COMPARATIVE INVESTIGATION OF EBW, FSW AND ARC WELDING OF 6082 ALUMINIUM ALLOY BASED ON MICROSTRUCTURE AND MECHANICAL PROPERTIES

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Introduction

The unique combination of light weight and relatively high strength makes aluminium the second most popular metal that is welded. Modern welding technology has developed greatly in recent years, new processes have been invented, and alternative welding processes such as FSW. Currently, a number of welding processes have the ability to weld thin aluminium alloys; MIG, TIG, PAW, LBW, EBW and FSW. There are differences in the output of the processes, and process choice is related to the application and demands of the customer. In literature, a large number of references to the topic of 6082 alloy combining with FSW and LBW methods can be found often in comparison with traditional welding methods, such as MIG and TIG. However, there is no comprehensive comparison of the properties of sheet metal joints from this alloy in relation to modern welding technologies.

The tests results of welding the most popular aluminium alloy EN AW-6082 is presented. The technologies used for welding were successively TIG, MIG, electron beam welding as well as FSW. The results of metallographic examination as well as mechanical tests were presented.

Experimental procedure

For examination purposes sheets of 6082 T651 aluminium alloy were used with dimensions of 2000×1000×6.35 mm. Samples for welding tests had dimensions of 150 x 300 mm. The welding process was carried out along the edge parallel to the rolling direction. In tests four different joining processes were used: MIG (150A, 18.5 [V], 350 [mm/min], EN ISO 14175-I1-Ar), TIG (178 [A], 13.6 [V], 130 mm / min, EN ISO 14175-I1 -Ar), electron beam welding - EBW (0.0187 [A], 120 [kV], 1600 [mm/min], 5×10^{-5}mbar) and friction stir welding- FSW (355 [mm/min], 710 [rev/min], tool – Triflute). The filler material in the MIG and TIG methods was AlMg4.5MnZr.

To determine the effect of welding procedures on the microstructure of welded joints metallographic examination based on light microscopy (LM, Olympus GX51) and scanning electron microscopy (SEM, HITACHI SU-70 SEM) were conducted. Macroscopic metallographic examination were carried out on the transverse samples. The microstructure was examined on the same sections after grinding, polishing and etching. Mechanical properties were determined based on uniaxial tensile test and hardness measurement.

Results and discussion

Fig. 1 shows the microstructure of the supersaturated and artificially aged 6082 T651 alloy. The average grain diameter, measured by the planimetric method, was 92 µm. Two types of phases can be distinguished on the figure: dark precipitates containing magnesium and silicon and light precipitates containing aluminium, iron, manganese and silicon. The analysis of the chemical composition (Table 1) allowed to state the presence of given chemical elements in individual phases. Based on the chemical composition and literature analysis, it can be concluded that the light areas are the Al (FeMn) Si phase. Depending on the chemical composition these phases can have different stoichiometric composition e.g. Al9Mn3Si, Al5FeSi, Al (FeMn) Si. They can also be characterized by a different morphology such as columnar structure, a polyhedral, and so-called "Chinese writing". Dark precipitations rich in Mg and Si (Fig. 1b) are the Mg_2Si phase whose presence have been confirmed in various scientific research articles.

