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Effect of Friction Stir Welding process parameters on Microstructure and Tensile properties of 6061 Aluminum alloy

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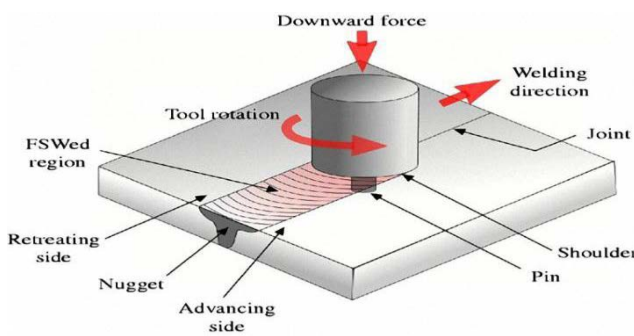
Abstract

AA6061 is a class of Al-Mg-Si heat treatable wrought alloy which has wide spread application in marine and aircraft industries. Fusion welding of this alloy will lead to many problems such as porosity, hot cracking, and micro-fissuring etc. However, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt or recast. In this process a non-consumable rotating tool is used to generate frictional heat in the abutting surfaces. The process parameters such as tool rotational speed, welding speed, axial force are playing a major role in deciding the weld quality. In this study an attempt was made to develop friction stir welding window (FSWW) for AA6061-T6 aluminium alloy. The formation of FSP zone has been analyzed microscopically. The joint fabricated using tool rotational speed of 1120rpm, traversing speed of 50mm/min, tool shoulder diameter of 24mm, straight cylindrical pin profile showed better mechanical properties compared to other joints.

Keywords: *Friction Stir welding, 6061 aluminum alloy, tool rotational speed, welding speed, tensile strength.*

1.Introduction

Friction stir welding (FSW) is a novel solid state welding process for joining metallic alloys and composites and has enormous potential in manufacturing applications .High joining speed, autogenous welding, improved metallurgical properties, and reduced need for human skill are amongst the most important advantages of FSW in comparison with conventional fusion welding methods . FSW uses a rotating cylindrical tool with a pin to heat the material by friction. The tool pin stirs the plasticized material and therefore joins two pieces together when it is moved along the welding line. Advantages of this technique include e.g. joining of materials that are difficult to fusion weld, low distortion, and excellent mechanical properties. During FSW, a rotating tool moves along joint interface, generates heat and results in recirculating flow of plasticized material near the tool surface. This softened material is subjected to extrusion by the tool pin rotational and traverse movements leading to formation of friction stir processing (FSP) zone the formation of FSP zone is affected by the material flow behavior under the action of rotating tool. However, the material flow behaviors is predominantly influenced by the material properties such as yield strength, ductility and hardness of the base metal, tool design, and FSW process parameters ,there have been lot of efforts to understand the effect of process parameters on material flow behavior, microstructure formation and hence mechanical properties of friction stir welded joints. The influence of the process parameters such as rotational speed (N) and traverse speed (ν), shoulder diameter (Ds), Pin Diameter (Dp),Ds/Dp ratio , tool pin profile on weld properties have been investigated in this present study. The objective of this paper is to identify the significant process and tool parameters of AA6061-T6 aluminium alloy in FSW process and tool parameters on tensile properties of joints.



2.Experimental Work

The base metal sheet of 5 mm thick 6061 Aluminum alloy was welded by butting two plates and stirring them together with a rotating tool assembly by using vertical milling machine as shown in Fig.1.

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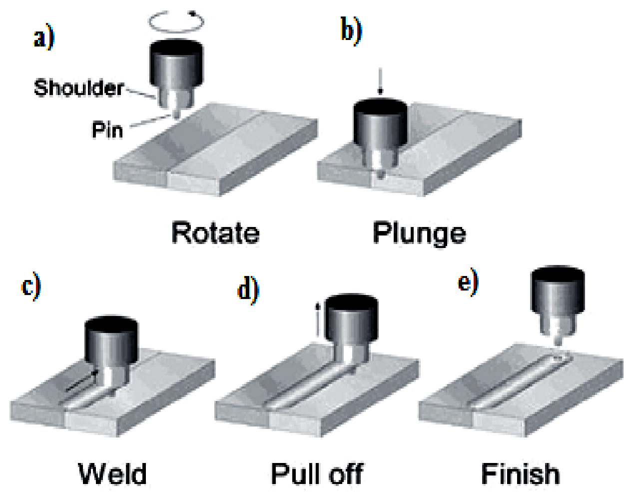
Fig. 1. Schematic sketch of weld configuration



