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# Joining of Dissimilar Aluminium alloys using Friction Stir Welding

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**Abstract— In the proposed work, two different aluminium alloys such as Al 6061 and Al 6063 of same family was selected to study the mechanical properties of the joint prepared by Friction Stir Welding. The experiments were conducted by changing the spindle speed in three different levels by maintaining the other parameters unvarying. Welded workpieces were tested for its tensile strength and micro structure in order to understand the behavior of the welding process. The results revealed that the tensile strength is increased initially when the spindle speed increases and decreased beyond the certain level. Microstructural analysis showed that, in stir zone grain refinement was happened due to which mechanical properties were improved.**

**Index Terms— Friction Stir Welding, Dissimilar Welding, Tool Rotational Speed, Microstructure.**

## I. INTRODUCTION (HEADING 1)

Aluminium alloys are more frequently useful in the automotive production, the joining of aluminium to itself, but in specific also to other materials becomes gradually important. When joining aluminium to other materials, three different groups can be categorized.

- Joining aluminium to compatible metals (with some degree of solubility in each other)
- Joining aluminium to incompatible metals (little or no solubility in each other)
- Joining aluminium to different types of material (e.g. plastics and composites, ceramics).

A basic instruction is that there is no particular process or a set of processing parameters which is best for all material amalgamations or fits all performance requirements. Thus each dissimilar material joint is best viewed as a exceptional application with unique requirements.

Friction Stir Welding is a solid-state thermo-mechanical joining process (a combination of extruding and forging), invented by W.Thomas of The Welding Institute (TWI) in 1991, that has become a feasible manufacturing technology of metallic sheet and plate materials for applications in various industries, including aerospace, automobile, defense, shipbuilding. [1].

FSW produces welds by using a revolving, non-consumable welding tool to locally soften a workpiece, through heat produced by friction, thus allowing the tool to “stir” the material at joining surfaces. In this welding process, a rotating welding tool is forced into the material at the interface, for example - two adjoining plates, and then translated along the interface. FSW offers ease of handling, precise external process control and high levels of repeatability, thus creating uniform welds. No special groundwork of the sample is required and little waste or pollution is created during the welding process.

Friction produced by the tool heats the material which is then basically extruded around the tool before being forged by the large downward pressure or axial load. The tool of FSW is composed of two parts a tool body and a probe. The tool technology is the heart of friction stir welding process. The tool shape determines the heating, plastic flow and forging pattern of the plastic weld metal. The tool shape determines the weld size, welding speed and tool strength.

The weld is made by the deformation of the material at temperatures lower than the melting temperature. The coordinated simultaneous rotational and translational motion of the welding tool during the welding process produces a characteristics asymmetry between the connecting sides.

Authors chose aluminum 6xxx series for this project. Alloys in the 6xxx series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide (Mg2Si), thus making them heat treatable. Although not as strong as most 2xxx and 7xxx alloys, 6xxx series alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength.

The tool material determines the rate of friction heating, tool strength and working temperature, the latter ultimately determines which materials can be friction stir welded. We have selected tool with square probe pin to analysis their effect on joint properties.

Hugo Robe et.al [2] studied the microstructural and mechanical characterization of a dissimilar friction stir welded butt joint made of AA2024-T3 and AA2198-T3. The aim of investigation was to evaluate the microstructural features, material flow, and post weld mechanical properties of a dissimilar joint made of AA2024-T3 and AA2198-T3 produced by friction stir welding. R.I. Rodriguez et.al [3] investigated the microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys. Under monotonic tensile loading, an increase in the joint strength was observed with the increase in the tool rotational speed. Regarding fracture, the joints consistently failed on the 6061 aluminum alloy side. SureshBabu et.al [4] studied the effect of tool rotational speed while joining metal matrix composites and concluded that when rotational speed increased from 1600 rpm onwards tensile properties were also increased and reaches maximum at 1800 rpm. If the rotational speed is increased above 1800 rpm, there is minimal change in the properties of the weld workpiece.

In the proposed work two different aluminium materials of same family was selected to prepare the joint and tested for mechanical properties such as hardness and microstructure.

## II. Experimental Procedure:

### *Workpiece Material*

Aluminum alloys in the 6xxx series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide ($Mg_2Si$), thus making them heat treatable. Although not as strong as most 2xxx and 7xxx alloys, 6xxx series alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength.

Relationship among the different 6XXX series with its application is given in the figure 1. [5].

Commercial AA6061 aluminum alloy and AA6063 aluminum alloy were used for friction stir welding technique and analysis.

