG methods AxioVision 4.8.2 software was used.

Metallographic examination revealed the existence of an explicit heat affected zone of HAZ in case of MIG welded joints and virtually lack thereof, in case of FSW welded joints.

Microscopic examination of AlZn5Mg1 alloy joints showed that the structure of the FSW welded joint is more homogeneous than the MIG welded joint. The analysis of the grain size of the characteristic zones of joints shows that in the case of joints welded by FSW the weld nugget has smaller grains than the native material. In case of the joint welded by traditional MIG method the biggest grains are in HAZ and the smallest in the native material.

Keywords: *microscopic examination, aluminium alloys, Friction Stir Welding (FSW), MIG welding, grain size*

1. Introduction

Aluminium alloys are getting more and more interest in the shipbuilding industry as these alloys allow a significant reduction in ship structure weight compared with the weight of steel structures. The use of aluminium reduces the weight by about 50%, thereby increasing the displacement of the vessel and maintaining the displacement for load or speed increase and stability improvement. Among weldable Al-alloys suitable to plastic working the group of Al-Mg alloys (of 5xxx- series) of good weldability and relatively good service conditions are still the most popular [4-7]. 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. An alternative to these alloys could be the Al-Zn-Mg (7xxx series) alloys. They exhibit higher strength properties than the mechanical properties of Al-Mg alloys. The disadvantage of the 7xxx series alloys is that they are prone to stress and layer corrosion [2, 5].

Currently, in the shipbuilding industry the most popular joining method of construction elements is MIG welding. It causes structural changes especially in the heat affected zone (HAZ), which affects the variation of mechanical properties and corrosion resistance of cross joints. An alternative to the traditional method of MIG welding is a friction stir welding FSW. It is based on a combination of structural elements in the solid state (below the melting point) so that the properties of joints may be higher than traditional welds MIG, TIG [1, 2, 5-8].

The strength properties of each joint determine the microstructure, which is in the all zones in that joint [2-4]. The area in the native material, which was changed by the heat delivered during the bonding is called the heat-affected zone (HAZ).

The aim of this study is to determine the structural changes and the appointment of a grain size of the zones in joints, depending on the method of bonding alloy AW-7020 (AlZn5Mg1).

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

Butt joints of AW-7020 alloy sheets made using FSW. Sheet thickness was g = 10mm. The sheets were welded on both sides using identical parameters.

The parameters of friction stir welding the are shown in Tab. 2.

Tab. 2. FSW parameters of 7020 aluminum alloy sheets

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]			
25	10	5.8	88.5	450	180

where:
D – shoulder diameter,
d – pin diameter,
h – pin length.

For the comparison, butt joints were used between sheets with a thickness g = 12 mm, made using the traditional MIG arc welding method. The preparation of welded joints was made in accordance with the procedures required by the shipbuilding industry. AlMg5 (Nertalic AG5 made by SAF) alloy wire was used as a filler. Argon was used as shielding gas with a purity of 99.99. The welding parameters used for joining sheets are shown in Tab. 3.

Welds made using both the FSW and MIG method were checked using X-ray flaw detection and showed no welding defects.

Tab. 3. MIG welding parameters of 7020 aluminum alloy sheets

Diameter of welding wire [mm]	Welding current [A]	Voltage [V]	Number of layers
1.6	190 - 230	4 + prewelding	16 - 18

The study was performed macro- and microstructures of joints bonded by FSW and MIG methods. Optical microscope ZEISS Axiovert 25 was used in research. The study of macro and microstructure of cuts prepared mechanically and digested Keller reagent to reveal the grain boundaries and the flow lines [C1, D1, No10]. Thus it became possible to identify areas of particular characteristic of bonded joints.

In addition, the grains size in the characteristic zones of the joints bonded by FSW and MIG methods were determined using AxioVision 4.8.2.

3. The research results

The structure of FSW joints analyzed in a cross is more complicated than the structure of a typical weld (joining by MIG, TIG). Fig. 1 shows a schematic of a typical structure of the FSW joints. In Fig. 2 provided an overview of the sample cross-section of FSW double-side welded 7020 aluminium alloy.

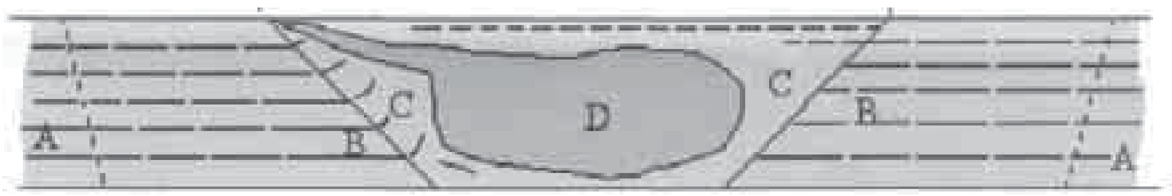


Fig. 1. Schematic diagram of the FSW joint structure welded on one side [P1]

In the FSW joint can be divided the following zones:
A – native material,
B – heat affected zone (HAZ),
C – thermo-mechanically affected zone (TMAZ),
D – weld nugget.

