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Research Article

Examining the Mechanical and Metallurgical Properties of Single Pass Friction Stir Welded Dissimilar Aluminium Alloys Tee Joints

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Abstract:

These experimental works aim to investigate the influence of Friction Stir Welding (FSW) process parameters on the mechanical and metallurgical properties of the dissimilar aluminium alloys Tee joint configuration. A 3.5 mm thick aluminium alloy 5052 and 6 mm thick aluminium alloy 6061 is taken for Tee joint configurations, where the AA 5052 act as the skin and AA 6061 act as the stinger. An FSW too with a hexagonal pin profile and flat shoulder profile was adopted for this work. The welding parameters adopted are three variable spindle speed, one welding speed, one plunge depth and three-tool tilt angles. The microstructure analysis shows that a fine grain structure was developed in the joint's welded Tee region. The lower parameter values prevent the metals from stirring well and causing the formation of defects and results in low joining strength. While increasing the parameter values, the joint strength was initially increased, and then it got decreased due to the drag of metal in the weld region, and it causes the formation of tunnel defect. A defect-free joint was fabricated using spindle speed 1100 rpm, welding speed 50 mm/min, plunge depth 0.5 mm and tool tilt angle 1°.

Keywords: *Friction Stir Welding, aluminium alloy, Tee Joint, Microstructure*

1. Introduction

To manufacture automobiles, vessels, aircraft structures, and other structural components, aluminium alloys of the 6xxx series and 5xxx series are widely used due to their mechanical strength, low density and good corrosion resistance. The vessels hulls fabricated by AA5052 alloys can provide good corrosion resistance. In contrast, bulkheads that are not directly exposed to seawater are manufactured from the AA6062 alloy to strengthen the structure. By adopting these metals, the vessels' weight can be reduced, and it increases the strength.

Aluminium alloys are challenging to weld via fusion welding due to the problems such as porosity, cracking and massive sheet distortion. FSW is a wise choice because it is viable for welding aluminium alloys and does not have the difficulties that fusion welding has. The FSW technique makes use of a rotary tool, shaped with the aid of a shoulder and a pin, inserted at the interface between the plates, producing heat via friction and plastic deformation, hence favouring plastic drift and the mixing of substances around the device as it advances, and creating a weld in the solid-state.

Nowadays, FSW is adopted for many industries to join similar materials and even dissimilar metals. Most of these researches are conducted on butt joint configurations, and only less or a low number of investigations were carried out on other structure like Tee joints. All these studies confirmed that there are some complications to obtain welds in dissimilar materials by FSW, and the mechanical properties of welds between dissimilar aluminium alloys need enhancement. The literature shows that numerous defects are found in welds due to the improper mixing of the metal in the nugget zone and the material flows generated by the pin and the tool shoulder, like tunnel defects.

The process parameters and their influence on metal mixing and grain growth are thoroughly studied to avoid weld defects. These studies show that the most dominating parameters for welding aluminium and its alloys are spindle speed and tool tilt angle. To analyze the metallurgical defects, the specimens undergo microstructure analysis like scanning electron microscopy and find out whether the metals sir well in the nugget zone and studied the grain growth in those regions.

Most of the researches are focused on butt or lap joints configurations in similar or dissimilar materials. Few studies are carried out for single-pass Tee joints in dissimilar materials. This research examines the influence of single-pass FSW parameters on the joints' mechanical and metallurgical properties.

2. Experimental methods

The aluminium alloys AA 6061-T6 and AA 5052-H32 were selected for this research. The mechanical properties and chemical compositions of the metals are given in tables 1 and 2, respectively.

Table 1. Mechanical properties of AA6061-T6 and AA5052-H32

Sl.No	Properties	Materials	
		AA6061-T6	**AA5052-H32**
1	Hardness(Brinell)	95	60
2	Ultimate tensile strength	310 MPa	228 MPa
3	Tensile yield strength	276 MPa	193 MPa
4	Elongation	12 %	12 %
5	Shear strength	207 MPa	138 MPa
6	Fatigue strength	96.5 MPa	117 MPa

Table 2. Chemical composition (wt. %)

Material	Mg	Si	Mn	Cr	Ni	Fe	Ca	Cu	Zn	Ti	Al
AA5052H32	2.30	0.15	0.02	0.10	–	0.20	–	0.02	0.01	0.01	Bal
AA6061-T6	0.92	0.60	0.06	–	0.18	0.33	0.2	–	0.03	0.02	Bal

The schematic Tee joint configuration for this work is given in figure 1. The top plate AA 5052 is taken as skin, and the AA 6061is the stringer. Due to the less plunge depth for the single-pass FSW, the weld surface has a high surface finish, and there is no requirement for further grinding or surface finishing.

