EXPERIMENTAL ANALYSIS ON MECHANICAL BEHAVIOUR OF FRICTION STIR WELDED DISSIMILAR ALUMINIUM ALLOY JOINTS

K.P.Yuvaraj
Assistant Professor
Department of Mechanical Engineering
Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India

R.Anandkumar
Assistant Professor
Department of Mechanical Engineering
KPR Institute of Engineering and Technology, Coimbatore, Tamilnadu, India

J.Abhimanyu, G.Akash, V.Balamurugan
UG Scholars
Department of Mechanical Engineering
KPR Institute of Engineering and Technology, Coimbatore, Tamilnadu, India

K.P.Boopathiraja
Assistant Professor
Department of Mechanical Engineering
Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, India

L.Haribabu
PG Scholar
Department of Mechanical Engineering
Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India

Abstract- In this present investigation, the impact of tool rotational speed on microstructural behaviour and mechanical properties of friction stir welded AA7075-T651 and AA6061 was studied. Experiments were conducted by varying the tool rotational speed as 1500, 2000 and 2500rpm and tool traverse speed is kept constant as 40mm/min. Macrostructure and microstructure analysis was carried by utilizing the optical microscope. The welded joint fabricated with tool rotational speed of 2000rpm exhibited maximum tensile strength and hardness due to the formation of fine grains and distribution of strengthening precipitate $MgZn_2$ in the Weld Stir Zone (WSZ). Tensile fractured surface analysis of the joint made with 2000rpm revealed the ductile mode of failure with very fine dimples.

Keywords – Friction Stir Welding, AA7075-T651, AA6061, Tensile Strength, Hardness, SEM, EDAX

I. INTRODUCTION

High strength to weight ratio play a vital role in automobile and aerospace industries to provide passenger safety and better fuel consumption [1]. Aluminium is the first choice for the engineer to satisfy the above mentioned factors. Conventional welding techniques facing lot of metallurgical problems in welding aluminium like distortion, hot cracking and loss of alloying elements due to heat [2]. Friction Stir Welding (FSW) process is a eco-friendly solid state welding technique which is suitable to overcome the problems in welding aluminium alloy and exhibit better mechanical properties when compared to conventional welding methods [3]. In the FSW process, tool parameters and machine parameters play a vital role in deciding the microstructure variation and mechanical properties of the welded joint [4]. The FSW tool parameters involves tool shoulder diameter, tool pin diameter, tool shoulder to pin diameter ratio, tool pin profile and tool shoulder concave profile. Heat generation, plastic deformation and material stirring actions were controlled by tool parameters [5]. The FSW machine parameters involve tool rotational speed, traverse speed, tool tilt angle and fixture design. Transportation and turbulence action of plastically deformed material was controlled by FSW machine parameters. However, optimization of FSW tool and machine parameters plays a vital in achieving the strength of the joint [6]. Softening of weld plates may affect the mechanical and microstructural behaviour of the weld joint. Many research works has been conducted by researchers to restore the strength of the weld joint by employing Post Weld Heat Treatment (PWHT) process. Even though, PWHT process is effective but it is very difficult to process on non-heat treatable alloys [7]. Among different approaches, FSW tool rotational speed play a dominating role in determining the strength of the joint. Heat generation due to the tool rotational speed affect the size of grain and distribution of strengthening precipitates in the WSZ [8]. In this present study, Friction Stir Welding of AA7075-T651 and AA6061 has been carried out by varying the tool rotational speed. To investigate the impact of tool rotational speed, the mechanical properties and microstructural behaviour of the weld joint were studied.

