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ISSN (PRINT): 2454-9762
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International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 1, January 2016

The Analysis of Strength Parameters in FSW Aluminium Alloy 6061

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***Abstract*--In many industrial applications, steels are readily replaced by non-ferrous alloys, in most cases by aluminum alloys. The main aim of goal is to satisfy the mechanical properties of Al alloy6061 like yield strength, ultimate tensile strength and percentage of elongation etc by using FSW technique. the work will be done by square tool pin profile as followed by triangular tool pin profile**

Index terms--FSW, Parameters, Al Alloy 6061 Properties, Hardness Test

I. Introduction

In many industrial applications steels are readily replaced by non-ferrous alloys, in most cases by aluminum alloys. Some of these materials have combination of mechanical strength and low weight properties. It is generally known that the fusion welding of aluminum alloys is accompanied by the defects such as porosity, slag inclusion, solidification cracks etc and these defects deteriorates the weld quality and joint properties, which leads to the development of Friction stir welding

II. Friction Stir Welding

Friction stir welding (FSW) was invented and patented in 1991 at TWI in Cambridge (UK) and has been developed to a stage where it is applied in series production. The work pieces of Aluminum Alloy have to be clamped onto a backing bar and secured against the vertical, longitudinal and lateral forces, which will try to lift them and push them apart (fixture).

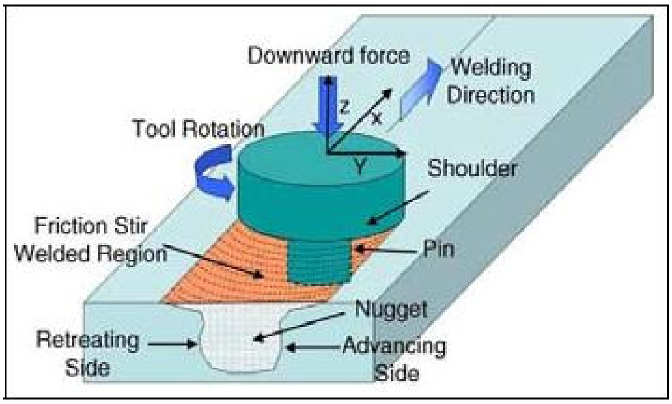

Fig. 1: Schematic Diagram of Friction Stir Welding With a Rotating Tool

Fig. illustrates the salient features of the process which operates by generating frictional heat between a rotating tool (of harder material than the work piece being welded) and work piece, to plasticize the abutting weld region.

III. Principle Of FSW

The two work pieces to be welded, with square mating (faying) edges, are fixture (clamped) on a rigid back plate, The fixturing prevents the work pieces from spreading apart or lifting during welding. The welding tool, consisting of a shank, shoulder and pin

IV. Parameters

- Tool
- Leading Edge and Trailing Edge
- Advancing side and Retreating side
- Forces
- Welding speed and Rotational speed

V. Defects Found In FSW Joints

The FSW which is a solid state welding process also produces several types of defects. They may be due to improper processing conditions and material flow problems inside the die cavity. The processing parameters can lead to either hot or cold processing conditions which in turn increase the occurrence of defects due to improper flow of the metal. In addition, an improper axial force can create defects regardless of the hot or cold conditions.

Experimental setup and running the experiment

A Conventional vertical 3 axis milling machine was used for friction stir processing (FSW) of AA6061-T6. The machine could achieve the maximum speed of 3000 rpm and 10-horse power.
The AA6061-T6 plate dimensions of 150 mm (L) 70 mm (W) 6 mm (T) were used in the present study. The AA6061-T6 plates were clamped rigidly on backup plate to

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produce butt joint using the FSW technique as shown in Fig. 3.1.The experiments were conducted on the AA6061-T6. Before the friction welding, the weld surface of the base material was cleaned. The FSW tool is then placed in to the bit and zero tilting angles is applied because FSW tool shoulder is flat.

