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Prediction of the fatigue life of AISI 304L cruciform joints that were gas tungsten arc welded with various LOP sizes

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Abstract:

Friction stir welding is carried out on plates made of the aluminium alloys 5052 and AA6061 that are 3.5mm thick. The FSW tool is hexagonal in shape, with a pin diameter of 4.5 mm, a pin length of 4 mm, and a flat shoulder of 20 mm. The tools rotated at 900, 1100, and 1300 rpm while the welding speed remained constant at 50 mm per minute. The successful manufacture of flawless welds is accomplished at each of these tool rotational rates. These experimental studies aim to investigate the effects of the Friction Stir Welding (FSW) process parameters on the mechanical and metallurgical properties of the butt joint configuration of various aluminium alloys. Welding parameters include three changeable spindle (rotational) speeds, one welding speed, one plunge depth, and one tool tilt angle. The microstructure examination revealed that the joint had a fine grain structure after being welded at 1100 rpm. Lower parameter values prevent the metals from mixing properly, which results in the development of flaws and low joining strength. The joint strength originally grew as the parameter values increased, but over time it decreased due to the drag of the metal in the weld zone, which causes tunnel flaws to form. A junction without any faults was constructed using a spindle speed of 1100 rpm, welding speed of 50 mm/min, plunge depth of 0.5 mm, and tool tilt angle of 1 degree.

Keywords: Friction Stir Welding; Aluminium alloy; Tensile strength; Microstructure

1. Introduction

Due to their high mechanical strength, low density, and superior corrosion resistance, aluminium alloys from the 6xxx and 5xxx families are frequently used in the manufacture of automobiles, vessels, aircraft structures, and other structural elements. The AA5052 alloys have high corrosion resistance in the hulls of their boats. Bulkheads that are not directly exposed to seawater, however, are made of the AA6062 alloy to strengthen the construction. By employing these metals, the weight of the vessels can be reduced while maintaining their strength. Fusion welding aluminium alloys is challenging due to problems like porosity, cracking, and considerable sheet deformation. FSW is a wise choice because it can weld aluminum alloys successfully and does not have the same issues as fusion welding. 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 favoring 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 investigations demonstrate that the most dominating parameters for welding aluminium and its alloys are spindle speed and tool tilt angle. The specimens are subjected to microstructure analysis, such as scanning electron microscopy, to examine the metallurgical flaws. This examination also looks at the grain growth in the nugget zone and determines whether the metals are stable there. The majority of studies concentrate on butt or lap joint arrangements in comparable or different materials. There aren't many studies done on single-pass Tee joints made of different materials. In this study, the effects of single-pass FSW parameters on the mechanical and metallurgical characteristics of the joints are investigated.

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	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

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The schematic butt joint configuration for this work is given in Figure 1. The dissimilar aluminium alloys were cut into dimensions of 100mm × 50 mm × 3.5 mm. A total number of 3 pairs were friction stir welded, positioning the AA6061 alloy on the advancing side and the AA5052 alloy on the retreating side. 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.

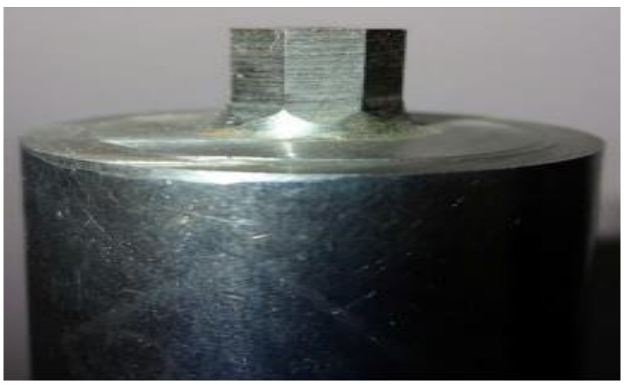

Figure 2: FSW pin profile and shoulder profile

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 butt joint for single-pass FSW. Three sets of experiments were conducted (see,Table 3), with different parameter combinations; the spindle speeds have been selected as the varying parameter. These 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.

