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Evaluation Of Mechanical Properties Of Friction Stir Welding Of Aluminium-6061 Alloy Using Conical Tool

Mahesh.B.R[1], Nandakumar.M.B[2], J. Satheesh[3], Akshay.S[4]

[1,2,4]Department of Automobile Engineering, Dayananda Sagar College of Engineering, Bangalore, 560078, India.
[3]Department of Mechanical Engineering, Sri Jagadguru Balagangadhara institute of Technology, Bangalore, 560068, India.

Abstract In recent years Friction Stir Welding (FSW) has been used as an alternative joining technique. Friction Stir Welding (FSW) is a solid-state process that can be beneficially used for various transportation and defence applications. In this study, optimization of process parameters ,tensile properties of friction stir welded Al6061 wrought aluminium alloys were investigated. The findings from these investigations will be presented and discussed.

Keywords FSW, Al6061, Taguchi technique.

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1. Introduction

Aluminium is a silvery white and ductile member of the 3^{ed} period & 13th group of chemical elements. Aluminium is too reactive chemically to occur in nature as the free metal. Instead, it is found combined in over 270 different minerals. The chief source of aluminium is bauxite ore (Al_2O_3).

In the present work Al 6061 is selected because it has high strength to weight ratio and widely used in aerospace applications. An aluminium alloy of 6000 series mainly consists of Zinc and Magnesium. Generally these alloys have a relatively small tendency for overageing. Furthermore, they are assumed to be rather insensitive to quench rate, which is especially of importance in the case of welding. Within the Al–Zn–Mg alloy system the 6061 is relatively new Aluminium alloy, tensile strength of the 6061 is 524 MPa with the ductility of 14.5 %, which is being increasingly used in light structures, such as Aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, Defence applications, bike frames, and all-terrain vehicle (ATV) sprockets. Aluminium alloys are widely used on aircraft structures especially on the fuselageand wing fairings. During the joining of these structures, the traditional technique, riveting is used. But riveting increases the structural weight of the aircraft and rivet holes form stress-concentration for the fatigue cracks. An alternative joining technique is welding. In traditional welding techniques metal is heated till the melting point for this reason the mechanical behaviour of the material deteriorates and also the weld ability of high strength materials is low. In recent years Friction Stir Welding (FSW) has been used as an alternative joining technique. Friction Stir Welding (FSW) is an innovative solid-state welding technique, which uses frictional heat and pressure from a rotating, non-consumable cylindrical tool to join sheet and plate materials, without melting them.

Friction Stir welding can be used for joining many types of materials and material combinations if tool materials and designs can be found, which operate at the forging temperature of the workpieces. Maximum thickness in a single pass is dependent on machine power, but values of 50 mm are achievable. No melting of the workpiece occurs in the FSW process. The mechanics behind FSW can be complicated, and require a balance of dynamic thermal and mechanical interactions as well as flow of solid metals. In the FSW process, maintaining tool rotational speed and position of the tool head in all three axes is critical in creating a weld with consistency. Since mills used in modern manufacturing are easily capable of producing the required output energy and maintaining the tool position to a high degree of precision, FSW can easily be instituted in most manufacturing facilities.

There are several benefits to using FSW as opposed to other joining techniques. Generally, joining operations are expensive and can be complicated, but FSW promises to offer significant cost savings over conventional welding techniques as a result of the simple mechanical nature of the process. Since FSW uses a non-consumable tool, filler material is not necessary as in conventional MIG or TIG welding; this eliminates filler material cost per unit length weld and the associated troubles of dealing with feeding and storing filler for each alloy to be welded. In addition, FSW only consumes enough energy to drive a rotating tool through the base material, not to melt the workpiece. For aluminum alloys such as Al6061, this can be a considerable saving in energy consumption, estimated to a total cost savings of nearly 30% over conventional fusion welding.

