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Influence of process parameter on tensile properties of friction stir welded butt joints in 6082 aluminium alloy

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ABSTRACT

Friction Stir Welding, a relatively new welding process, was developed in 1991 at The Welding Institute near Cambridge, England. In this process parts are mated together, rigidly fixtured, and joined in solid-state by forcing a rotating tool into the joint, and traversing that tool along the joint. This process creates weldments with properties comparable to the base metal and in most cases superior to traditional fusion welding techniques. During the Friction Stir Welding (FSW) process, the forging forces under the tool plastically deform the material, "stirring" the material around the tool pin and against the tool shoulder, thus joining the mated parts together. This process induces large shear forces in the plastically deforming material, raising the temperature of the material to approximately 80% of the melting temperature. The FSW process parameters such as tool rotational speed, welding speed, axial force, etc. play a major role in deciding the weld quality. In present investigation, the effect of processing parameters on mechanical properties of AA6082-O joints produced by friction stir welding was analyzed. Different welded specimens were produced by varying rotating speeds of the tool as 900 & 1200 rpm and by varying welding speeds as 50 & 63 mm/min. The FSW joints mechanical properties of the material such as yield strength, tensile strength and percentage of elongation were evaluated by means of tensile tests.

Introduction

Friction stir welding (FSW) was developed and patented by The Welding Institute (TWI) of U.K. in 1991 by Thomas W.M. et al[1] as a solid-state joining technique, and it was initially applied to aluminum alloys[2-3]. Friction stir welding (FSW) is capable of fabricating either butt or lap joints, in a wide range of materials thickness and lengths. During FSW, heat is generated by rubbing a non-consumable tool on the substrate intended for joining and by the deformation produced by passing a tool through the material being joined. The rotating tool creates volumetric heating, so as the tool is progressed, a continuous joint is created. FSW, like other types of friction welds, is largely solid state in nature. As a result, friction stir welds are not susceptible to solidification related defects that may hinder other fusion welding processes. The FSW process is diagrammed in figure1.

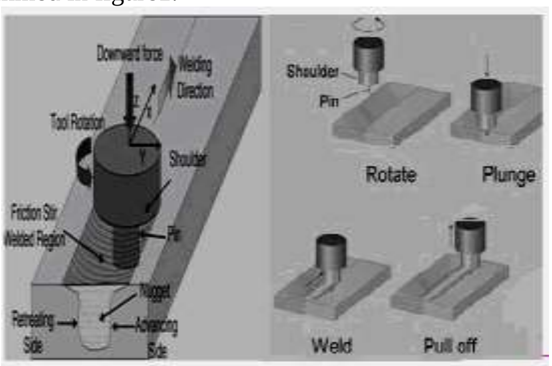

Figure 1.
Principle of the FSW process for butt joints

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The parts intended for joining are usually arranged in a butt configuration and clamped on to a backing bar. The rotating tool is then brought into contact with the work pieces. The tool has two basic components: the probe, which protrudes from the lower surface of the tool, and the shoulder, which is relatively large diameter. The length of the probe is typically designed to match closely the thickness of the work pieces. Welding is initiated by first plunging the rotating probe into the work pieces until the shoulder is in close contact with the component top surface. Friction heat is generated as the rotating shoulder rubs on the top surface under an applied force. Once sufficient heat is generated and conducted into the work piece, the rotating tool is propelled forward. Material is softened by the heating action of the shoulder, and transported by the probe across the bond-line, facilitating the joint.Unlike fusion welding, there is no actual melting and the weld has the same fine-grained condition as the parent metal. FSW is considered to be the most significant development in metal joining in a decade and is a 'green' technology due to its energy efficiency, environment friendliness, and versatility. As compared to the conventional welding methods, FSW consumes considerably less energy, no cover gas or flux is used, thereby making the process environmentally friendly. The joining does not involve any use of filler metal and therefore any aluminum alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding[4]. FSW joints usually consist of four different micro-structural zones as shown in figure 2.

Micro-structural features of Friction Stir Welds

They are: (A) unaffected base metal (B) heat affected zone (HAZ) (C) thermo-mechanically affected zone (TMAZ) and (D)

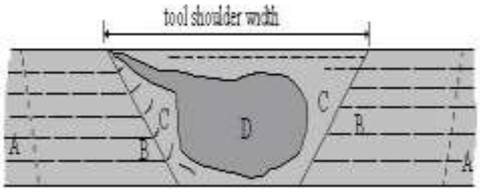

Figure 2. Micro-structural features of Friction Stir Welds

friction stir processed zone. The formation of above regions is affected by the material flow behaviour under the action of rotating non-consumable tool. However, the material flow behaviour is predominantly influenced by the different tool pin profiles & tool geometry[5-7] and FSW process parameters like rotating speed[8-9]& welding speed[10-12].The present research work is aimed to study the effect of rotating and transverse speed on mechanical behaviour of AA6082-O welded plates of 5mm thickness.