Fig. 2. Macrostructure of FSW welded joint (double-sided welding) - marked by circle welds fragment selected for microscopic examination

The cross section of FSW welded joints can be easily distinguished characteristic zones of this type of joints. The shape of the weld nugget differs from the characteristic “onion” given as an example (Fig. 1) because it uses double-sided welding, which resulted in the symmetric deformation in both directions. Thermo-mechanical affected zone spreading from the nuggets toward the welding face of the width characteristic of the tool shoulder the same on both sides of the weld. At the macro welded joints can not be observed HAZ.

Figure 3 shows the macrostructure of the MIG welded sample of 7020 alloy.

The cross section of the MIG welded joint on the background of the native material clearly stands out joint. The reason for this phenomenon is both a difference in structure and in the chemical composition of that zones of the weld. In the case of MIG welded joints as well as for FSW welded joint the heat-affected zone is not noticeable at the applied magnification.

For it was possible to observe structural changes, especially in the heat affected zone, it was necessary to use higher magnifications of cross sections of researched joints.

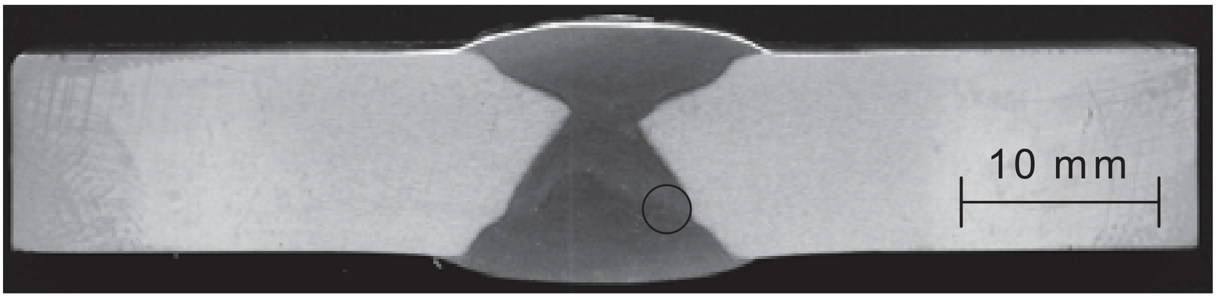
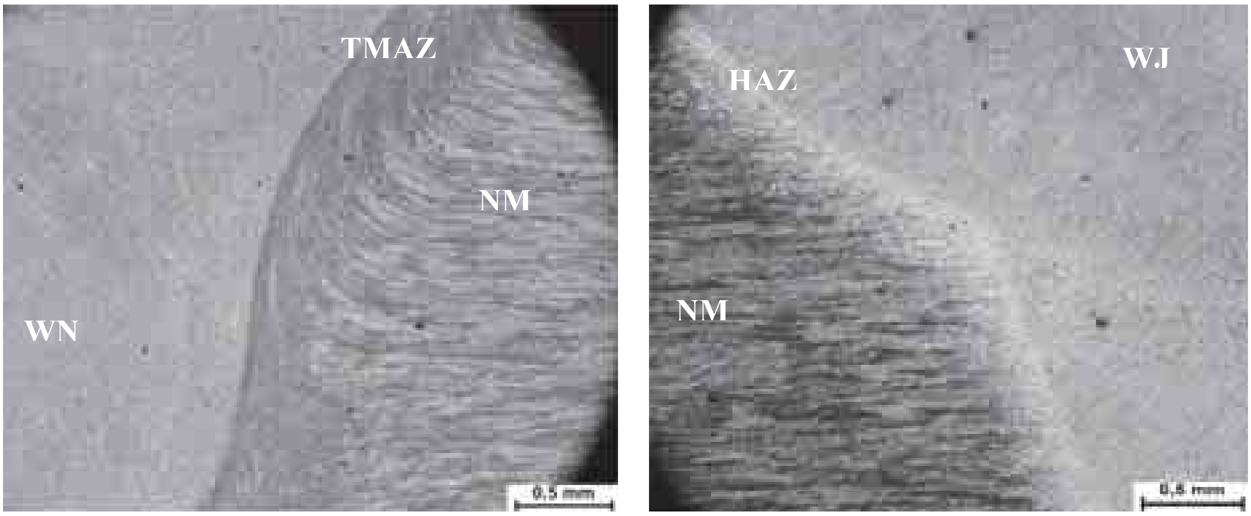