II. MATERIALS AND METHOD

2.1 Experimental details –

Aluminium plates of 300mm x 75mm x 6mm were used in this research work. High Speed Steel (HSS) cylindrical tool with tool shoulder diameter 20mm and tool pin diameter 6mm was employed to fabricate the weld joints as shown in figure 1. FSW machine with suitable fixture, rigid base and digital speed indicator was used for the weld joint fabrication. The chemical composition of the base materials were identified with spectral analysis of X-ray is shown in table 1. Power hack saw was used to cut the samples perpendicular to WSZ for microstructure analysis. Various grades of emery sheets were used to polish the surface and finally cleaned with acetone to remove dirt particles in the polished surface. Universal Testing Machine (UTM) with 100kN load capacity and 0.5mm/min cross head speed was used to conduct tensile test. Tensile samples were prepared as per ASTM-E8 standard [9]. Hardness of the welded joint was evaluated by using Vicker's microhardness tester with 100g of load and 15s dwell time. Scanning Electron Microscope (SEM) with EDAX was used to analyze the fractured surface of tensile specimen and examine the presence of strengthening precipitates.

Figure 1. Photograph of FSW tool used

Table -1 Chemical composition of AA7075-T651 and AA6061

Base Metal	Cu	Mg	Zn	Cr	Fe	Si	Ti	Al
AA7075-T651	1.2-2	2.1-2.9	5.1-6.1	0.18-0.28	0.5	0.4	0.2	Balance
AA6061	0.15-0.4	0.8-1.2	0.25	0.04-0.35	0.7	0.4-0.8	0.15	Balance

III. Results and Discussion

3.1 Macrostructure analysis of welded joint

The macrostructure analysis was conducted to ensure the absence of tunnel, pinholes, warm holes and other macro defects [10]. The influence of FSW tool rotational speed on macrostructure of the weld joints are shown in table 2. The specimen 1 fabricated with 1500rpm exhibited warm holes along the WSZ due to lack of heat generation. Sufficient heat generation and material transfer in the specimen 2 joined with 2000rpm exposed defect free WSZ. Material softening due to excess of heat generation in the tool rotational speed of 2500rpm revealed tunnel formation along the weld path [11]. Macrostructure analysis revealed that the formation of defect free joint needs suitable tool rotational speed.

Table - 2 Macrostructure analysis to evaluate the influence of tool rotational speed

Sl.no	Specimen	Macrostructure	Defects
1.	Specimen 1 (1500rpm)		Warm holes
2.	Specimen 2 (2000rpm)		No defects
3.	Specimen 3 (2500rpm)		Tunnel formation

3.2 Microstructure behaviour of welded joint

In the FSW process, tool rotational speed influences the translational velocity which may affect the strain rate of the plastically deformed material in the WSZ. More heat generation resulted from high rotational speed and also declines the cooling rate in WSZ. The FSW tool rotational speed of 1500rpm generates lack of heat generation which causes elongated grains in the WSZ of specimen 1. In the specimen 2, the WSZ exhibited very fine equiaxed grains due to sufficient heat generation [12] and uniform flow of stirred material as shown in figure 2 a. The specimen 3 fabricated with 2500rpm exhibited coarse grains along WSZ due to the excessive heat and turbulence. This action dragged the plastically deformed material to the weld surface and creates lack of fill in the WSZ as shown in figure 2 b.