A. Properties of AA6061-T6

Properties of aluminum alloy AA6061-T6 are given below

Table 1: Chemical Composition of AA6061-T6

Elements	Mg	Mn	Fe	Si	Cu	Cr	Al
Base Metal (6061 - T6)	1.1	0.12	0.35	0.58	0.22	0.04 -0.35	Bal

Table 2: Physical Properties of AA6061-T6

Physical Property	Density (kg/m³)	Melting Point, °C	Modulus of Elasticity, GPa	Poisson's Ratio
Base Metal (6061 - T6)	2700	580	69	0.33

Table 3: Mechanical Properties of AA6061-T6

Mechanical Property	Yield Stress, M Pa	Ultimate Tensile Strength, M Pa	Hardness Number, BHN	Elongation, %
Base Metal (6061 - T6)	235	283	95	10-13

Table 4: Thermal Properties of AA6061-T6

Thermal Property	Thermal Conductivity, W/mK	Thermal Capacity, J/KgK	Coefficient of thermal expansion, 10-6/deg C
Base Metal (6061 - T6)	180	896	23.6

The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. Young's Modulus is 10×10^6 psi (69 GPa) regardless of temper.

Annealed 6061 (6061-O temper) has maximum tensile strength no more than 18,000 psi (125 MPa), and maximum yield strength no more than 8,000 psi (55 MPa). The material has elongation (stretch before ultimate failure) of 25–30%.

T6 temper 6061 has an ultimate tensile strength of at least 42,000 psi (300 MPa) and yield strength of at least 35,000 psi (241 MPa). More typical values are 45,000 psi (310 MPa) and 40,000 psi (275 MPa), respectively.[4] In thicknesses of 0.250 inch (6.35 mm) or less, it has elongation of 8% or more; in thicker sections, it has elongation of 10%. T651 temper has similar mechanical properties.

B. Selected Process Parameters.

Table 5:

Process parameters	Values
Rotational speed (RPM)	800,1200,1600 rpm
Welding speed (mm/min)	28 mm/min
Axial force	7 kN
Tool material	High carbon High Chromium with 60-62 HRc
Tool dimensions	Shoulder dia 18mm, pin dia 6mm and pin length 5.8mm.
Tool pin profiles	Straight cylindrical
	Triangular
	Square

C. Evaluation of Mechanical Properties.

Tensile test

Experimental Data after Tensile Test

Table 6: Mechanical properties are obtained by Straight Cylindrical tool pin profile for Constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
800	164.5	199	4.2
1200	188	226.4	8.4
1600	176.25	212.25	6.8

Table 7: Mechanical properties are obtained by Triangular tool pin profile for constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
800	180.5	210	6.7
1200	197.1	252	9.7
1600	188.7	225	8.4

Table 8: Mechanical properties are obtained by Square tool pin profile for constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
800	190.4	224	9.2
1200	210.2	268.2	11.2
1600	201.2	237.8	9.4

D. Hardness Test

- **Brinell Hardness Test**

The Brinell Hardness Number (BHN) which is the pressure per unit surface area of the indentation in kg per square meter is calculated as follows:

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$$BHN = \frac{P}{\prod D*[D-\sqrt{D^2-d^2}]}$$

Where
W is load on indenter, kg
D is diameter of steel ball,
mm
d is average measured diameter of indentation, mm

Table 9: Hardness values are obtained by Straight Cylindrical tool pin profile for constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Distance from the weld centre		
	Advanced Side 9mm	Weld center 0	Retreating Side 9mm
800	59.5	54.6	56.4
1200	65.5	62.4	63.2
1600	61.5	58.4	60.5

Table 10: Hardness values are obtained by Triangular tool pin profile for constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Distance from the weld centre		
	Advanced Side 9mm	Weld center 0	Retreating Side 9mm
800	68.4	64.5	66.3
1200	72.5	66.5	69.9
1600	65.3	63.8	62.4

Table 11: Hardness values are obtained by Squarz tool pin profile for constant welding speed (28mm/min) and axial force (7kN)

Tool Rotational speed (RPM)	Distance from the weld centre		
	Advanced Side 9mm	Weld center 0	Retreating Side 9mm
800	69.4	66.3	67.6
1200	79.5	76.3	77.4
1600	72.4	69.4	71.3

VI. Experimental Results

The experimental results of the strength of the parameters in Friction Stir Welding in Aluminium Alloy 6061 as follows.

