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Effect of Post Weld Heat Treatment, Tool Rotational Speed and Pin Profile on Metallurgical and Mechanical Properties of Friction Stir Welded Aluminium Alloy Joints

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Abstract: **Effect of the pin profile on defects of friction stir welded aluminium alloy is investigated. The proposed work is to combine study the effect of post weld heat treatment with tool rotational speed and pin profile on metallurgical &mechanical properties for friction stir welded aluminium alloy joints. Microstructure of the welding zone showed that the tunnel produced by triangle pin has smaller dimensions is compared three pin profile (3 profiles) and for each tool rotation speed. The results of optical microscope indicated that the size of grains resulted from square pin is smaller than the other kinds of tools.**

Keywords**: Metallurgical, Microstructures, Ag alloy, Rotational speed, weld zone.**

1. INTRODUCTION

Friction stir tool rotational speed and the profile of pin have large influence on the metallurgical and mechanical properties of friction stir welded metals and metal matrix Welded joints.Further literature reported that the post welded heat treatment has considerable influence on the mechanical properties in general and tensile strength properties in particular of friction stir welded metal and metal matrix joints. Rotational speed of the tool, tool traverse speed, and vertical pressure on the plates during welding are the main process parameters of FSW[10]. An attempt is made in this paper to study the overall influence of post weld heat treatment, tool rotational speed and pin profile on the metallurgical and mechanical properties of stir welded metal and metal matrix joints.

A specific case of friction stir welded AA6061 aluminum alloy joints were considered for above studies[6]. Hot rolled plates of 6-mm thick of above aluminium alloy was chosen and the friction stir welded joints were fabricated. Three tool rotational speeds of 600 rpm, 950 rpm and 1300 rpm, and three different tool pin profiles of straight square (SS), straight hexagon (SH), straight octagon (SO) were selected for the study[2]. The post weld heat treatment consists of solution treatment, artificial aging treatment and a combination of both. Microstructures of the welded joints were analyzed using optical microscopy and transmission electron microscopy[4]. The unmixed region, mechanically mixed region and mixed flow region were observed in the weld zone. Further the tensile properties such as yield strength, tensile strength, elongation and joint efficiency were evaluated. The above experiments were conducted for each pin profile (3 profiles) and for each tool rotation speed (3 speeds)[9]. It has been concluded that a simple artificial aging treatment was found to be more beneficial than other treatment methods to enhance the tensile properties of the friction stir-welded AA6061 aluminium alloy joints.

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Further the tool rotational speed and pin profile considerably influenced the microstructure and tensile strength of the joints. The fabricated joint using tool rotational speed of 950 rpm and straight square pin profile yielded highest tensile strength of 273 MPa. AA6061, a metal matrix of Al–Mg–Si alloy is an age harden able alloy having more strength due to the precipitation of Mg2Si phase upon solution zing and artificial aging. Friction stir welding (FSW) is an emerging metal joining process in which the material that is neither welded nor melted and recast. Recently, the FSW process is finding wide applications in joining most of the aluminium alloys.

The FSW process is observed to offer several advantages over fusion welding processes because of parent metal melting absence. The changes in the heat and temperature distribution in the welding process alter the strength and ductility of the joints. Though FSW joints yield better joint efficiency compared to fusion welding processes, the gap between strength values of the base metal and the weld metal is considerably large. Hence a detailed experimental study on the effect of post weld heat treatment, tool rotational speed and pin profile on metallurgical and mechanical properties of friction stir welded aluminium alloy joints is undertaken to study and conclude the effect of various parameters on strength properties and metallurgical properties. The process of FSW consists of a non consumable rotating tool harder than the base material is plunged into the abutting edges of the plates to be joined under axial force and along the line of the joint. The material is softened by the frictional heat generated by the tool rotation. Advancement of the tool pushes plastically deformed material from front to back of the tool and forges to complete the joining process.. The aluminium alloys are extensively used in the fabrication of aircraft structures and other structural applications[3]. The proposed system objective is to 1. Select of proper metal matrix is very important for smooth conduct of experimental work. 2. The mechanical properties measuring instruments should be properly chosen to cover the complete range of values. 3. The tool rotation speeds should be so selected in order that optimum rotation speeds are covered with in the range of rotation speeds.