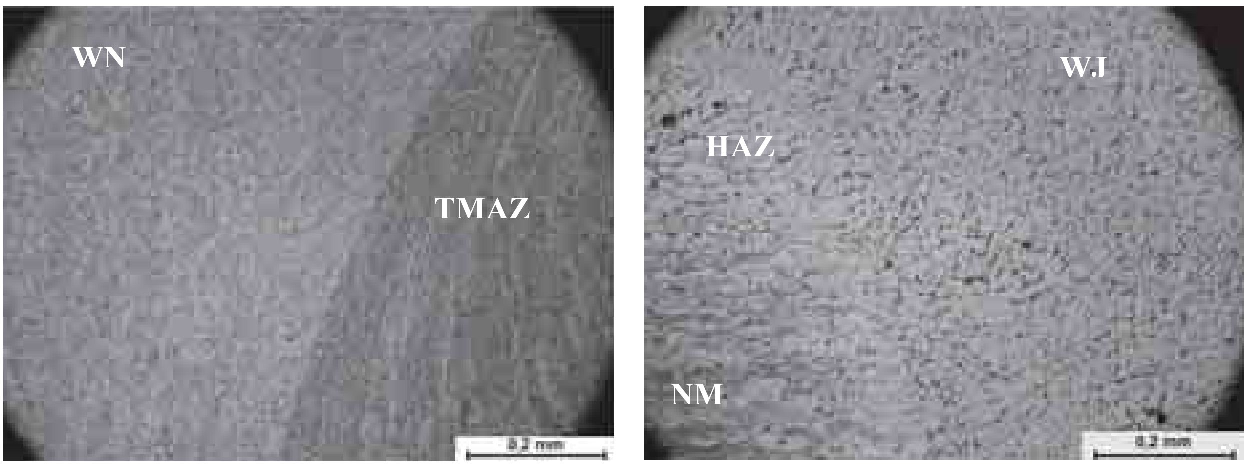
Fig. 3. Macrostructure of MIG weld - marked by circle welds fragment selected for microscopic examination

In order to determine the effect of bonding methods to change the structure of the material performed microscopic examination. Photos of microstructures FSW welded joints and welded using MIG were performed using an optical microscope ZEISS Axiovert 25. Some of the microstructure, the same areas of joints, using different magnifications (from smallest to largest), are shown in Fig. 4-6.



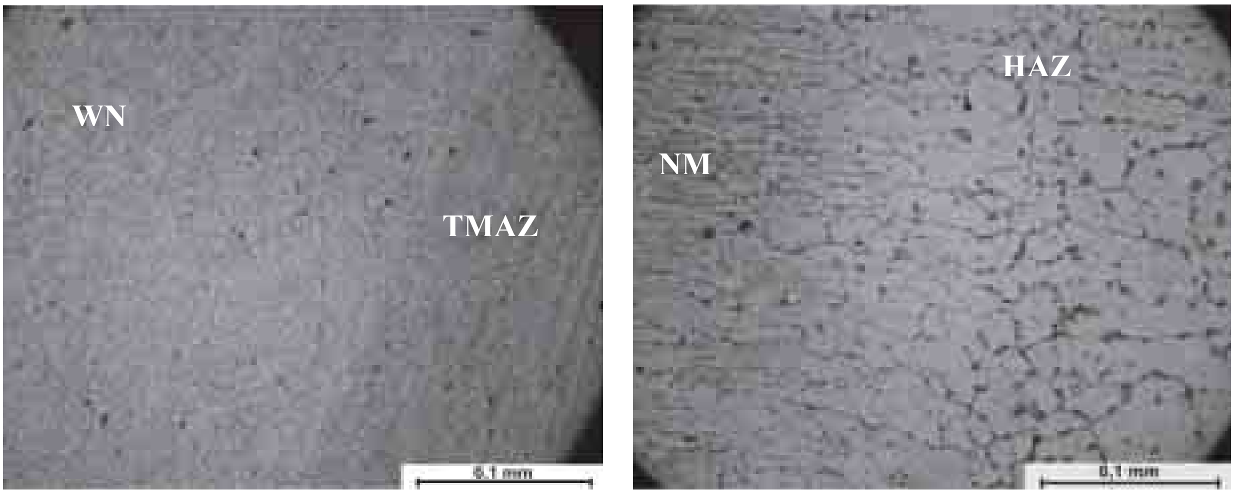
a) b)

Fig. 4. Microstructure of joints: a) welded by FSW, b) welded by MIG



a) b)

Fig. 5. Microstructure of joints: a) welded by FSW, b) welded by MIG



a) b)

Fig. 6. Microstructure of joints: a) welded by FSW, b) welded by MIG

Symbols used in the Fig. 4-6 represent the characteristic joints zones:

NM – native material,
WN – weld nugget,
WJ – weld joint,
TMAZ – thermo-mechanically affected zone,
HAZ – heat affected zone.