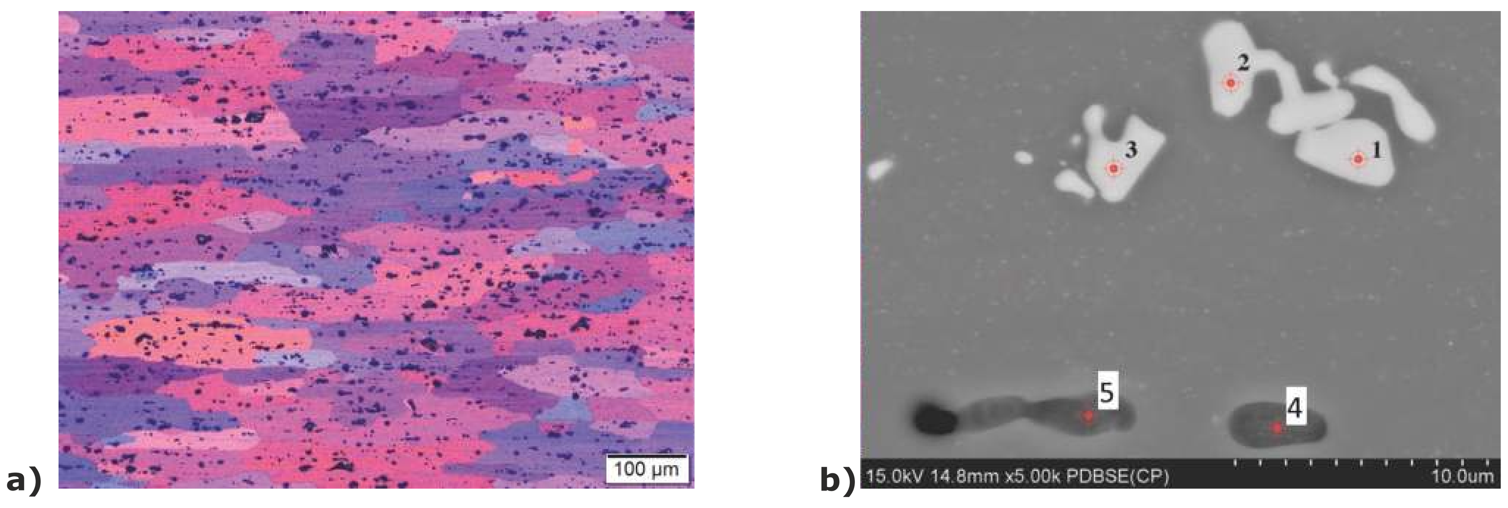

Figure 1. Microstructure of the AA 6082 alloy, a) LM, b) SEM

No.	Chemical composition % wt.				
	Mg	Al	Si	Cr	Mn
1	0.00	60.38	8.86	0.78	11.86
2	0.00	61.47	8.91	0.53	12.36
3	0.00	61.36	9.35	0.83	14.03
4	36.75	43.98	18.98	0.00	0.17
5	14.43	73.32	12.14	0.00	0.12

Table 1. Point analysis of the chemical composition of the AA 6082 alloy

Figure 2 presents the microstructure of welded joints obtained by various methods. Depending on the amount of heat delivered during welding, the welds differ in shape and size. Figure 2A presents the microstructure of the welded joint obtained with the MIG method. Observations have shown that heat affected zone (HAZ) on both sides of the joint area has an average width of 2.55 mm, whereas the weld surface is 67.6 mm². The weld microstructure observed at higher magnifications (Fig. 2A) is characterized by a cast microstructure with intermetallic precipitates present in the interdendritic spaces of the solid solution. Fig. 2B shows the microstructure of the welded joint obtained with the TIG method. The obtained weld shape is regular and symmetrical, with an area of 61 mm², while the average width of the HAZ is equal to 1.89 mm. In the central area of the weld (Fig. 2B), a dendritic microstructure with a eutectic mixture distributed along the grain boundaries is often associated with the particles of phases containing Al, Fe, Mn, Si. A typical microstructure of an electron beam welded 6082 alloy is shown in Figure 2C. Compared to welded joints using the MIG and TIG methods, the weld in the EBW has the smallest surface area of 9.81 um² as well as the smallest average width of the HAZ - 1mm. The SEM studies carried out with the use of larger magnifications (Fig. 2C) indicate that precipitates were significantly reduced in size relative to the parent material (Fig. 2A).

Both morphology and dispersion of iron phases (white precipitations) changed depending on area of examination. The microstructure of FSW joint is shown in Fig. 2D. Examination revealed lack of welding imperfection. Enlarged area on the figure represents the microstructure of the weld core. In terms of microstructure, this area is characterized by the smallest differentiation and it consists both of recrystallized grains, with an average diameter of 9 µm and Al(FeSi)Mn phase particles which have been fragmented during welding process.

