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Investigation of Metallurgical Structure and Mechanical Properties of Double-Sided Friction Stir Welded joint of AA5083 Plates

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1. Introduction

Among the aluminum alloys, 5083 aluminum alloy represents good mechanical properties such as formability and strength as well as high corrosion resistance in sea water. Because of these properties, 5083 alloy is used extensively in transportation industry including marine transportation and car industry.

In 5xxx aluminum series, which the main alloying element is magnesium, the evaporation of magnesium leads to defect occurrence during fusion welding. These defects cause the reduction of joint quality so that the joint strength would be between 50 to 70 percent of the base metal strength. These difficulties can be solved by friction stir welding (FSW) technique which was invented in 1991 by The Welding Institute (TWI). In this method, joining the material is obtained in a solid state without forming any melt. The required heat is supplied by friction between the shoulder of a rotating pin and the base material. Then, the workpieces to be joined are plasticized by the generated heat. Nowadays, this method of joining is used at a large extent in airplane, ship, and car industry. In most cases, FSW is done on one side of joint. In such a case, the root defects appear on the other side of joint (especially in the joining of thick parts). These defects weaken the welded area and lead to the fracture of parts from the joint area under tensile and bending tests. Also, as the tool rotates and moves forward simultaneously, the produced heat and the flowing of material are unequal for the two joint parts, which result in the difference between the microstructure and mechanical properties of two areas that are called advancing and retreating sides. In addition, for joining metals with high thicknesses, the higher length of the pin and the increased force on it cause the fracture of the tool. Furthermore, the residual stresses are reduced by using multiple-pass welding. Thus, this research investigates the relationship between traverse speed, rotational speed, and pin length on the microstructural features and mechanical properties of double-sided friction stir welding butt joints made of 10 mm thick AA5083 alloy.

2. Exprimental

The commercial AA5083 aluminum alloy with the dimensions of 140 mm × 60 mm × 10 mm was used. The pins with different lengths of 6 and 4.7 mm were used for double-sided friction stir welding. In order to study the effects of the rotational and traverse speeds in double-sided friction stir welding, various joints were conducted. Also, to investigate the pin length effect, the best parameters (i.e., rotational and traverse speeds) of joining was chosen according to the observations of microstructure and tensile testing, joints were produced by two pins with the lengths of 4.7 mm and 9.5 mm. The different welding conditions are summarized and listed in Table 1.

Table 1. Process parameters of the different FSWed joints

Sample Code	D-L-40-6	D-L-80-6	D-M-40-6	D-M-80-6	D-H-40-6	D-H-80-6	D-M-80-4.7	S-M-80-9.5
Rotational Speed (rpm)	800	800	1000	1000	1200	1200	1000	1000
Traverse Speed (mm/min)	40	80	40	80	40	80	80	80
Pin Length (mm)	6	6	6	6	6	6	4.7	9.5

In order to study the microstructural evolutions, all samples were cross-sectioned perpendicular to the welding direction. They were polished and finally etched by a Poulton's reagent-solution and barker Barker's reagent as well. Sub-sized tensile specimens were extracted from the welded samples perpendicular to the welding direction using an electrical discharge machine. Tensile tests were carried out at room temperature with a crosshead speed of 1mm/min. The fracture surface of all the tensile test specimens was also studied by using scanning electron microscopy (SEM). An energy dispersive X-ray spectrometer (EDS) was also used for identification the chemical composition of the intermetallic compounds. In addition, microhardness test was done along a path perpendicular to the direction of tool traverse. The measurements were carried out in the middle of the thickness and on the cross section.

3. Results and Discussion

No defect was found in the joints area obtained by double-sided friction stir welding with different parameters. Although, during the conventional single-sided friction stir welding, the used pin which had the length of 9.5 mm was broken. Generally, the heat input is proportional to the ratio of rotational speed to traverse speed, i.e. ω/v. As Table 2 shows, when the heat input increases, the width of stir zone increases as well. Thus, it can be stated that the size of joint area in double-sided friction stir welding has a close relationship with the heat produced in joint area (i.e., ω/v).

Table 2. Properties of stir zone for the different joints

Sample Code	D-L-40-6	D-L-80-6	D-M-40-6	D-M-80-6	D-H-40-6	D-H-80-6	D-M-80-4.7
ω/V	20	10	25	12.5	30	15	12.5
width of stir zone (μm)	8348	6196	8543	6663	8360	7000	5598

For 5083 aluminum alloy, the compounds of Al_3Mg_2 and $Al_6(Mn,Fe)$ are known as intermetallics, and there is a small amount of β-Mg_2Si precipitates. The stirring action of pin in the SZ causes the fragmentation of coarse $Al_6(Mn,Fe)$ intermetallic into the smaller particles. Considering the temperatures experienced in the SZ,

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Al_3Mg_2 and β-Mg_2Si are likely to be dissolved. In this regard, the EDS analyses of white particles distributed in stir zone are shown in Figure 1.

