RESEARCH ARTICLE

International Journal of Multidisciplinary and Scientific Emerging Research

Available at http://www.ijmser.com/ (ISSN 2349 – 6037)

Effect of Heat Input on Tensile Properties of Friction Stir Welded AA6061-T6 and AA7075-T6 Dissimilar Aluminum Alloy Joints.

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Accepted **08 October** 2014, Available online **27** October 2014, **Vol.3, No.1 (October 2014)**

Abstract

Friction Stir Welding (FSW) is a solid state process widely used to join dissimilar aluminium alloys. High quality and strength joints can be fabricated using this technique when compared to other conventional methods. The welding parameters play major role in determining the quality of the weld. This paper aims in presenting the effect of heat input on tensile properties of the joints between AA6061-T6 and AA7075-T6 aluminium alloys. A total of 15 experiments were conducted by varying the tool rotational speed from 600 RPM to 1400 RPM in a step of 200 RPM, welding speed of 32 mm/min, 45 mm/min and 53 mm/min, axial load form 3 kN to 5 kN in an increment of 1and shoulder diameter from 12 mm to 18mm. Microstructural characterization and the tensile strength were measured for the various heat inputs and analysed. The joint fabricated with the intermediate heat conditions yielded the maximum tensile strength. The formation of finer grains and proper material mixing in the stir zone are the main reasons for the superior tensile strength.

Keywords: *frictions stir welding, dissimilar aluminum alloys, tensile strength.*

1. INTRODUCTION

In today's scenario there is a heavy demand for using light weight materials in various industries like aerospace, automobiles and marine. FSW invented in late 1991 by The Welding Institute addresses the issue of joining dissimilar metals (Thomas WM and Nicholas ED, 1997). The aluminum alloys AA6061 and AA7075 finds its application in aerospace, automobile and marine industries aiming in using the light weight, high strength materials. Rajneesh et al studied the process forces and heat input with the varying process parameters of AA5083 FSW joints. They found that tool rotational speed, welding speed and tool shoulder diameter are the most significant parameters affecting axial force and heat input (Rajneesh, et al., 2012). Alkinlabi et al have reported the effect of heat input on the mechanical properties of joints between aluminum and copper. They have used three different shoulder diameter and varied tool rotational speed and welding speed. They measured the microstructures, grain size, micro hardness and electrical resistivity of the joints. They observed that the electrical resistivity of the joint increased as the heat input of the weld increases (Esther.T.Akinlabi, et al., 2012). Xue et al friction stir welded pure copper plates of 5mm thick. The effect of heat input conditions on the various zones and the mechanical properties were investigated. They found that at low heat input condition defect free joints were made. There was no significant difference in the tensile strength. Yield strength and elongation are lowered with the increase in heat input (Xue, et al., 2010). Rajakumar et al established a mathematical relationship for the process parameters of FSW of different aluminum alloys to predict the tensile strength and sensitivity analysis was carried out to compare the impact of input parameters on tensile strength and also discussed the effect of heat input on mechanical properties of the welded joints (Rajakumar, et al., 2012). Madhusudhan et al carried out an experimental study to find the effect of weld parameters on mechanical and micro structural properties of dissimilar aluminum alloys (Madhusudhan, et al., 2012). Caroline et al have welded AA2014-T6 and AA7075-T6 aluminium alloys for various welding parameters. Torque, Temperature, macrograph and micro hardness were measured. They found that torque, temperature and hardness profile depend on the amount material mixture in the stir zone (Caroline, et al., 2013). In this research work an attempt is made to study the effect of heat input on tensile strength and microstructure of dissimilar friction stir welded AA6061-T6 and AA7075-T6 aluminium alloys. Guo et al studied the effect of process parameters on dissimilar AA6061and AA7075 FSW joints. In detail they have presented the effect of material position, welding speed on material flow, microstructure and hardness profile (Guo, et al., 2014). In this paper the effect of heat input on tensile properties of dissimilar AA6061-T6 and AA7075-T6 were studied in detail and presented.