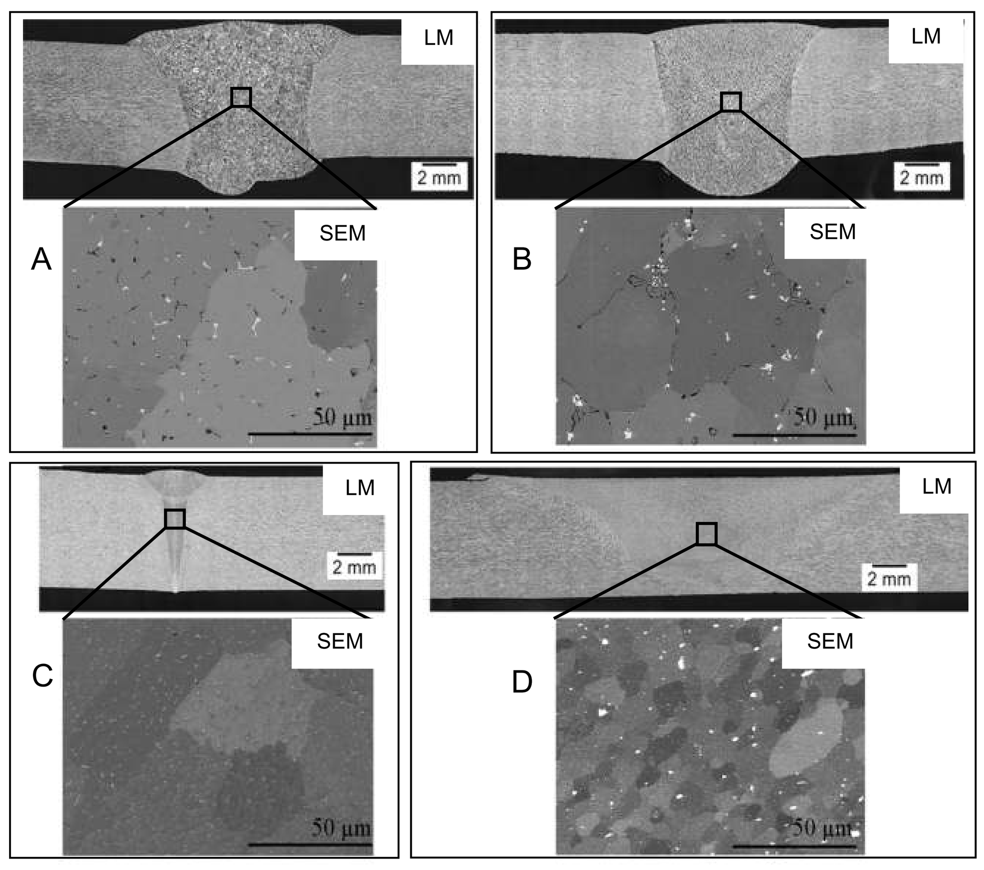

Figure 2. Macro- and microstructures of welded joints obtained by LM and SEM:
a – MIG, b – TIG , c – EBW, d – FSW

On Fig. 3 examination results of joints hardness test have been presented. Significant differences in hardness were observed depending on weld area. In the case of welded joints obtained with the MIG, TIG and FSW methods (Fig. 3A, 3B, 3C), hardness profiles reflect the shape of the letter "W" and are distinguished by two local minima of about 62 HV. The reason for hardness decrease in these zones (compared to the parent material) is most likely result of two effects. The first is complete or partial dissolution of the strengthening phases after supersaturation and aging, caused by the local increase in temperature during the welding process. The second reason is structure renewal due to temperature in the HAZ which reaches the highest values just next to the fusion line then decreases with the distance from the weld axis. Therefore, the highest hardness of the HAZ in the area adjacent to the fusion line can be attributed to the phenomenon of solution strengthening and the secondary precipitation of strengthening phases, which decreased along with the distance from the weld. After reaching the local minimum, where the highest percentage of Mg_2Si phases coagulated, the hardness increased, which can be explained by the decrease in the volume of the dissolved strengthening phase. In case of FSW joint hardness profile (Fig. 3C), the curve consists of a central area parallel to the abscissa axis and corresponds to the width of the weld. The hardness in this section was about 78 HV and decreased by 26% compared to the parent material. The difference in hardness between the welded joint area and the parent material is caused by the effect of deformation and high temperature during FSW process. The profile and map of the hardness distribution of the EBW 6082 weld are shown in Fig. 3D. In comparison to hardness profiles of joints obtained with the MIG, TIG, and EBW methods, the hardness profile for the EBW joint resembles the letter "V". The center of the weld was characterized by the lowest hardness value of 72 HV. The decrease in hardness by 35% in this area is caused by the dissolution of the strengthening phases (formed as a result of supersaturation and aging) and the formation of the dendritic structure shown in Fig. 2C. The average hardness in the HAZ was approx. 90 HV.