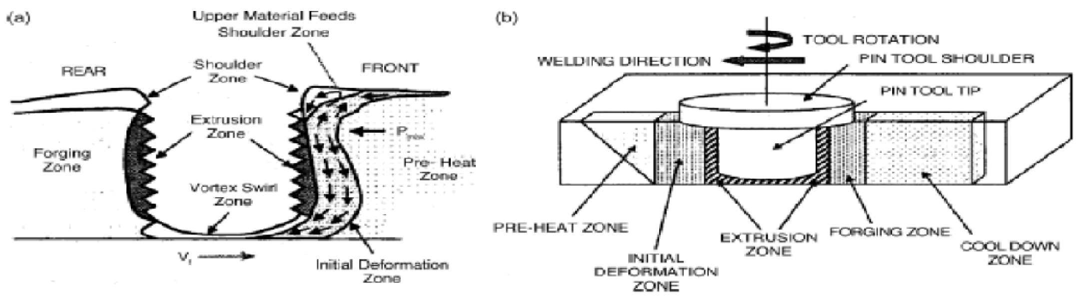

Figure 1(a).shows zones of different mechanical processes, and Figure 1(b).depicts the mechanical interactions determining these processes.

When the FSW tool traverses a seam, the tool rotation causes a difference in relative velocity between both sides of the weld. The difference in relative velocity of the tool results in a directional plastic flow from one side of the tool to the other. The difference in plastic flow characteristics between the two sides causes different microstructures to form. Consequently, the two sides of the weld are described using different nomenclature. One side of the weld is denominated the advancing side, while the other side is termed the retreating side. The advancing side of the weld experiences a higher relative velocity in relation to the tool, while the retreating side experiences a lower relative velocity. This nomenclature is dependent upon the direction of tool rotation and travel. Regardless of the material in which a friction stir weld is performed, the resulting microstructure has three distinct zones that result from the welding process. The area of all three of these zones comprises what is commonly referred to as the Weld Affected Zone (WAZ). The first constituent of the WAZ is the Dynamically Recrystallized Zone (DXZ), also known as the weld nugget, which lies at the centre of the weld along the weld seam.

The DXZ is defined as the area that has direct interaction with the tool probe and is also referred to as the weld nugget. Dynamic recrystallization is the process by which extreme strain and elevated temperature cause recrystallization of material in the weld nugget as the tool passes through it, resulting in a dispersion of fine, equiaxed grains in this area. The DXZ is relatively small, and is characterized by a shape loosely resembling the FSW tool used.

2. Experimental procedure

The chemical composition and the mechanical properties for Al6061 are given in the tables below:

Table 1. Chemical composition of 6061

Alloy	Zn %	Mg %	Cu %	Cr %	Mn %	Ti %	Si %	Al %
6061	Max-0.25	0.8 - 1.2	0.15-0.4	0.04-0.35	Max 0.15	Max 0.15	0.4 - 0.8	95.8 - 98.6

Table 2. Mechanical properties of 6061

Alloy	Tensile strength Mpa	Yield Strength MPa	Elongation %
6061	310	276	12-17

Figure 3.shows the tensile specimen used.

Commercially available Aluminium Alloy 6061 from 6000 alloy series is chosen for study. The material was in the form of big sheet with a dimension 300x150mm. With uniform thickness of 5 mm, it was cut into flat bars for the experimental purpose. In this investigation mechanical testing and metallographic examination were carried out for 6061. It has been reported that the geometry of the FSW tool has a major influence on the microstructure and mechanical properties of the weld. The geometry of the tool for FSW process being used in IISc for welding of Aluminium 7020 and 2024 has been adopted in the present work. The tools were made of hot die steel with fixed probes. The shape of the tool used is a conical type. Initially the experimental trials were carried out on a single bar of workpiece. This is also called as Bead-on-plate, to get familiar with the working of FSW Machine.

Butt Joint

A square butt weld preparation was used in all trials and this was achieved by milling the abutting edges. The work pieces were prepared to suit the fixtures, which were attached to the longitudinally traversing table of the FN3V machine. The FSW tool was loaded into the chuck, brought up to the set rotation speed and then plunged into the abutting joint.

Substrate specimen dimensions were: 4.7mm nominal thickness x 75mm wide x 300mm long. These plate dimensions were selected for convenience to suit existing fixtures and are not representative of the heat sink inherently associated with larger or smaller work pieces. All welds were inspected visually for surface roughness, presence of surface grooves and extent of any side flash. Acceptable welds have a smoothly rippled and consistent surface. If a line (parallel to the weld centreline but approximately 3 to 5mm offset) is visible on the surface, this can only be caused by an internal or surface-breaking void. The width of the weld should be constant.