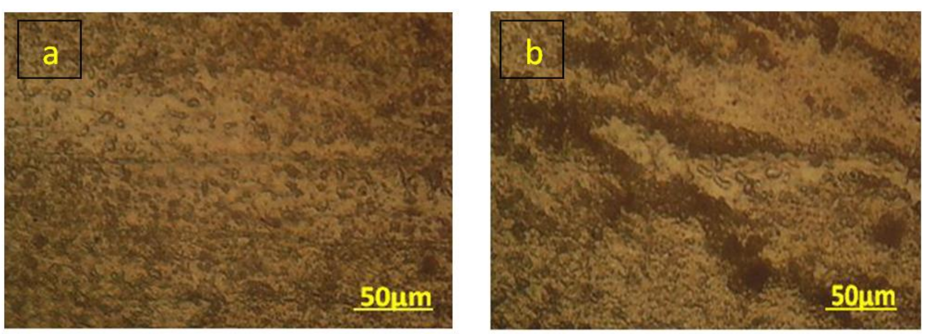

Figure 2. Microstructure analysis of a) Specimen no. 2 and b) Specimen no. 3

3.3 Evaluation of Hardness on welded joint

The FSW joint comprise five different zones and the distribution of hardness along the different zones of FSW joints are shown in figure 3. Grain size variation determines the hardness of the weld joint. Inadequate heat generated in the FSW joint fabricated at 1500rpm exhibited the moderate hardness of 106HV due to the formation of patchy elongated grains in the WSZ. In the specimen 2, formation of very fine grains in the WSZ due to sufficient heat revealed the maximum hardness of 142HV. Minimum hardness of 91HV was exposed by the specimen 3 joined at 2500rpm due to excessive heat generation and coarse grain structure [12].

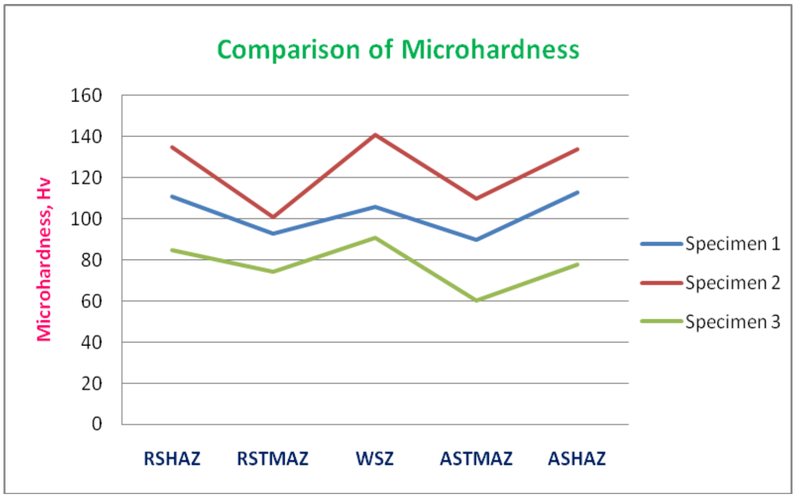

Figure 3. Distribution of hardness in different zones of FSW joints

3.4 Evaluation of Tensile Strength of welded joint

The influence of tool rotational speed on tensile strength of FSW joints are shown in figure 4. Evaluation of the tensile behaviour of FSW joints reflects the relationship between the mechanical properties hardness and tensile strength. The FSW joints with maximum hardness exhibited maximum tensile strength. Moreover, the tensile fractures also occurred in the region between ASTMAZ and WSZ with hardness value fluctuation. The FSW joint fabricated with 1500rpm exhibited the reasonable tensile strength. The specimen 2 joined at 2000rpm revealed the maximum tensile strength of 289MPa and joint efficiency of 93% due to sufficient heat generation and very fine grains in the WSZ. Excessive heat generation and turbulence material flow coarsened the grain structure in the WSZ of specimen 3 and exhibited minimum tensile strength of 164MPa and joint efficiency of 53% when compared to other joints.