2. EXPERIMENTAL METHODS

Rolled plates of AA6061-T6 and AA7075-T6 of 5mm thickness were considered for butt configuration. Each plates of size 150 x75 x 5mm were prepared by using power hacksaw and milling. The welding was performed normal to the rolling direction. AA6061-T6 was placed in the advancing side and AA7075-T6 was placed in the retreating side (Guo, et al., 2014). The chemical composition and the mechanical properties of the base materials are shown in the Tables 1 and 2. The parameters considered for the study include Tool rotational speed (N), Welding speed (S), Axial Load (L), and shoulder diameter (D). The ranges of the parameters are found by number of trial run and identified for the major defects using macroscopic investigation. The various parameters and their corresponding ranges are shown in the Table 3. Five tool rotational speed, three welding speed, axial speed and Shoulder diameter to fabricate the joints. A computer numerical control FSW machine was used to produce the joints. The tensile specimen was prepared as per the ASTM E8M-09 guidelines (ASTM E8 M-09, 2009) and the dimensions are shown in the Fig.1. A servo controlled universal testing machine was used to find the tensile strength, From each joint three tensile specimens were prepared perpendicular to the welding direction and the average of the same was recorded. For the metallographic examination the specimen was prepared to the required size from the joint which comprises the stir zone, thermo mechanically affected zone heat affected zone and the base metal.

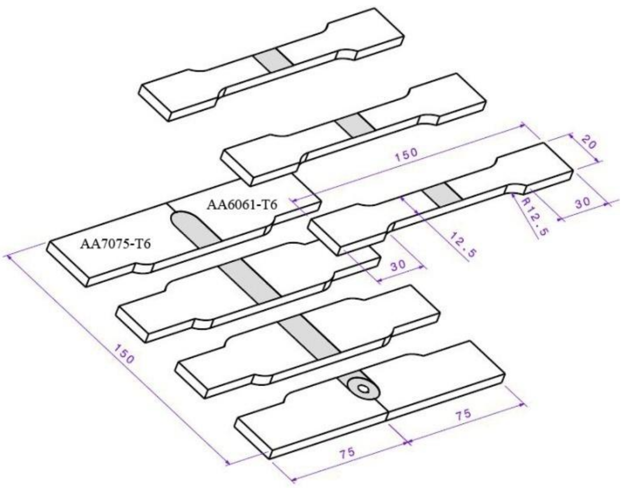

Figure 1: Dimension of Work piece and tensile specimen.

The specimen was finally polished using diamond compound and the samples were etched using 10% NaOH to show the general flow structure. Keller's reagent made of 5ml HNO_3, 2ml HF, 3ml HCL, and 190ml H_2O was used to reveal the microstructure of the weld. Macro and micro structural analysis was carried out using light optical microscope and the fractured surface of the tensile specimen was examined by a scanning electron microscope. Micro hardness test were performed for the low, intermediate and high heat input conditions.

Base Material	Tensile Strength (MPa)	Yield Strength (MPa)	Percentage Elongation
AA6061-T6	283	235	26
AA7075-T6	485	410	12

Table 1: Mechanical Properties of AA6061-T6 and AA7075-T6

Aluminum Alloy	Si	Mg	Mn	Fe	Cu	Al
AA6061-T6	0.58	1.1	0.12	0.35	0.22	Bal
AA7075-T6	0.58	2.1	0.12	0.35	1.2	Bal

Table 2: Chemical Composition of AA6061-T6 and AA7075-T6

Parameters (Unit)	Range
Tool Rotational Speed (N) (RPM)	600,800,1000,1200,1400
Welding Speed (S) (mm/min)	32,45,53
Axial load (L) (kN)	3,4,5
Tool Shoulder Diameter (D)	12,15,18

Table 3: Process Parameters.