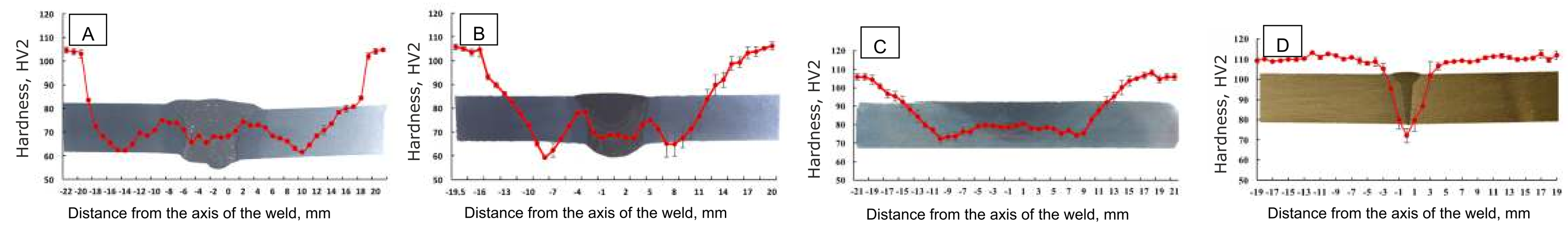

Figure 3. Hardness distribution map: A – MIG, B – TIG, C – FSW, D – EBW

The influence of the heat input during welding processes is clearly visible in case of hardness profiles (Fig. 3). On the other hand, the results of mechanical properties obtained in the uniaxial tensile test are given in Table 2. In the case of welded joints obtained with the MIG, TIG, and FSW methods, these properties were similar: the average UTS was about 223 MPa, while the yield strength and total elongation reached values of approximately 172 MPa and 4%, respectively. The highest strength properties were obtained in EBW welded joint: the average tensile strength was 256 MPa and the yield point was 195 MPa. On the basis of the welds UTS values, the effectiveness of the joints was calculated (the ratio of the joint UTS to UTS of the initial material multiplied by 100%). The efficiency of TIG, MIG and FSW connectors was approximately 74% while in the case of the EBW joint, this value was the highest reached approximately 85%.

Process	Rm [MPa]	$R_{p0.2}$ [MPa]	A [%]
MIG	223.3	172.7	4.2
TIG	218.7	173.2	4.0
FSW	223.0	150.0	3.2
EBW	256.0	195.0	2.1
6082 T651 min	300.0	255.0	9.0

Table 2. Mechanical properties of welded joints

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Conclusion

The present work reported the mechanical properties, microstructural characteristic of 6082 aluminium alloy welded joints. Four different welding proceses, such as MIG, TIG, FSW and EBW, were applied. The following conclusions can be made from the study:

- In welds obtained with the MIG, TIG and EBW methods, there are a dendritic structure resulting from the secondary melting of the parent material or filler.
- The applied technologies of welding 6082 aluminium alloy allowed to obtain homogeneous welded joints without imperfection with similar mechanical properties; the highest joint efficiency was noted for electron beam welding technology (approx. 81%).
- It has been shown that the average hardness of 6082 alloy joints in the joint area has decreased by about 40 units compared to parent material. The decrease in hardness in the joint area was caused by the dissolution of the strengthening phases and the renewal of the microstructure by dynamic recovery and recrystallization.

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