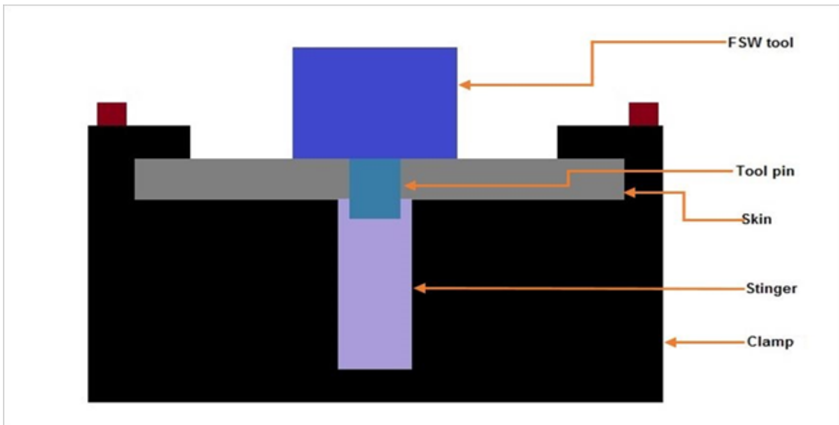

Figure 1. *Schematic representation of the FSW process*

The tools used for this work is a tool grade high-speed steel. The tool pin profile adopted for this work is hexagonal, with a pin diameter of 4.5 mm and a length of 4mm, and the shoulder is flat with a 20 mm diameter. The tool image is given in figure 2.

Figure 2. *FSW pin profile and shoulder profile*

This hexagonal pin profile helps to agitate the metal well in the nugget zone; compared to other profiles, the hexagonal profile provides more metal movements. A vertical milling machine is adopted for conducting this experiment. A specially designed fixture was used to configure the Tee joint for single-pass FSW.

Three sets of experiments were conducted, with different parameter combinations; the spindle speed and the tool tilt angles are selected as the varying parameters. These two parameters have a predominant influence on the mechanical properties and the metallurgical properties of the joint. The other two parameters, like plunge depth and welding speed, were kept constant as per the previous experiments' results and literature. The welding process combinations are given in table 3.

	Specimen - 1	**Specimen – 2**	**Specimen - 3**
Spindle speed	900 rpm	1100 rpm	1200 rpm
Welding speed	50 mm/min	50 mm/min	50 mm/min
Plunge depth	0.5 mm	0.5 mm	0.5 mm
Tool tilt angle	0º	1º	2º

Three joints were produced by using these parameter configurations. The specimen image of the weldments is given in figure 3.

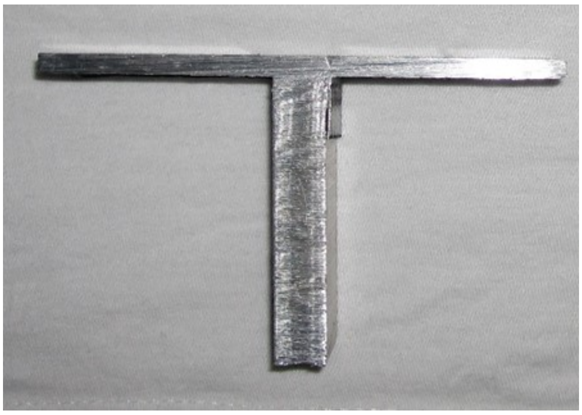

Figure 4. *Tee Joint*

The specimen for tensile testing was cut using a power hacksaw; a unique method is adopted for conducting the tensile test, a specially designed arrangement used for this—the tensile testing arrangement as shown in figure 5.