Table 12:

	Tool rotational Speed (RPM)								
Tool Profile	800			1200			1600		
	YS	UTS	POE	YS	UTS	POE	YS	UTS	POE
Straight Cylindrical	164.5	199	4.2	188	226.4	8.4	176.25	212.25	6.8
Triangular	180.5	210	6.7	197.1	252	9.7	188.7	225	8.4
Square	190.4	224	9.2	210.2	268.2	11.2	201.2	237.8	9.4

YS-Yield strength; UTS: Ultimate tensile strength;

POE- Percentage of elongation.

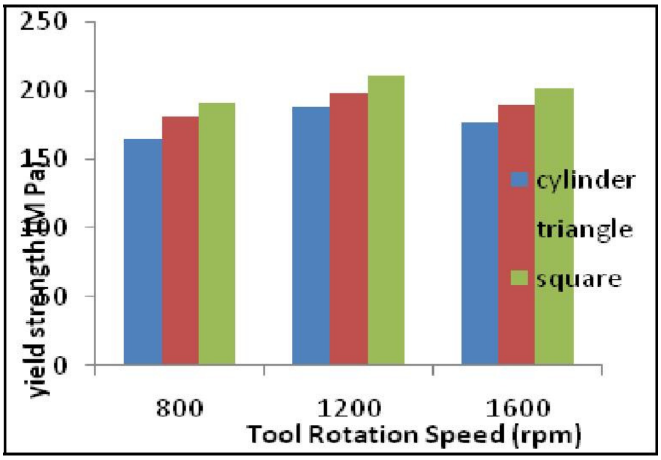

Fig. 2: Effect of Tool Profiles and Rotational Speed on Yield Strength

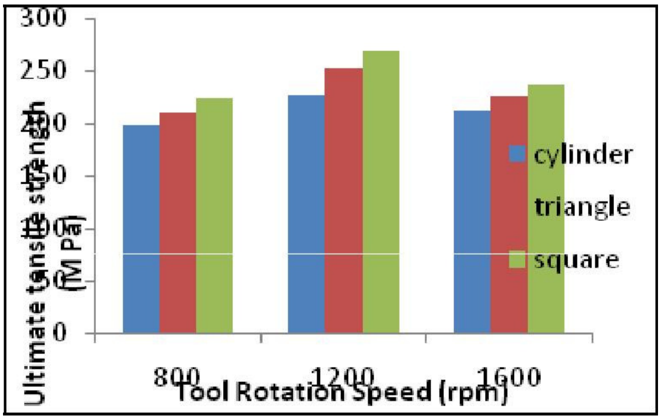

Fig. 3: Effect of Tool Profiles and Rotational Speed on Ultimate Tensile Strength