Batch	Joint No	Process Parameters					Response
		Tool Rotational Speed (N) RPM	Welding Speed (S) mm/min	Axial Load (L) kN	Shoulder Diameter (mm)	Heat input kJ/mm	Tensile strength (MPa)
1	Joint 1	600	32	3	12	0.509	146
	Joint 2	800	32	3	12	0.679	161
	Joint 3	1000	32	3	12	0.849	173
	Joint 4	1200	32	3	12	1.018	172
	Joint 5	1400	32	3	12	1.188	166
2	Joint 1	600	45	4	15	0.604	158
	Joint 2	800	45	4	15	0.804	166
	Joint 3	1000	45	4	15	1.005	186
	Joint 4	1200	45	4	15	1.206	179
	Joint 5	1400	45	4	15	1.408	172
3	Joint 1	600	53	5	18	0.768	144
	Joint 2	800	53	5	18	1.024	160
	Joint 3	1000	53	5	18	1.280	168
	Joint 4	1200	53	5	18	1.537	162
	Joint 5	1400	53	5	18	1.793	154

Table 4: Experimental Results

3. RESULTS AND DISCUSSION

The heat input for friction stir welding process is calculated using the following expression (Heurtier.P, et al., 2006)

$$q = \left(\frac{2\pi}{3S}\right) \mu L \omega R_s \eta \qquad (1)$$

where μ is the coefficient of friction, L is the normal force in kN, ω is the rotational speed in r/s, R_s is the shoulder radius in m, S is the welding speed in mm/min, η is the efficiency of the process (assumed as 0.8).

3.1 Tensile Strength

The joint fabricated with the tool rotational speed 1000 RPM, welding speed 60mm/min, axial load 4kN and shoulder diameter of 15 yielded the maximum tensile strength. Three different batches of joints were made by varying the tool rotational speed form 600 RPM to 1400 RPM. A total of 15 joints were made and three tensile specimens are prepared and the average tensile strength was tabulated in Table 4 with the corresponding heat input. The Fig 2 - Fig 4 shows the values of the tensile strength and the heat input for the various tool rotational speed at constant welding speed, axial load and shoulder diameter. In low heat input conditions the amount of heat generated was not sufficient enough to pull the material from the retreating side to the advancing side there by resulting in the poor mixing of materials which yield a lower tensile strength. At Intermediate heat input friction resulting in proper mixing of materials. Dynamic recrystallization occurs due to which fine grain structure are obtained. This could be the reason for the higher tensile strength in the corresponding joints. In high heat input, turbulent flow of material takes places resulting in the improper mixing of materials thereby reducing the tensile strength. The grain structures are coarse due to the slow cooling rate.

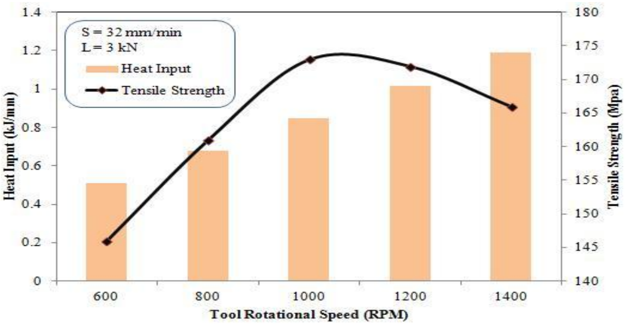

Figure 2: Tool Rotational Speed versus Heat Input and Tensile Strength with the 12 mm Shoulder Diameter Tool.

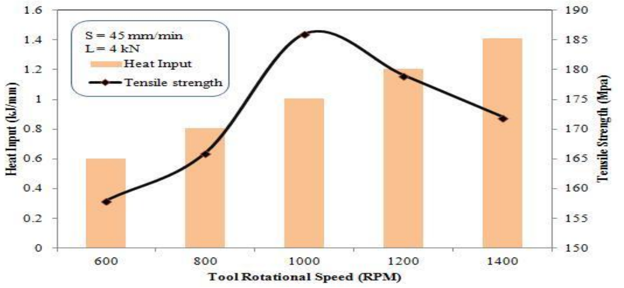

Figure 3: Tool Rotational Speed versus Heat Input and Tensile Strength with the 15 mm Shoulder Diameter Tool.

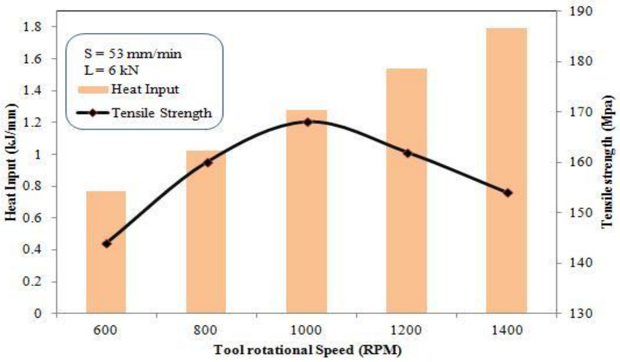

Figure 4: Tool Rotational Speed versus Heat Input and Tensile Strength with the 18 mm Shoulder Diameter Tool.