Experimental Procedure:

The plates to be welded by FSW are fixed by a clamping fixture on a vertical milling machine model VM-3 as shown in figure 3.

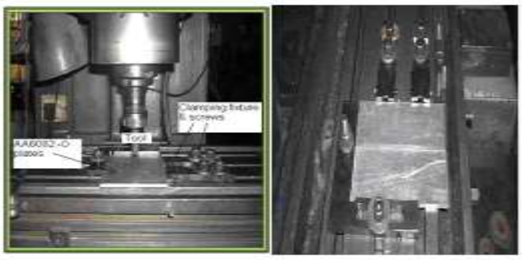

Figure 3.Experimental Setup for FSW on vertical milling machine

The rolled plates of 5mm thickness, AA6082-O aluminium alloy (HE30) have been cut into the required size (16mm×60mm) by power hacksaw cutting and milling. Which is a precipitation hardened aluminum alloy widely used in aerospace applications. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the FSW joint. Figure 4 shows the FSW joints obtained by performing friction stir welding operation on vertical milling machine

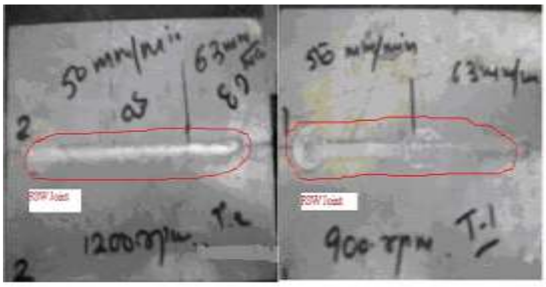

Figure 4. FSW Joints of AA6082-O

The chemical compositions and mechanical properties of base metal are presented in table-1 & table-2 respectively.

Table 1: Chemical composition of base metal

Chemical composition of base metal AA6082-O									
Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
% Present	0.7 to 1.3 %	0.5%	0.1%	0.4 to 1.0 %	0.6 to 1.2 %	0.2%	0.1%	0. 25 %	Balance

Non-consumable tool made of Cold Work Die Steel (WPS) have been used to fabricate the joints which is quenched at hardening temperature of 920 ˚C to 980 ˚C, and characterized by 58 to 65 HRC hardness.

Table 2: Mechanical properties of AA6082-O

Mechanical properties of AA6082-O				
Proof Stress 0.2% (MPa)	Tensile Strength(MPa)	Shear Strength (MPa)	Elongation A5 (%)	Hardness Vickers (HV)
60	130	85	27	35

The primary function of the non-consumable rotating tool pin is to stir the plasticized metal and move the same behind it to have good joint. Pin profile plays a crucial role in material flow and in turn regulates the welding speed of the FSW process. The profile of tool used in this work is cylindrical tri flute type, as shown in figure 5. The welding parameters and tool geometrical characteristics are presented in table 3.

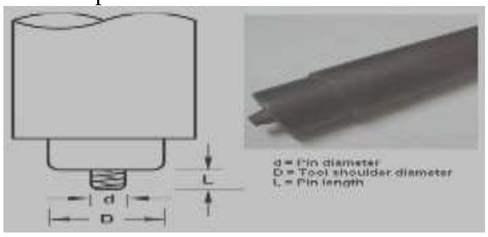

Figure 5. Image of the tool pin profiles

Table: 3 Welding parameter & tool geometry

Welding parameter & tool geometry				
Rotating speeds (rpm)	Advancing speeds (mm/min)	Pin length (mm)	Pin diameter (mm)	Tool shoulder diameter (mm)
900,1200	50, 63	4.7	4	18

Result and Discussion:

In fusion welding of aluminium alloys, the defects like inclusion of slag, porosity, solidification cracks, etc. deteriorates the quality of weld and properties of joint. Usually, friction stir welded joints are free from these defects since there is no melting takes place during welding and the metals are joined in the solid state itself due to the heat generated by the friction and flow of metal by the stirring action. However, FSW joints are prone to other defects like pinhole, tunnel defect, piping defect, kissing bond, cracks, etc. due to improper flow of metal and insufficient consolidation of metal in the friction stir processing region.

Friction Stir Welding Studies

Friction stir welding has become a very effective tool in solving the joining problems in aerospace industry, where high ductility and tensile strength are required. In the present work, different FSW butt welds of AA6082-O sheets were successfully obtained by varying the processing parameters like rotating and advancing speed and the welded joints were mechanically characterized.