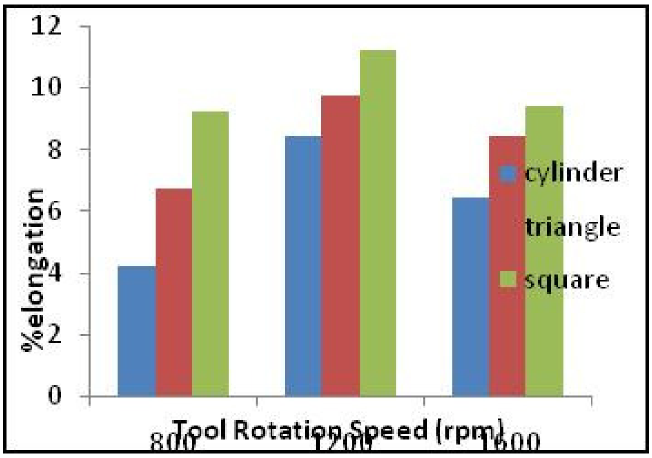

Fig. 4: Effect of Tool Profiles and Rotational Speed on Percent of Elongation

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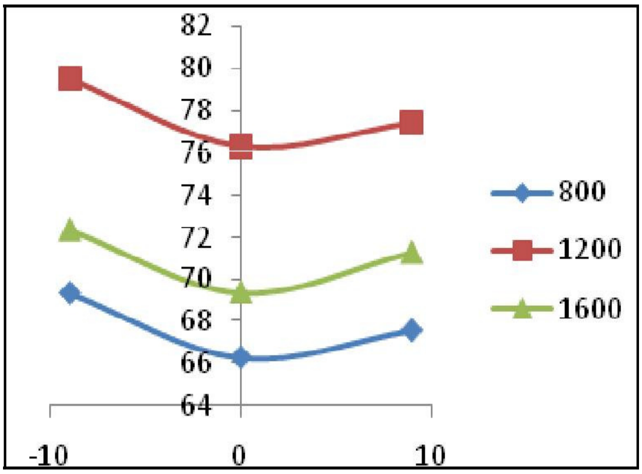

Fig. 5: Effect of Straight Cylindrical Tool Profile and Rotational Speed on Hardness.

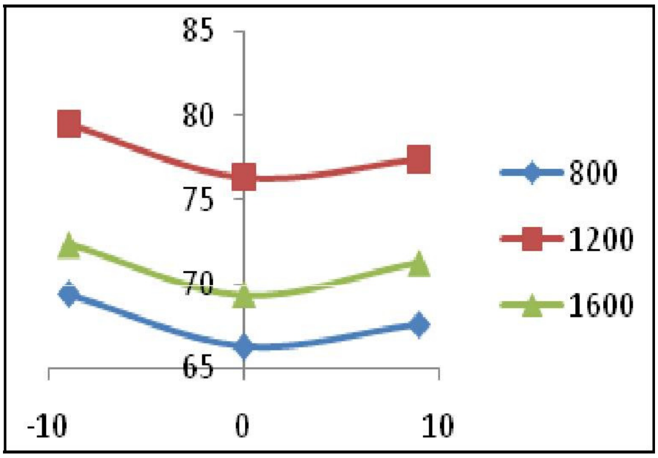

Fig. 6: Effect of Triangular Tool Profile and Rotational Speed on Hardness.

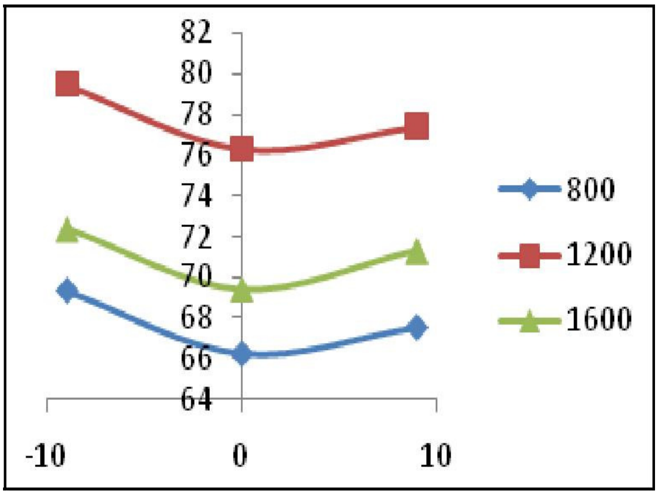

Fig. 7: Effect of Square Tool Profile and Rotational Speed on Hardness

VII. CONCLUSION

The butt joining of AA 6061 aluminum alloy was successfully carried out using FSW technique. The optimum operating conditions of FSW have been obtained for two plates of aluminum alloy AA6061 welded in butt joint.

- From the experimental results, the better performance was achieved by the SQUARE tool pin profile followed by TRIANGULAR pin profile.
- The optimal FSW process parameter combinations are rotation speed at 800, 1200, 1600rpm, axial force 7kN, welding speed at 28mm/min.
- Out of the three profiles, the maximum yield, ultimate tensile strength and percentage of elongation are 210.2, 268.2 MPa and 11.2% respectively was observed for square tool pin profile at 1200rpm.
- Out of three profiles, the maximum hardness is 76.3 at weld center for square tool pin profile was observed.
- The reasons for the square tool pin profile are
  - More pulsating action(80 pulse per second)
  - Flat faces
  - Reasonable relationship between static to dynamic volume (1.58).

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Available online at www.ijarmate.com

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