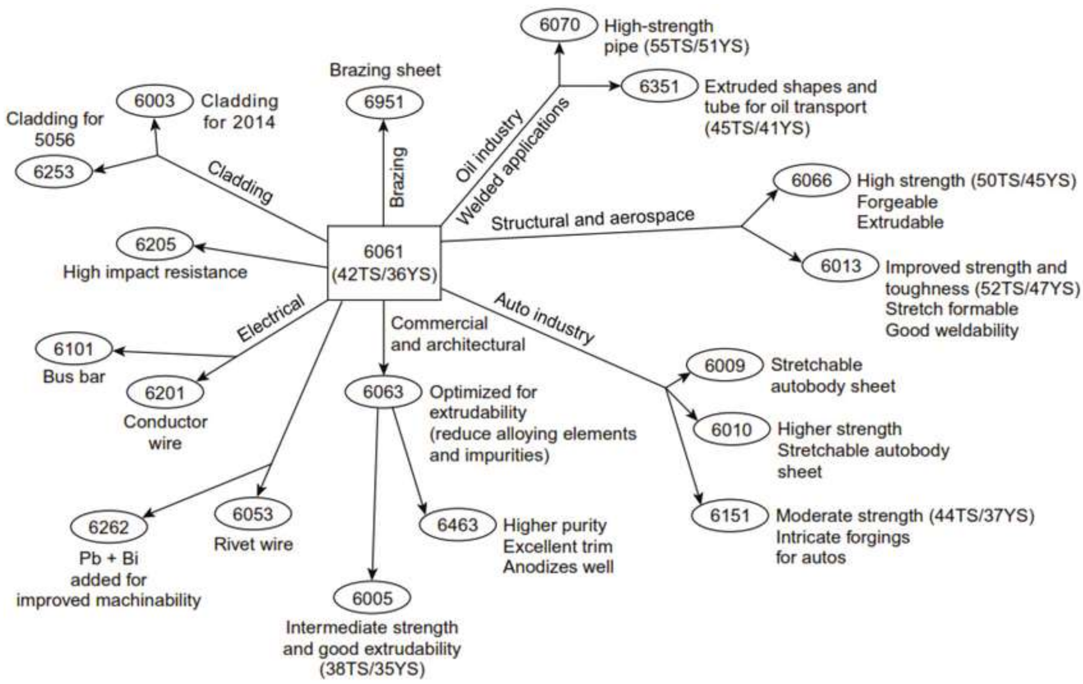


Fig.1: Relationship among commonly used 6XXX aluminum alloy [5]

### *Tool Selection:*

Tool geometry affects the heat generation rate, traverse force, torque and the thermo-mechanical environment experienced by the tool. The flow of plasticized material in the work piece is affected by the tool geometry as well as the linear and rotational motion of the tool. Important factors are shoulder diameter, shoulder surface angle, pin geometry including its shape and size, and the nature of tool surfaces. We have selected tool with square probe pin to analysis their effect on joint Properties.

Table 1. Details of the FSW Tool

| | |
|---|---|
| Material | High Speed Steel M7 |
| Hardness | 70 HRC |
| Tool Probe Profile | Square |
| Shoulder Diameter | 18mm |
| Side of the Pin | 4 mm |
| Pin length | 4 mm |

### *Selection of Process parameters*

The Friction stir welding process has limited process parameters to control as compared to Fusion welding process. The main input parameters in friction stir welding are as follows are tool Rotational Speed, welding Feed Rate, ,Axial Force, tool tilt angle and tool pin profile. In the present investigation, tool rotational speed had changed in three different levels by maintaining the other parameters constant. In table 2, the various parameters and their values are given. In the present work, tool rotational speed is varied in three different levels without changing the values of others parameters.

Table 2. Process Parameters and their levels

| **Parameters** | **Level 1** | **Level 2** | **Level3** |
|---|---|---|---|
| Rotational Speed(rpm) | 1600 | 1800 | 2000 |
| Feed rate(mm/min) | 65 | 65 | 65 |
| Axial force (KN) | 5 | 5 | 5 |
| Tool Profile | Square | Square | Square |

***Conducting the Experiments***

For conducting the experiments, a vertical milling machine setup is used which is shown in the figure 2. Commercially available Al 6061 and Al 6063 was select as work piece materials and cut in to pieces of size 100 mm X 50mm X 5mm using power hacksaw. The workpiece is rigidly clamped in the vice in order to withstand the axial force applied during plunging which is shown in the Figure 3. In order to analyze the tensile strength, Hardness, and microstructure of the weldment totally three experiments were conducted.

Fig 2.Machine set up used for Welding

Fig.3. Workpiece clamed in machine vice

## Results and Discussion

The welded specimen was tested for tensile strength for which the welded specimen is cut in to the specific form following the ASTM standards. The sample of the tensile test specimen before and after the test is shown in the Figure 4 and 5 respectively.

Fig. 4. Tensile test Specimen (Before Test)

Fig. 5. Test specimen (After Test)

The results of tensile test revealed that there was an optimum spindle speed at which the tensile strength is high. When the speed was higher and lower than that value, the tensile strength was minimum. This is because at lower spindle speed stirring of the material was poor and heat input was lower and higher spindle speed unnecessary release of stirred material on the top surface which in turn weakens the tensile strength. The results of the tensile test is shown in the figure 6.