Table 3: The welding process combinations are given

No of weld joints	Specimen - 1	Specimen - 2	Specimen - 3

Spindle speed	900 rpm	1100 rpm	1300 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	1°	1°	1°

Three joints were produced by using these parameter configurations. The specimen for tensile testing was cut using a power hacksaw as per the ASTM standard on the 3.5 mm thick plate. Tensile tests were performed to determine the tensile properties of the weld material such as tensile strength and percentage of elongation. Tensile tests were conducted at Computer Controlled AUTO Make Universal Testing Machine. For each welded plate, three specimens were prepared and tested and average value is reported. Figure 3 shows the tensile specimen before and after fracture. The fracture has occurred mostly in the HAZ on the retreating side of the weldment. Analysis of the mean for each of the experiments gives better combination of parameter levels. 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 micro-structure 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.

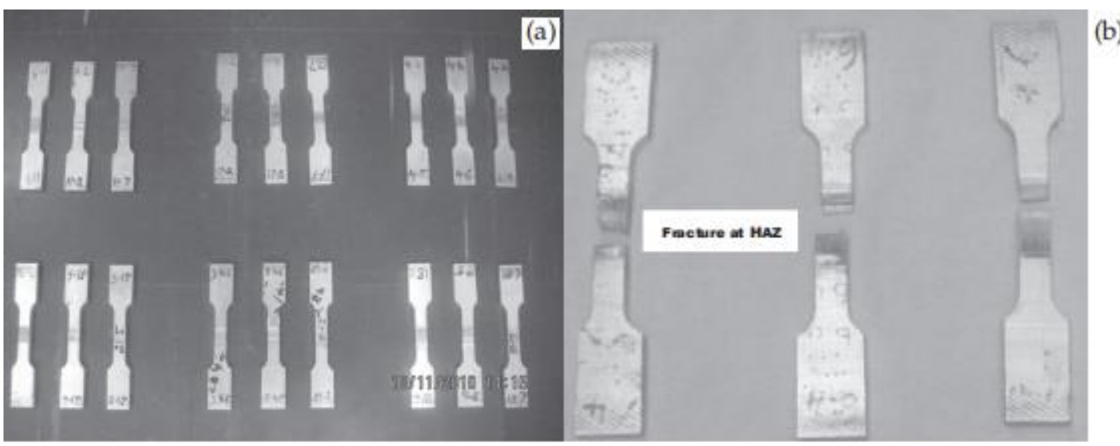

Figure 3: Specimen (a) before and (b) after tensile test

3. Results and discussion

1.1 Weld joints structure characterization

Three joints were fabricated by using the single-pass friction stir welding method at different welding speeds.The Figure 4displays macrographs of upper surface of the weldjoints that were prepared at different speeds.There is no defect apparently observed on the weld joints. More flash is noticed in joint 1 as the tool rotational speed is insufficientfor filling of the stirring

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materials at rotational speed 900rpm. It is concluded from the investigations thatat higher rotational speed better welding seam is observed in weld joints 2 and 3. The defect-free weldment was attained with joint3 as the tool rotationspeed1300rpm plasticizes the metals more than the adequate level.

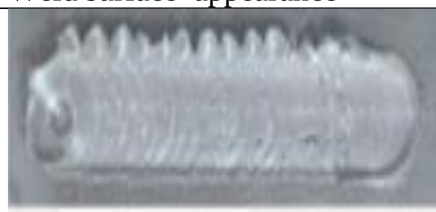
Weld joints	Weld surface appearance	Observation
Joint 1 @900rpm		Weld surface with lateral flash with insufficient filling
Joint2@1100rpm		Smooth weld surface with little flash
Joint3@1300rpm		Smooth weld surface

Figure 4: Top surface macrograph ofFSW joints

1.2 Tensile strength of the joints

Table 4 shows the ultimate tensile strength, the joint efficiency, and the elongation for the three different joints 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 is made from a sound joints with out any tunnel defects or kissing bonds.