Results and discussions

The tensile strength of the welded joints for all the 8 trials for conical tool has been mentioned in the Fig1.6 and is used to determine the optimum values of process parameters(Rotational speed, Welding speed, Plunge depth) using Taguchi technique.

The Taguchi techniques comprises of the following steps:

Step (1) Detemination of S/N ratio:

In this step S/N ratio is determined by using the formula:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right)$$

where *n* is the number of tests, y is the means of tensile strength. In the present study, the S/N ratios are obtained by using MINITAB Software.

Step (2) Plotting of main effects of the process parameters:

In this step main effect plots for S/N ratio and welding parameters like rotational speed, welding speed and plunge depth are obtained by using MINITAB Software which is as shown in Fig1.7.

Step (3) Identifying the optimum values of process parameters:

Using main effect plots optimum values of process parameters are identified. The optimized values from graph are as follows rotational speed 1000rpm, welding speed 40mm/min, and plunge depth 4.93mm.

Step (4) Determination of estimated value of Tensile strength for the identified optimum values of the process parameters:

The estimated value of tensile strength can be computed as Tensile strength=RS+WS+PD-2T

Where *T* is the overall mean of tensile strength, MPa, RS is the average tensile strength at optimised level of rotational speed i.e. 1000 r/min; WS is the average tensile strength at optimised level of welding speed i.e. 40mm/min, PD is the average tensile strength at optimized Plunge depth 4.3mm. Substituting the values of various terms in the above equation, then Tensile strength =155.628 N/sq. mm

Step (5) Conducting of Confirmation test:

The final step is verifying the improvement in tensile strength by conducting experiments using optimal conditions. The confirmation experiments were conducted at optimum setting of process parameters. The rotational speed, traverse speed and plunge depth were set at optimized value and the average tensile strength of friction stir welded AA-6061 Aluminium alloy found to be 155.628 N/sq. mm which was within the confidence interval of the predicted optimal tensile strength.

Figure 4.shows the friction stir welding machine

Si No.	Tool Speed (rpm)	Welding Traverse Speed (mm/min)	Plunge depth (mm)	Tensile strength N/mm2	Breaking load
1	500	40	4.2	65.378	578.613
2	500	40	4.3	126.278	529.578

3	500	40	4.4	117.178	1039.542
4	710	40	4.2	107.848	372.666
5	710	40	4.3	136.910	402.087
6	710	40	4.4	149.441	3393.222
7	1000	40	4.2	156.108	3687.432
8	1000	40	4.3	155.628	3599.169
9	1000	40	4.4	158.623	3700.12

Table 3.shows the observations recorded

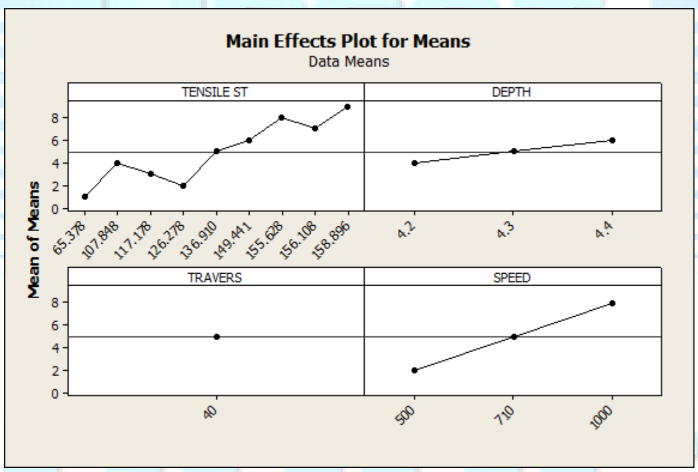

Figure 6.

3. Conclusions

1) For conical tools the optimized parameters are spindle speed 1000rpm, feed 40mm/min and 4.4mm plunge depth.
2)For optimised parameters tensile strength of the specimen is found to be 158.623 N/mm^2 .
3) FSW provides a novel, relatively hazard- free, solid phase joining process, which produces sound longitudinal butt joints.
4) It is a simple process and doesn't require flux, filler material and shielding gas.
5) The reason for the high strength of the weld is that the material never reaches the melting temperature where crystal structure of the basic material changes, as in the fusion welded joint.

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