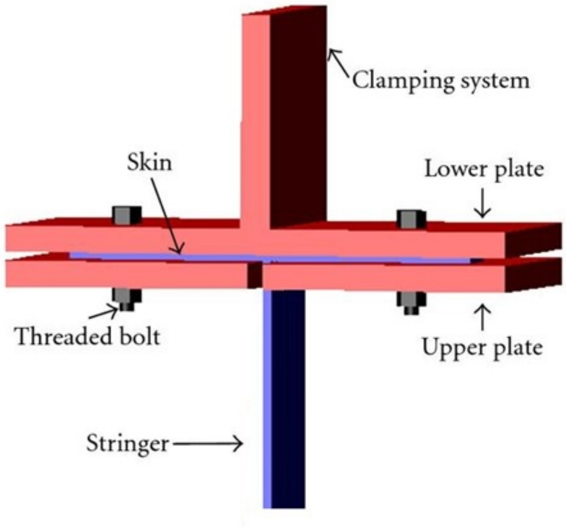

Figure 5. *Tensile testing arrangement*

The specimens for microstructure analysis were taken transversely to the weld direction. Before undergoing metallographic testing, the specimens were polished and etched as per ASTM standards (Poulton's reagent). The microstructure analysis was conducted on an optical microscope, identifying the defects in the weldments and analysing the stir zone. In contrast, the scanning electron microscope helps to identify the grain refinement in the weldments.

3. Results and discussion

3.1. Morphology of the joints

Three Tee joints were fabricated by using the single-pass friction stir welding method. The welding bead geometry was analyzed by using an optical microscope, given in figure 6.

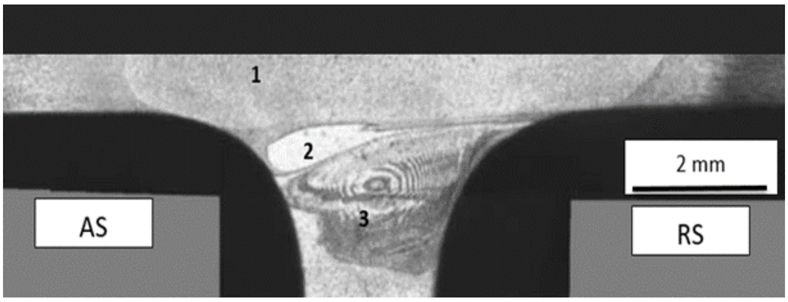

Figure 6. *Bead geometry of the weldment*

The bead geometry of the Tee joint clearly shows the AA 5052 skin and AA 6061 stinger. The number 1 in the image indicates the joint's thermomechanical affected zone, whether the number 2 suggests the nugget zone, and number 3 shows the onion ring formation in the welded region. This indicates that the metal in this region was agitated well. This bead geometry clearly shows the material movement in this region. The maximum metal movement has happened on the joint's retreating side due to the hexagonal pin tool movement. It is also visible that the narrow veins of AA 5052 rise from the stinger to the skin, on both the advancing and retreating sides.

Specimen 2 provide the best joint. While examining specimen 2 and specimen 3, the surface finish was more or less similar to specimen 2; while examining its morphology, it is visible that both specimen 1 and specimen 2 have tunnel defects in the advancing side and a kissing bond in the retreating side. While increasing the tool rotation speed to 1100 rpm and changing the tool tilt angle to 1° reduces defects and further increases in the parameter like tool rotation speed to 1300 rpm and changing the tool tilt angle to 2°, accelerate the defect formation. The reason for such defect formation in specimen 1 is: the spindle speed and tool tilt angle is not sufficient to plasticize the metals in the weld region, and it results in the improper mixing of joints and results in the formation of kissing bond defects. In specimen 3, the tool rotation and tool tilt angle was high, and the tool rotation plasticizes the metals more than the adequate level, and the tool tilt angle drags the metals from the nugget zone and results in the formation of tunnel defects. In contrast, the defect-free weldment was attained with specimen 2.

3.2. Tensile strength of the joints

Table 4 shows the ultimate tensile strength, the joint efficiency, and the elongation for the three different specimens. The ratio between the ultimate tensile strength of the joint and the parent metal strength provides joint efficiency. Specimen 2 shows the best results, with an efficiency of 93%, this specimen does not have any tunnel defects or kissing bonds, and it is visible in specimen 2.

Table 4. Joint efficiency

Joints	Maximum stress (MPa)	Joint efficiency (%)	Extension (mm)
Specimen 1	271	82	8.7
Specimen 2	314	93	12.2
Specimen 3	260	77	4.2