2. EXPERIMENTAL WORK

Rolled 6-mm thick plates of AA6061 aluminum alloy (Sufficient in number for conducting experiments) were machined to the required dimensions (300×150 mm) as shown in fig.1 fabrication of FSW joints is done by square butt joint. A single pass welding procedure is used. The yield strength and tensile strength in MPa was measured for base metal and also for the different heat treated conditions namely, (i) solution treated (ST) joints, (ii) solution treated and aged (STA) joints and (iii) artificially aged (AG) joints. These values are reported in table 2.

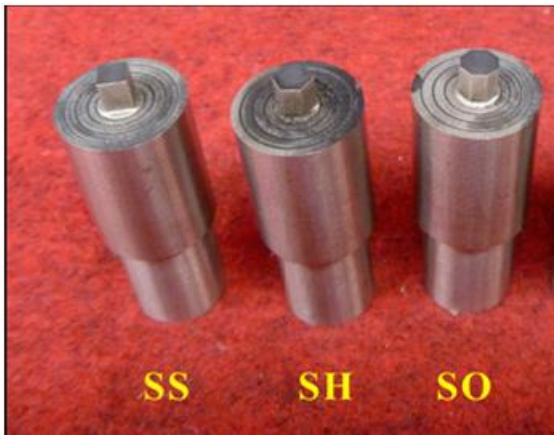

Fig 1: Fabricated FSW tools (SS,SH and SO).

Table 1: Chemical composition (wt.%) of base metal

Material	Chemical Composition (wt %)
Mg	1.1
Mn	0.12
Fe	0.35
Si	0.58
Cu	0.22
Al	Rest

A specially designed and developed machine (15 hp; 3000 rpm; 25 kN) was used to fabricate the joints. Initially experiments were conducted to finalize the optimized FSW parameter. Four joints were fabricated using previously optimized FSW parameters [1]. To study the influence of post-weld heat treatment (PWHT) on tensile properties, the welded joints were grouped into three different categories, namely, (i) solution treated (ST) joints, (ii) solution treated and aged (STA) joints and (iii) artificially aged (AG) joints. The tensile strength of each of these joints were determined immediately after fabrication, without post-weld heat treatment, to obtain the As-welded (AW) joint properties. Solution treatment (ST) was carried out at an elevated temperature of 550°C for a soaking period of 80min[5]. For the ST, joints were placed in an induction furnace and heated from room temperature to the 550 °C solution temperature at a rate of 100°C per hour. After completion of the soaking period, the joints were removed and quenched in a cold water bath. Artificial aging (AA) treatment was carried out at 180°C for a soaking period of 18 h.

Table 2: Transverse tensile properties of friction stir welded AA6061 joints

Joints	Yield strength (MPa)	Tensile strength(MPa)
ST (solution treated)	70	160
STA (solution treated and aged)	90	170
AG (artificially aged)	130	210

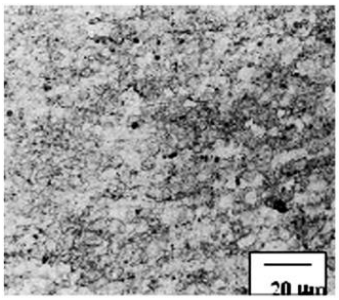

Fig 2: Optical micrographs of FSW zones of AA6061 joints.- solution treated (ST) joint

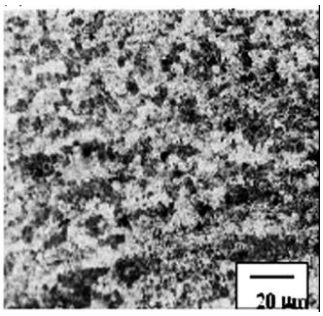

Fig 3: Optical micrographs of FSW zones of AA6061 joints- solution treated and aged (STA) joint

