Effect of Tool Geometry on Mechanical Properties of Friction Stir Welded AA6082 T6 Aluminium Alloy

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Abstract- *AA 6082 T6 has gathered wide acceptance in the fabrication of the light structures required to high strength. In this experimental work, an investigation has been carried out on (Friction Stir Welding) FSW butt joint. Welded joints were made with the help of tool made of high Carbon high chromium steel. Tools were of three different pin profiles that is cylindrical, square and combining the features of polygon and taper cylindrical pin profile. The welded joints are being made on aluminium grade AA 6082 T6 plates of 5 mm thick and being tested to determine tensile strength. In this experiment the welding speed, rotational speed and the tilt angle are varied with respect to the three pin profiles. From results it observed that TRS(910 rpm), WS(2 inch), tilt angle(4 degree) shown the best results.*

Keywords- Friction Stir Welding (FSW), Aluminium AA 6082, Tensile strength

I. INTRODUCTION

FSW was invented by TWI (The Welding Institute), Cambridge, UK, in 1991. FSW doesn't melt and re-solidify, the resultant weld metal is free of porosity with lower distortion. It is an environmental friendly process.

It is a simple process in which a rotating cylindrical tool is inserted between the two abutting plates to be joined. And the tool is traversed along the joining line between two plates. The plates are tightly clamped on the backing plate of vertical milling machine. It is done so because it avoids the plate from coming out from the clamp. The rotating cylindrical tool at high speed is inserted into the weld line between the plates. The rotating tool is inserted into the weld line until the shoulder touches the upper surface of plate material. A downward axial force is applied to maintain the contact with the plates. As the tool rotates between the abutting plates, frictional heat is generated between the rotating tool and the material of plates. This in turn causes the plate material to get heated and softened without reaching to melting point.

As the tool is moved along the weld line, the leading edge of the tool forces the softened material on either side of the weld line. In effect of this, the transferred material is pressed against the tool on the plate.

The FSW process consists of a tool with a cylindrical shoulder and a probe called as pin. The tool rotates with a velocity measured in rpm. The various process parameters in FSW process are, tool rotational speed, welding speed, axial force, shoulder diameter, pin diameter, tool hardness.

Fig. 1 shows the forces acting on the plate. The force along X-axis is referred as translational force, force along Y-axis is referred as transverse force and the force along Z-axis is referred as axial force.

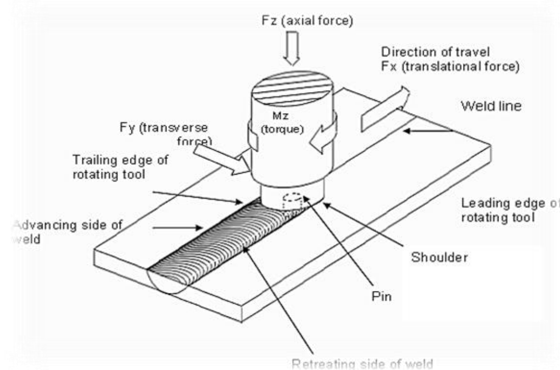

Fig.1 Schematic of FSW process

1) Tool Rotational Speed: The speed of spindle of machine is measured in revolutions per minute. Excessive tool speed causes tool wear. Using correct spindle speed will have great effect on tool life and quality of weld.

2) Welding Speed: Welding speed is the speed of rotating tool at which it is fed, that is the advancement of the tool against the work piece. It is expressed in rpm.

3) Axial Force: A downward force exerted by the shoulder of tool on the work piece is known as axial force. A axial force is necessary to maintain the position of shoulder at or below the material surface.

4) Tool Shoulder Diameter: The heat generated during the friction process is totally depend on the tool shoulder diameter. The material transport on the top surface of FSP region takes place due to the action of rotating tool. Shoulder also provides the confinement for the heated material volume.

5) Pin Diameter: In FSW process the pin diameter decides the volume of material being stirred. If the pin diameter have larger value then the volume of the stirred material will also have higher value and vice versa. For smaller pin diameter, higher heat will be supplied to small material volume. This leads to turbulent material flow and grain coarsening in the weld region. On the other hand larger pin diameter causes lower heat supplied to larger material volume which in turn leads to insufficient material flow and inadequate plasticization. Both conditions leads to lower tensile strength.

6) Tool Hardness: The coefficient of friction (μ) is depends on the tool hardness. If μ is higher, then the friction between the tool and base metal will be higher and the heat generation will be higher. If μ is lower, the fiction will also be lower and the heat generation will be lower. In both the cases, that is very high heat generation and very low heat generation will deteriorate the strength properties of the weld joint.

II. LITERATUR REVIEW

The purpose of this chapter is to present a literature review summarising the previous published work to research work in improving the weld strength and influence of various process parameters on the mechanical properties.

Yan-Hua Zao et al.[1] have investigated four tool pin profiles which are column screw thread pin, taper screw thread pin, column pin and taper pin on 2014 aluminium alloy. In this study the pin was rotated at 400 rpm and the welding speed was kept same at 100 mm/min and only the pin geometry is varied. During this investigation they found that the tensile properties of joints welded by column screw and taper screw thread pin are higher than rest two.

S. J. Vijay and N. Murgan[2] have investigated 18 different pin profiles. The authors have considered mainly six pin profiles, straight square pin, straight hexagon pin, straight octagon pin, taper square pin, taper hexagon pin, taper octagon pin on Al–10 wt.% TiB2 metal matrix composite. They varied D/d ratio for each pin profile and the values of ratio are 2.8, 3, 3.2. From this experiment they concluded that the joint welded by square pin profiled tool exhibits high tensile strength when compared to other joints. The joint fabricated by using tapered square pin profiled tool has the least tensile strength. The tensile strength of joints, welded using hexagon, tapered hexagon, octagon and tapered octagon pin profiled tools do not change significantly.