Tensile Properties

Tensile properties of FSW joints such as yield strength, tensile strength, percentage of elongation have been evaluated. Some specimens for the mechanical analyses have been prepared and sectioned in the perpendicular direction along the weld line. The dimensions of tensile testing specimen are shown in Fig. 6.

Specimen Geometry used in Tensile Testing.

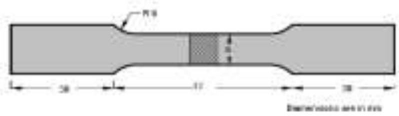

Figure 6. Specimen Geometry used in Tensile Testing.

Three specimens are tested and average of the results of three specimens is measured as a final result. The experimental results of tested specimens are acquired from tensile test machine. The effect of rotation speed and welding speed on tensile properties are shown in figure 7 to 11.

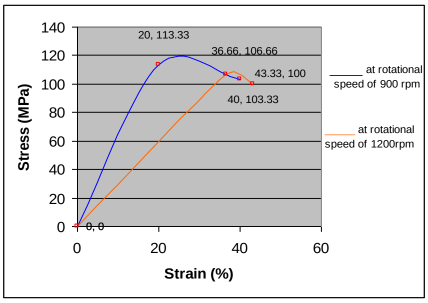

Figure 7. Stress –Strain curves for rotating speed

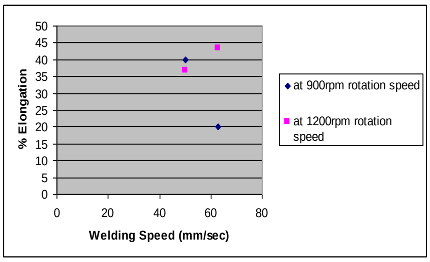

Figure 8. Effect of welding speed on elongation

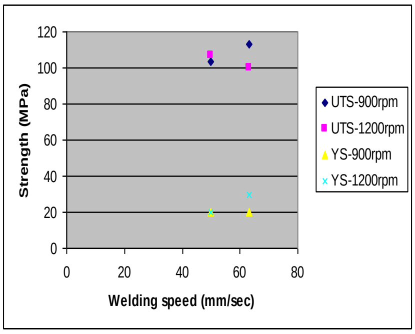

Figure 9. Effect of welding speed on Strength

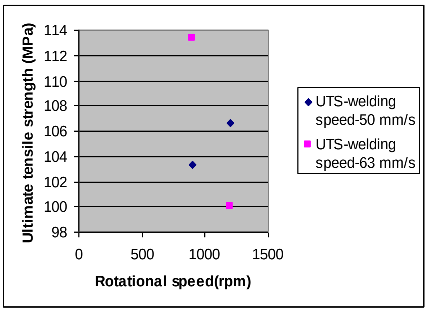

Figure 10. Effect of rotating speed on Strength

The tensile strength and percentage elongation of the base material AA6082-O as well as FSW joints are calculated at different rotation and welding speed. From the experimental result, it is observed that the tool rotating speed and welding speed having influence on tensile properties of the FSW joints. The FSW joint fabricated at a rotation speed of 900 rpm & advancing speed of 63 mm/min is showing superior tensile properties compared to other FSW joints.

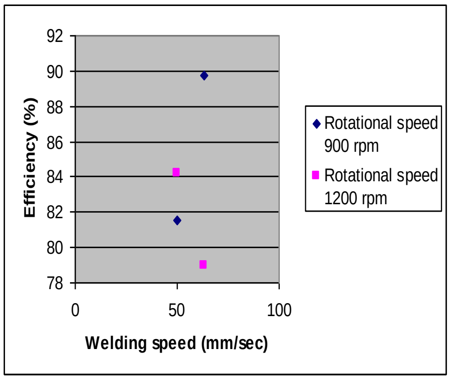

Figure 11. Effect of welding speed on joint efficiency

Conclusion

The effects of rotating and welding speed on mechanical properties of AA6082-O have been analyzed in the present paper. The yield strength and ductility of the aluminium alloys play major role in deciding weld quality of FSW joints and hence the formation of friction stir processing region. The yield strength, tensile strength, percentage of elongation of FSW AA6082-O joints has been measured with respect to rotating speed & advancing speed. Of the two rotating and advancing speeds used to fabricate the joints, the joints fabricated at a rotating speed of 900 rpm and advancing speed of 63 mm/min exhibited the best tensile properties with respect to parent metals and has joint efficiency of 89.71% ([strength of the weld / strength of the parent metal] x100) as compared to other FSW joints.

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