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

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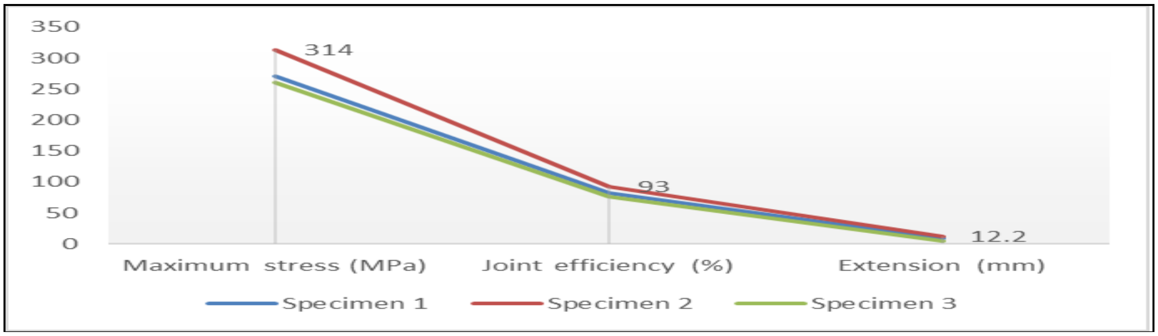

Figure 5: Stress Vs Joint Efficiency Graph

1.3 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.

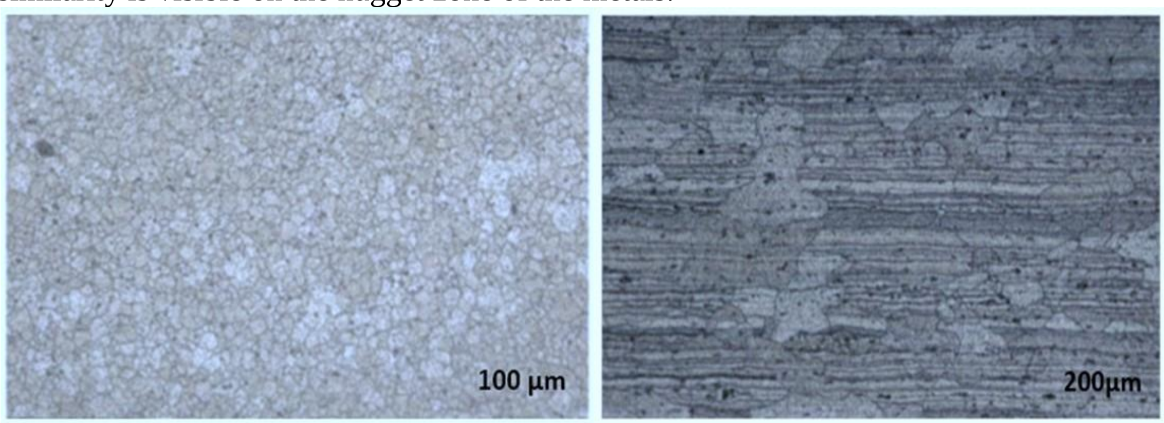

Figure 6: Specimen 2 Microstructure

The microstructural image of the nugget zone of specimen 2 is given in Figure 6, with two different magnifications, 100 µm and 200 µm. The micrograph reveals the homogeneous grain formation in the nugget zone of the weldment. An elon-gated 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.

Conclusions

The analysis of several aluminium alloys leads to the following conclusions:

- The single-pass FSW approach was used to configure and successfully join a defect-free AA 5052 and AA 6061 joint.
- For combining AA 5052 and AA 6061 in a single pass, the ideal parameter combinations are spindle speed of 1100 rpm, welding speed of 50 mm/min, plunge depth of 0.5 mm, and tool tilt angle of 1o, respectively.
- The joint efficiency of specimen 2 is higher, at 93%.

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