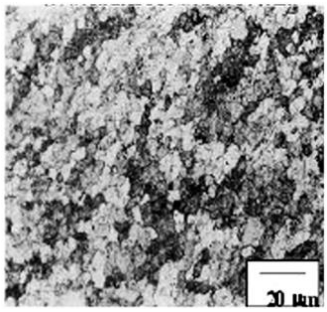

Fig 4: Optical micrographs of FSW zones of AA6061 joints-artificially aged (AG) joint.

It has been observed that best values for yield strength (130 MPa) and tensile strength (210 MPa) were in the case of artificially aged FSW.

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3. EFFECT OF TOOL ROTATIONAL SPEED AND PIN PROFILE

For conducting these experiments work pieces of 100 mm X 50 mm X 6 mm made from AA6061 were prepared sufficient in number. The welding parameters and fabricated tools are presented in Table 3. The FSW was carried out using (M/s RV Machine Tools, Coimbatore, INDIA).

A 40x7x6 mm tensile specimens were prepared as per ASTM E8 standard. Three such tensile specimens were prepared from each joint and the average value of ultimate tensile strength (UTS) was taken. The UTS was estimated using a computerized universal testing machine (HITECH TUE-C-1000).

Table 3: Welding parameters

Process parameters	Values
Tool rotational speed (rpm)	600, 950 and 1300
Welding speed (mm/s)	60
Axial force (kN)	8
Tool tilt angle (deg.)	0
Tool shoulder diameter (mm)	18
Tool shoulder surface	Flat
Pin diameter (mm)	6
Pin length (mm)	5.7
Pin profile	SS, SH, SO

It has been observed that the tool rotational speed and pin profile considerably influenced the microstructure and tensile strength of the joints. By setting the tool rotational speed of 950 rpm and straight square pin profile yielded highest tensile strength of 273 MPa the fabrication is carried out[8].

4. RESULTS AND DISCUSSIONS

Fracture surfaces of the tensile samples were investigated by scanning electron microscope (SEM) as shown in fig. 1. Standard test specimens of recommended dimensions were fabricated using AA6061 aluminium alloy for FSW purpose. Standard FSW test specimens as per recommended dimensions were prepared sufficient in number using AA6061 aluminium alloy.

From the experimental results, it was found that the tensile properties of AW joints were much lower than those of the base metal. Of the three PWHT methods examined, the artificial aging (AG) treatment enhanced the tensile properties of the joints substantially but the other two methods, solution treatment (ST) and solution treatment followed by aging (STA), deteriorated tensile properties of the joints[7]. Most of the specimens failed at the FSW region during tensile testing. In particular the tool rotational speed and pin profile considerably influenced the microstructure and tensile strength of the joints. The joint was fabricated using tool rotational speed of 950 rpm yielded highest tensile strength of 273 MPa.

5. CONCLUSIONS

The effect of post-weld heat treatment on the tensile properties of FSW joints of AA6061 alloy was analyzed in detail. From this investigation, the following important conclusions are obtained.

i) Of the three PWHT methods examined in this investigation, a simple artificial aging (AG) treatment enhanced the tensile properties of the friction stir-welded AA6061 aluminium alloy joints (210 MPa – refer table 2).

ii) The influence of tool rotational speed and pin profile on the microstructure and tensile strength of AA6061 aluminium alloy FSW joints were study. The joints fabricated using straight tool profiles had no defects under the experimental conditions considered. The following three regions namely unmixed region, mechanically mixed region and mixed flow region were observed in the weld zone. The joints fabricated using tapered tool profiles and tool rotational speed of 600 rpm showed absence of mixed flow region. The joint fabricated using tool rotational speed of 950 rpm and straight square pin profile yielded highest strength of 273 MPa.

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