3.2 Macrostructure

Friction stir welding when compared to fusion welding, the defects like porosity, cracks and slag inclusion will not occur. However defects like pin hole, tunnel defect, kissing bond and worm hole can be seen. Each joint was analysed using a low magnification optical microscope for any defects.

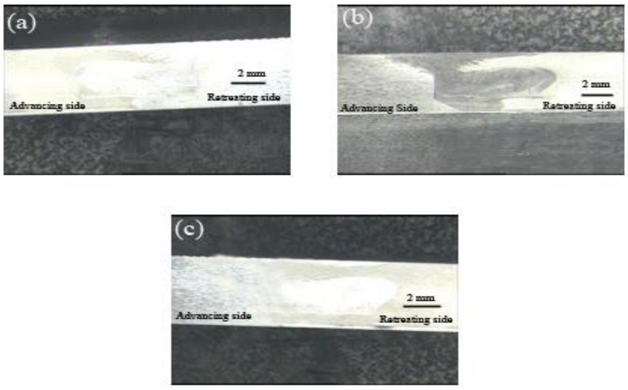

Figure 5: Macrostructures of Batch 2 (a) Low Heat Input Condition (b) Intermediate Heat Input Conditions (c) High Heat Input Condition.

The Fig. 5 shows the macrostructure at low heat input condition, intermediate heat input and high heat condition at a welding speed of 60 mm/min, axial load of 4kN, shoulder diameter 15mm and at the tool rotational speed of 600 RPM, 1000 RPM and 1400 RPM respectively. From the analysis it was inferred that sufficient amount of heat input is needed to produce a good quality weld. In the macrostructure of the intermediate heat input condition, the sphere shaped stir zone can be seen clearly and free from defects.

3.3 Microstructure

The microstructure of the three heat input conditions namely low, intermediate and high at the stir zone was shown in Fig.6. It was observed that the stir zone contains

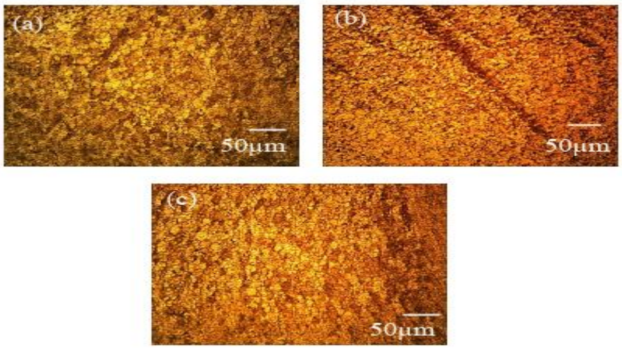

Figure 6: Microstructures of Batch 2 (a) Low Heat Input Condition (b) Intermediate Heat Input Conditions (c) High Heat Input Condition.

equiaxed fine grains which results in the higher tensile strength. The microstructure of the joint fabricated with the intermediate heat input conditions has a very fine grain size when compared to other two conditions. And it was clearly seen that there was a proper mixture of two different material which aids in the higher tensile strength. These equiaxed fine grain structures are due to the occurrence of the dynamic recrystallization.

4. CONCLUSIONS

The effect of heat input on tensile strength of AA6061-T6 and AA7075-T6 dissimilar aluminum alloy studied and presented. The following inferences observed.

1. Heat input has the significant influence on tensile strength of the dissimilar FSW Aluminum alloys.
2. The joint fabricated with the tool rotational speed 1000 RPM, welding speed 60mm/min, axial load 4kN and shoulder diameter of 15 yielded the maximum tensile strength of 186 MPa.
3. The maximum tensile strength was observed in all the intermediate condition form all the batches.
4. The microstructural analysis shows the uniform material mixing and fine equiaxed grain structure.

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