A constant axial force is 5 KN applied and tool onward tilt angle of 1.5^0 for all the FSW experiments. It is that found to be defect free welds, the surface morphologies of the FSW joints. Special welding jigs and fixtures are designed to hold two plates of 200 mm X 100 mm in 6 mm thickness. Non consumable tool made of H13 tool steel is used to fabricate joints .The tools used for the present study are straight cylindrical pin,tapered cylindrical pin and taper threaded with shoulder. After FSW, microstructural observations were carried out at the cross section of NZ of weld ments normal to the FSP direction, mechanically polished and etched with Keller's reagent (2 ml HF, 3 ml HCl, 20 ml HNO_3 and 175 ml H_2O) by employing optical microscope (OM). Microhardness tests were carried out at the cross section of NZ of weld ments normal to the FSW direction, samples with a load of 5kg using a Vickers digital microhardness tester. The tensile specimens were taken from the surface hybrid composites normal to the FSW direction and made as per ASTM: E8/E8M-011 standard by wire cut Electrical discharge machining to the required dimensions. The tensile test was conducted with the help of a computer controlled universal testing machine at a cross head speed of 0.5 mm/min. Selected welding process parameters is presented in Table1.

Table1. Selected welding process parameters

The plates are positioned in the fixture, which is prepared for fabricating FSW joints by using mechanical clamps so that the plate will not be separated during welding illustrated in Figure2. The tool is fixed in the tool holder of the milling machine and the milling head is tilted with a rake angle of 0^0 to 1.5^0 to the vertical axis. The tool speed can be selected in the range between 710 to 1800 rpm based on the plate material and it thickness to be welded. Tool is lowered while in rotation and plunged in to the plates when the shoulder touches the plate, heat is generated.

Sl.no	**Condition of Parameters**		
Sample 01	Rotational speed (Rpm)	Traverse speed (mm/min)	Tool used
	1120	30	Taper thread
Sample 02	1120	40	Taper cylindrical
Sample 03	1120	50	Straight Cylindrical

Table1. Selected welding process parameters

After few second, table movement is given and it can be varied from 16 to 800 mm/min. This paper design of three newly developed tools which were used in the present work is illustrated in Figure3. It should be noted that, in each design shape and size is different . The shoulder diameters also different. The shoulder area in contact with work piece surface is same in all three cases. Two same shapes of the pin which were used flat shoulder profile with threaded pin. It should be noted that length of the pin is same. For welding purpose Universal Milling Machine is used. Trial runs were conducted prior to conducting actual experiments. Other process parameter like mechanical performance of the welding, tensile strength is measured and the calculated value compared with the base material.

Fig2.universal milling machine

Fig3. Tool profiles

a)Taper thread

b)Taper cylindrical

c)Straight cylindrical

3.Results & Discussions

Macrostructure

The macrographs of all Aluminum alloy Friction stir weldments are shown in Fig.4. FSW is a well-known severe plastic deformation process. The stirring action was observed at the weld centre and produces finer grains. It is observed that, the joints made by Taper with threaded pin profile tool resulted in very much smaller equiaxed grains compared to base material. During FSW, the material flow around the tool pin is due to the heat generated by the friction and stirring action. In fusion welding of aluminium alloys defects like porosity, slag inclusions solidification cracking etc., deteriorates the weld quality and joint properties. Usually, fiction 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 heat generated by friction and flow of the metal by the stirring action.

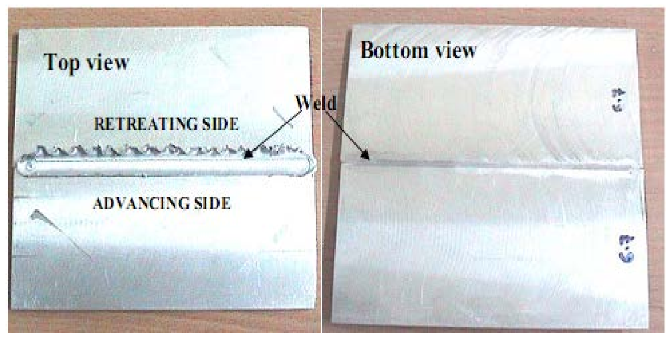
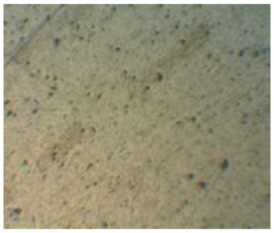


Fig.4. The macrographs of all Aluminum alloy Friction stir weldments

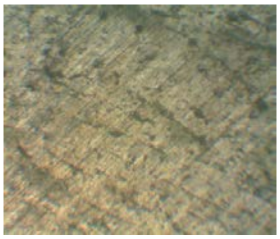
3.1.observed microstructures at different loctions of welded piece

For Specimen 01.