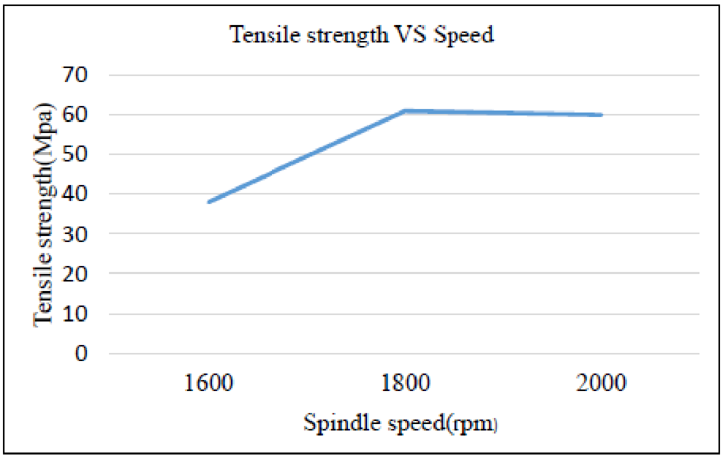

Fig.6. Tensile strength results

## III. Microstructural Examination

In order to understand the basic mechanism involved in the joining process, microstructural examination was carried out. The specimens were prepared as per the standard procedure. The steps involved in the specimen preparation were cutting, mounting, grinding, polishing and etching. Specimen prepared for microstructural examination is shown in the Fig .6.

Fig. 6. Specimen prepared for Microstructural Examination

The microstructure of the various zones like Thermo Mechanically Affected zone (TMAZ), Heat Affected Zone (HAZ), Stir zone (SZ) of the welded specimen was taken in order to understand the behavior of the joining process. Microstructure of the stir zone different spindle speed is shown in Figure 7, 8 and 9.

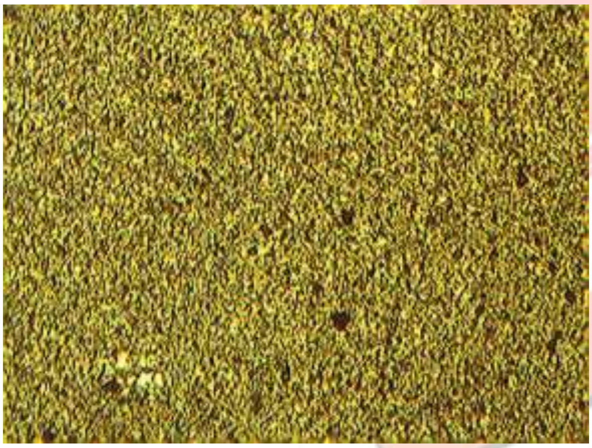

Fig. 7. Stir Zone of Sample 1(1600 rpm)

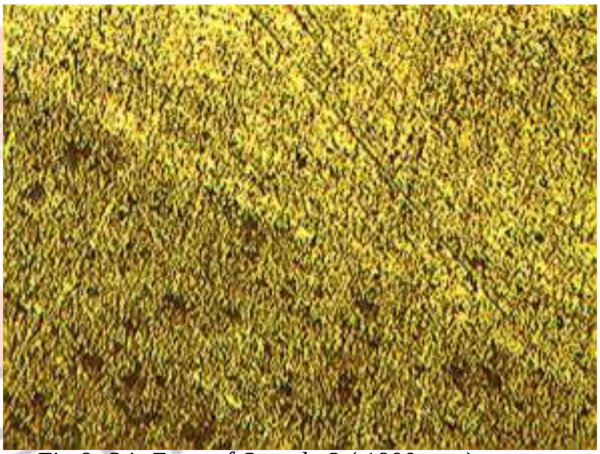

Fig.8. Stir Zone of Sample 2 ( 1800 rpm)

For 1800 rpm, the grains are fine, uniform and equally distributed due to which the strenth of the weldment was high. This was supported by the results submittted by W. Y. Li [5]. For higher spindle speed due to expellsion of material from weld zone, the small voids were found which reduces the strength.

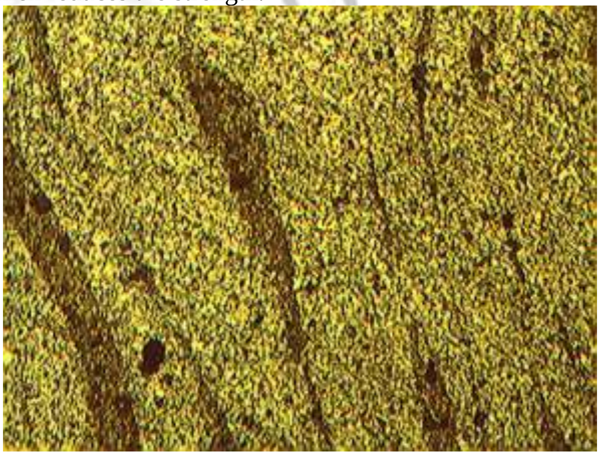

Fig.9. Stir Zone of Sample 3 (2000 rpm)

## IV. Conclusion

In the present work, the two different aluminium materials from same family group was selected to investigate the effect of spindle speed on tensile strength and microstructure during friction stir welding. Experiments were conducted with different speed without altering the other parameters. The experimental results revealed that there was an optimum speed to obtain the maximum tensile strength. Spindle speed above and below that optimum level results lower tensile strength. Microstructural investigation was carried out to analyze the behavior and results showed that at optimum speed, the grains were fine, uniform in size and distributed evenly which results higher strength.

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