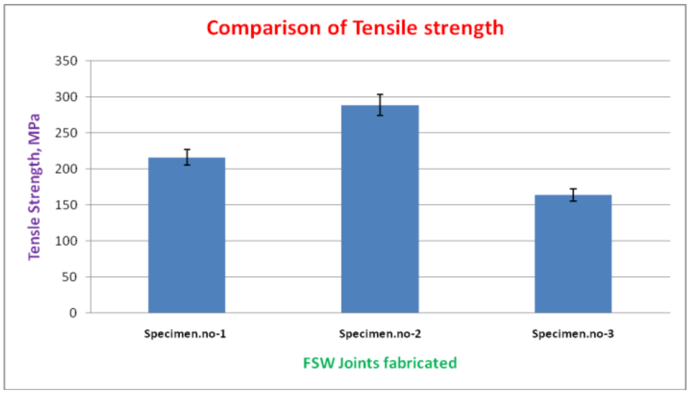

Figure 4. Comparison of tensile behaviour of the FSW joints

3.5 Analysis of Tensile Fractured Surface

The tensile fractured surface has been analyzed to determine the mode of failure. Aluminium alloy has face centered cubic crystallographic structure [13]. Mostly these structured material got fracture through ductile mode. However, the FSW joints exhibit cleavage fractures which may not happen in aluminium alloys with FCC structure. Therefore, it is necessary to examine the tensile fractured surface of friction stir welded aluminium alloy joints. Dislocation density and grain size variation plays a vital role in the ductility of the weld joint [14]. The specimen 1 fabricated at 1500rpm exhibited shallow and sheared dimples due to inadequate heat generation which affects the plastic deformation of the material in the WSZ. Very fine and deep dimples [15] were observed in the specimen 2 joined at 2000rpm which shows the good elongation of the FSW joint as shown in figure 5a. In the specimen 3, mixed mode of sheared dimples and cleavage facets were observed due to higher heat input at the tool rotational speed of 2500rpm as shown in figure 5b. The EDAX analysis of the specimen 2 revealed the presence of strengthening precipitate MgZn2 as shown in figure 5c.

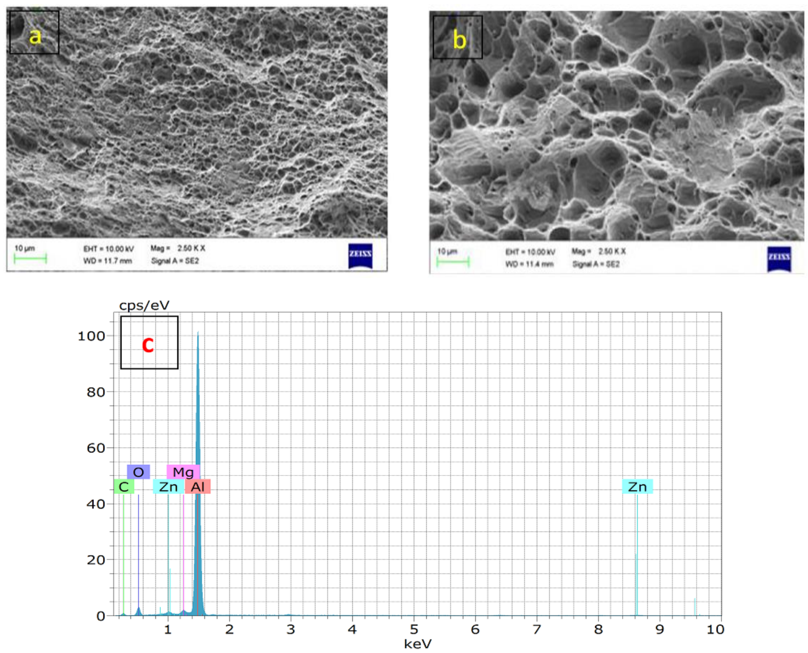

Figure 5. Tensile Fractography of a) Specimen no. 2 b) specimen no. 3 and c) EDAX analysis of specimen no. 2

IV.CONCLUSION

The influence of FSW tool rotational speed on microstructural variation and mechanical properties of friction stir welded AA7075-T651 and AA6061 joints were explored and the following conclusions are derived.
a) The FSW joint fabricated at 2000rpm speed exposed defect free joints in micro and macro level and yielded maximum tensile strength of 289MPa and joint efficiency of 93%.
b) While comparing the three different tool rotational speeds used, the specimen 3 fabricated at 2500rpm revealed minimum tensile strength of 164MPa and joint efficiency of 53%.
c) Adequate heat generation, formation of fine grains in the WSZ and presence of strengthening precipitate MgZn2 are the reason for better performance of FSW joints fabricated with tool rotational speed of 2000rpm.
d) The specimen 2 fabricated with 2000rpm has very fine grain formation in the WSZ and exhibited the maximum hardness of 142HV.

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