Microstructural analysis of the images presented in Fig. 4 allows to conclude that the FSW joint has a more homogeneous structure than comparable MIG weld.

To analyze the microstructure of welded joints by FSW, a fragment of the joint from the advanced side of the tool was chosen. This is that zone of the weld where are greatest strain, both mechanical and thermal. In the joint are visible characteristic lines of the material flow under the influence of impacts on the tool. Clear evidence of the impact of the tool is visible in the thermo-mechanical affected zone. Native material showed signs of cold forming (rolling) and heat treatment in the form of horizontal bands that make up the grain.

Homogeneous colour of weld nugget (compared to the native material) is caused by partial recrystallization with simultaneous deformation of plastic materials mixed with each other during welding process. Additionally, have broken down and mixed oxides during welding and forming a passive layer of intermetallic phases occurring mainly at grain boundaries.

Separation of phases, the most common in the joints alloy AW-7020 is: β (Al_3Mg_2) and η ($MgZn_2$) [9]. With Keller's reagent digestion samples that phases are shown as dark areas on the background of bright grains of solid solution α.

In the joint welded by traditional MIG method can be distinguished typical for the weld dendritic structure. Dendrite growth direction is approximately perpendicular to the fusion zone [9]. At the border weld - native material is clearly noticeable heat affected zone HAZ.

The microstructure fragments of the joints welded by consideration methods presented in Fig. 5 and 6 presents the areas described above in greater magnification. There is possible to compare the grain size of the welds zones. Moreover, one can observe the distribution of intermetallic phases and structural changes caused by heat supply during the joining process.

Grains in the weld in FSW welded joint are much smaller than in the native material. At grain boundaries, both in the weld nugget and in the thermo-mechanically affected zone, almost can not notice the presence of intermetallic phases, which were broken during the welding process. A small number of intermetallic phases in the form of fine precipitates are present inside the grains. When used magnifications can not see the structural changes at the border of weld - native material in the form of grains overgrowing indicative of the occurrence of heat-affected zone HAZ.

Further magnification fragments MIG welded joints confirm the presence of grains of different sizes depending on where they appear in the joint. The adjacent the weld heat affected zone HAZ are shown elongated grains whose shape is the result of combined metal forming. The structure of the HAZ is coarse-grained. The presence in the area of large grains typical of overheating zone of HAZ means weakening the strength properties of the joint. In contrast to the FSW welded joints, various separation phases occur mainly at grain boundaries. This favours the occurrence of increased susceptibility to intergranular corrosion.

To determine the grain size in the different zones of joints welded by FSW and MIG methods AxioVision 4.8.2 software was used. The average values of grain size were shown in Tab. 4.

Tab. 4 Mean values of grains size in the joints zones

Joint zone	Native material	FSW TMAZ	FSW Nugget	MIG weld	MIG HAZ
Grain size [μm]	13 - 20	2 - 6	6 -11	26 - 42	53 - 100

The smallest grains in FSW welded joint, are present in thermo-mechanically affected zone. They are less than or equal to the grains in the weld nugget material. The largest size of grains in the FSW joint found in the native material.

In the case of the MIG welded joint grain size is much more diverse. The largest grains occur in the heat affected zone, but the average grain size that occurs in the weld also exceeds those of the native material.

The grain size of the material has a significant effect on strength properties of the material. The smaller grain size indicates that these properties are higher. This relationship, identifying the impact of grain size on the lower yield strength can be described by the Hall-Petch equation [10]:

$$\sigma_d = \sigma_i + k_y d^{-1/2}, \quad (1)$$

where:
σ_d – lower yield strength,
σ_i – friction stress of busy dislocation (a material constant),
k_y – resistance of grain boundaries for the movement of dislocations (a material constant),
d – diameter of the grain.

4. Summary

Microscopic examination of AlZn5Mg1 alloy joints showed that the structure of the FSW welded joint is more homogeneous than the MIG welded joint.

The analysis of the grain size of the characteristic zones of joints shows that in the case of joints welded by FSW the weld nugget has smaller grains than the native material. It means that the nugget is more durable. In case of the joint welded by traditional MIG method the biggest grains are in HAZ and the smallest in the native material. It means that in that that case the strongest part of the joint is native material. Such variation of the mechanical properties of characteristic zones in the joint welded by MIG is highly undesirable and limits the benefits of high-strength alloy for the construction of welded structures.

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