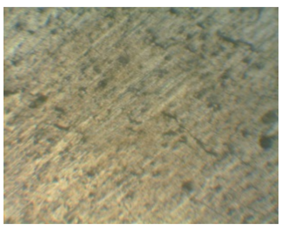
Stir zone



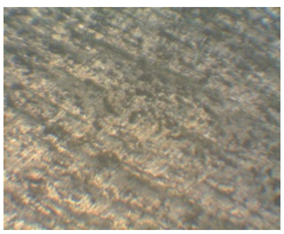
Thermomechanically HAZ



Heat affected Zone

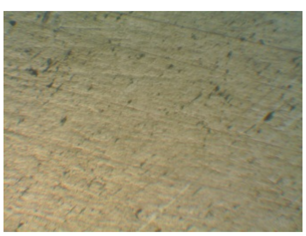


Base metal Zone



For Specimen 02.

Stir zone



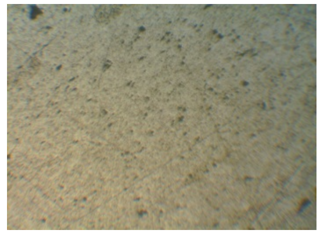
Thermomechanically HAZ

Heat affected Zone

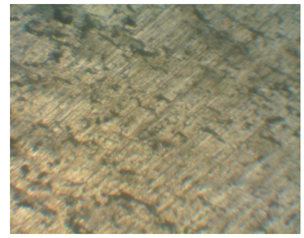
Base metal Zone

For specimen 3.

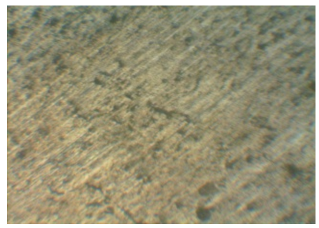
Stir zone



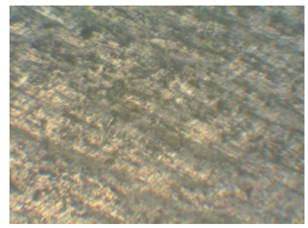
Thermomechanically HAZ



Heat affected zone



Base metal zone



3.2.Experimental Testing observtions

3.2.1.Tensile properties

Sl.no	**Tensile properties (Mpa)**		
Sample 1	UTS(Ultimate tensile strength)	YS(Yield strength)	% EL (Elongation)
	174.419	126.29	7.120
Sample 2	150.30	102.36	8.6
Sample 3	176.73	120.43	10.00

Micro Hardness of welded specimen (Vickers)

Specimen 01.

Sl.no	Location	Observed values in HV
01	Stir zone	49.50
02	HAZ	79.70
03	Base metal zone	93.40

Specimen 02.

Sl.no	Location	Observed values in HV
01	Stir zone	52.60
02	HAZ	89.40
03	Base metal zone	92.30

Specimen 03.

Sl.no	Location	Observed value in HV
01	Stir zone	77.0
02	HAZ	87.2
03	Base metal zone	90.0

3.3 Impact test (Charpy) Report of welded specimen

S.no	Impact(Joules)
Sample 1	30
Sample 2	10
Sample 3	20

4.Conclusions

It can be concluded that by varying the process parameters within the range:

Case 1: The joints made by straight cylindrical pin profile tool resulted in very much smaller equiaxed grains compared to base material. It is observed that microhardness increases than as received Aluminum alloy. It is seen that all the tensile properties of FSWed Al is increased as compared with the as-received Al alloy.

Case 2 : It can be observed that when tool rotational speed 1120 and traverse speed is 50mm/min with straight cylindrical tool having 24/6 D/d ratio got maximum tensile strength in the order of 176.73 Mpa. Compared to other joints it is optimal value.

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