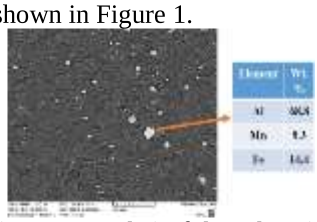

Fig. 1. EDS analysis of showed particle

Figure 2 shows the effect of rotational and traverse speeds on the average grain size of the SZ (i.e., ω/v). Two main factors which affect the grain size in the stir zone are: 1) dynamic recrystallization as a result of stirring action of the pin that decreases the grain size, and 2) annealing which leads to grain growth as a result of generated heat that increases the grain size. By increasing the traverse speed, the material experiences a severe mechanical work and is significantly influenced by dynamic recrystallization, which results in an increase in the nucleation sites and therefore, decreases the grain size. Further severity of stirring action caused by higher rotational speed leads to more grain size reduction. On the other hand, the increase in the rotational speed causes an increase in heat input and growth of the grains. As can be seen in Figure 2, for the traverse speed of 80 mm/min (i.e., the ratio of ω/v= 10, 12.5, 15), the increase in the rotational speed does not have any effect on the average grain size. In this case, it can be concluded that the annealing and recrystallization effect counteract each other. Also, it can be stated that the recrystallization has not been completed. However, for the traverse speed of 40 mm/min (i.e., the ratio of ω/v= 20, 25, 30), with increasing the rotational speed the grain size increases due to the dominance of annealing effect.

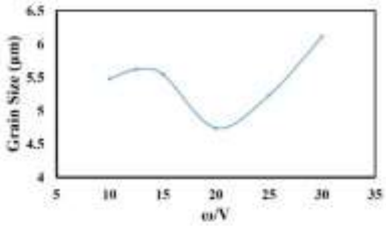

Fig. 2. SZ average grain size obtained for different rotational and traverse speeds

According to Hall-Petch equation, due to the intensive reduction of grain size happened in stir zone, the microhardness values must increase significantly; however, there is little change in the hardness of SZ compared to the base metal. This phenomenon can be due to the uniform distribution of small particles, known as Orowan mechanism (obstruct the dislocation movement). Grain size plays no role in determining the value of hardness (Figure 3). All the samples had the strengths almost equal to the base metal; however, the three samples L-40-6, M-40-6 and M-80-6 showed higher elongation and toughness compared to the base metal. The high elongation and toughness of the welded samples can be explained by releasing the residual stresses generated during the rolling of the base metal, the refinement of grain size of the stir zone. Moreover, overlapping of each side at the centre of joint area is effective. The fracture path in all the joints passed through the border or vicinity of stir zone and TMAZ; thus, it can be stated that the fracture has probably happened from this area. Due to the characteristics of friction stir welding, some deformation happens in TMAZ. Therefore, during the tensile test, dislocation pile-up in this area is faster than that in the base metal. This causes the accumulation of applied strain in this area until the strain reaches the sufficient level required for crack nucleation (Figure 4).

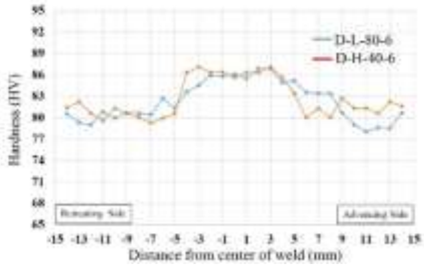

Fig. 3. Microhardness profile obtained for the samples D-L-80-6 and D-H-40-6

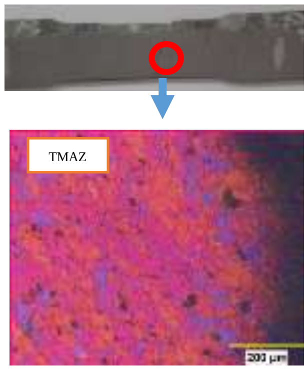

Fig. 4. Microstructure of H-40-6 in fracture location

4. Conclusion

To investigate the double-sided friction stir welding of 5083 aluminum alloy, the samples with different traverse and rotational speeds, and pin length were prepared. No defect was observed in all joints area. Dynamic recrystallization as a result of stirring action of the pin decreased the grain size. Although, annealing effect can be caused the increasing of grain size slightly. For the traverse speed of 80 mm/min, the increase in the rotational speed did not not have any effect on the average grain size. In this case, it can be concluded that the annealing and recrystallization effects counteract each other. Also, in this traverse speed, it can be stated that the recrystallization has not been completed. However, for the traverse speed of 40 mm/min, with increasing the rotational speed, the grain size was increased due to the dominance of annealing effect. Despite the sharp decline in grain size of stir zone compared to the base metal, there is no meaningful variation in hardness between the two zones. It can also be stated that the uniform distribution of small particles, known as Orowan mechanism, could affect the Hall-Petch equation. In tensile test, the high amount of elongation of the welded samples obtained probably due to the grain refinement of the stir zone as well as releasing the residual stresses generated during the rolling of the base metal. In addition, due to pile-up of dislocations in TMAZ, the fracture of various welded samples were happened in this zone.