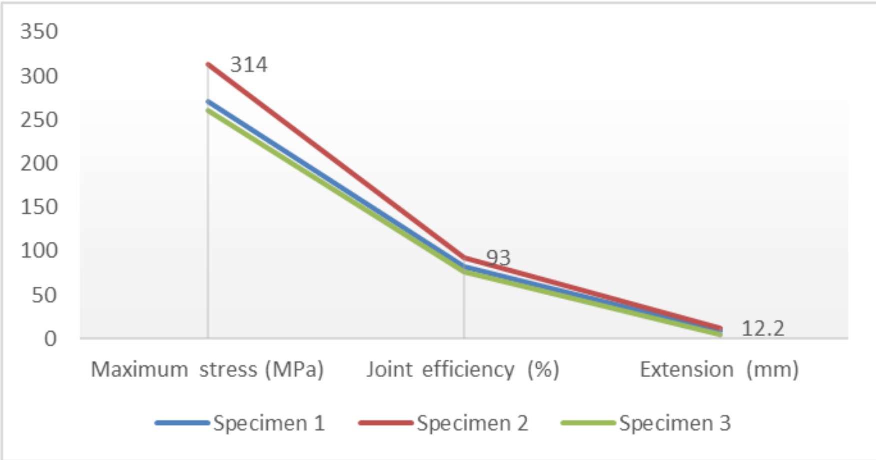

Figure 7. *Stress Vs Joint Efficiency Graph*

3.3. Microstructure

The microstructure analysis shows that all three have more or less similar microstructure, and the dissimilarity is visible on the nugget zone of the metals.

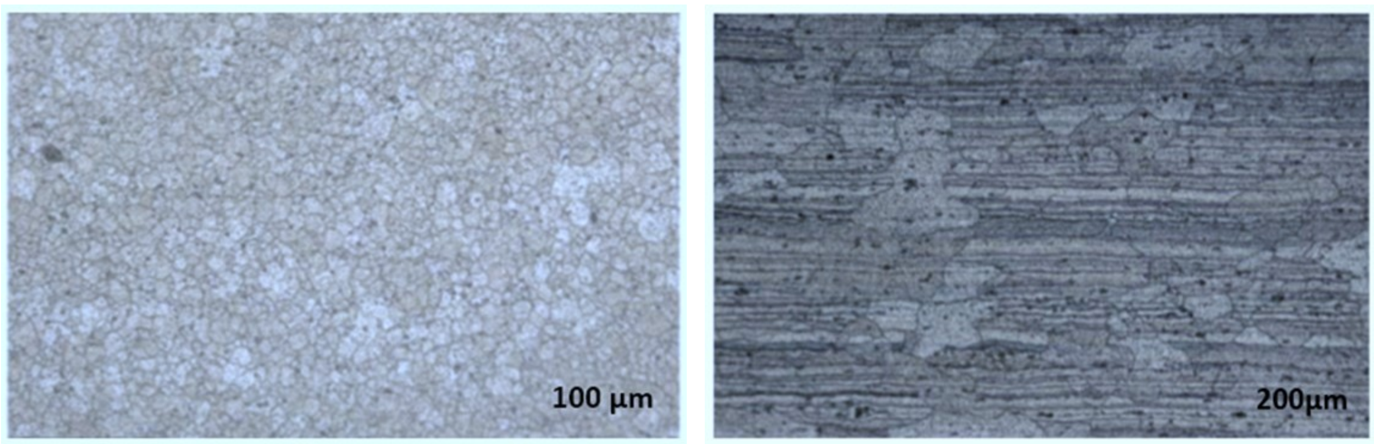

Figure 8. *Specimen 2 Microstructure*

The microstructural image of the nugget zone of specimen 2 is given in figure 8, with two different magnifications, 100 µm and 200 µm. The micrograph reveals the homogeneous grain formation in the nugget zone of the weldment. An elongated grain in the rolling direction is visible in the AA 60601. The grain size in the thermos mechanical affected zone is comparatively more extensive than the nugget zone. An abrupt transition of structures between AA 5052 and AA 6061 is found in the nugget zone. This structure transfer and the formation of equiaxial grains accelerate the strength of the joint. The material flow in the weld zones has visible differences due to the quick material movement on the advancing side compared to the retreating side. In contrast, the grain size in the nugget zone is much smaller than the parent metals.

4. Conclusions

The investigation carried out on dissimilar aluminium alloys draw the following conclusions:

- A defect-free AA 5052 and AA 6061 Tee joint was configured and joined successfully using the single-pass FSW method.
- The best parameter combination for single-pass FSW for joining AA 5052 and AA 6061 are spindle speed of 1100 rpm, welding speed 50 mm/min, plunge depth 0.5 mm and tool tilt angle 1º, respectively.
- Specimen 2 exhibits a higher joint efficiency of 93%.
- The parameter combinations and the skin metal have a significant influence on nugget zone grain formation.

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