K. Elangovan, V. Balasubramanian[3] have done experimentation on five different pin profiles namely straight cylindrical, threaded cylindrical, tapered cylindrical, square and triangle on AA6061 aluminium alloy. And the author concluded that out of five joints the joints fabricated by square pin profile tool exhibited superior tensile properties. Also he found that the joints fabricated by D/d =3 have shown higher tensile strength and elongation as compared to the values of D/d ratio 2.5 and 3.5.

Hidetoshi Fujii et al.[4] have tested three pin profiles, cylindrical, cylindrical pin profile with threads and triangular pin profile and he observed that cylindrical profile with threads and without threads shown superior tensile properties at higher speed and triangular pin profile shown inferior tensile properties at that speed.

R. Palanivel[8] have conducted experimentation on two dissimilar material plates AA6351 and AA5083 using five different pin profiles, straight square, straight hexagon, straight octagon, tapered square and tapered octagon. In this experimentation welding speed was kept constant and rotational speed was varied. And he found that the moderate rotational speed exhibited higher tensile strength for all tool profiles. Among the five tool pin profiles studied, joints fabricated using SS pin profile yielded highest tensile strength.

III. PROJECT DEFINITION

To design and manufacture Friction Stir Welding tools and study effect of process parameters and pin profiles on the friction stir welded aluminium alloy.

IV. OBJECTIVE

To optimize FSW process parameters to obtain best weld strength and to obtain better microstructure.

V. METHODOLOGY

1) To do literature review based on friction stir welding methods, workpiece material, tool material, methods of analysis etc.
2) Selection of appropriate values for various process Parameters based on literature review.
3) Finalise the values for process parameters for main Experiments.
4) Design of experiment using Taguchi method and to gate orthogonal array.
5) Perform the experiments on vertical milling machine.
6) Obtain the readings of response variables.
7) Find out the optimum set of process parameters
8) Finalise process parameters for validation of experiments
9) Perform validation experiments using Minitab.
10) Analyse and compare with main experiment.

11) Interpretation and conclusions.

A. Material Selection for Friction Stir Welding

In this investigation, the base materials, AA6082, which is a precipitation hardened aluminium alloy widely used in aerospace applications due to its high strength.

TABLE I. CHEMICAL COMPOSITION OF ALUMINIUM ALLOY AA6082-T6

Element	Chemical Composition
	Wt. %
Si	0.75
Fe	0.18
Cu	0.01
Mn	0.4
Mg	0.42
Cr	0.01
Ni	<0.005
Zn	0.01
Ti	0.02
Pb	<0.05
Sn	0.01
V	0.01
Zr	<0.005
Sr	<0.01
Al	98.1

TABLE II. MECHANICAL PROPERTIES OF AA6082-T6

Material	Mechanical Properties	
	Property	Value
AA6082-T6	Hardness(HV)	95
	Ultimate Tensile Strentgth(MPa)	250
	% Elongation	10

The usual procedure for preparation of test specimen is,

1. Cutting Stage

The Aluminum sheet has a certain dimension. However, the aluminum alloy plates are to be cut based on the dimensions of the work table and the design of the clamping system. Then, using a sheet metal cutter by a shear cutting technique the material can be cut into the specified dimensions as shown in Figure.

Fig. 2 Sheet Metal Cutter

2. Machining Stage

The Aluminium plates will be machined at the sides in order to make them flat to ensure accurate face-to-face contact at weld joint. This was accomplished by using the shaper machine and a vice for holding the plates firmly.

3. Grinding Stage

The last stage is to grind the sheet's surface at and close to joint surface of the plate so as to remove any oxide layer to have clean weld.

4. Friction Stir Welding Machine and the process

The machine used for friction stir welding of 6082 Aluminium alloy is shown in Figure

Fig. 3 Friction Stir Welding Machine

Friction stir welding is done by holding the plates to be welded securely in the fixture so that the plates stay in place and do not fly away due to the welding forces. The rotational motion of the spindle is started and the tool comes in to contact with the surface of the plates and the probe is penetrated to a predetermined depth in between the faying surfaces of the plates to be welded.

Fig.4 FSW Machine Fabricating the Welds

The tool is given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced, this time is called as pre-heat time and after the pre-heat time, and the tool is given forward motion which formed the weld. The tool is withdrawn after the weld is fabricated.

B Material Selection for tool

The following characteristics have to be considered for material choice,

- ambient and elevated temperature strength,
- elevated temperature stability,
- wear resistance,
- tool reactivity,
- fracture toughness,
- coefficient of thermal expansion,
- machinability

There are many types of tool steels:
1. High Speed Steels.
2. Hot Work Steels.
3. Cold Work Steels.
4. Shock resisting Steels.
5. Low-alloy, Special-purpose tool steels.
6. Water Hardening tool steels.

From the above types, the Cold Work Tool Steel HCHCr was selected as the tool material for FSW.

1. Tool Material: High Carbon High Chromium Steel

Proper material selection should be carried out to prepare tool for friction stir welding. As we are using AL 6082 as a work material we should select a material for tool which should be harder than work material. After preparing the tool for fsw we should carry the hardening process. Here we are choosing High Carbon High Chromium Steel(C 1.55%, Si 0.40%, Mn 0.30%, 11.55% Cr). The hardness of this material can be achieved up to 50 to 55 HRC.

Characteristics:

i. High-carbon, high-schromium cold work tool steel.

ii. Deep hardening, with low distortion and high safety in hardening.

iii. Good wear resistance and good softening resistance at elevated temperature.

TABLE III CHEMICAL COMPOSITION OF HCHCR

Element	Chemical Composition
	Wt.%
C	2.04
Si	0.164
Mn	0.178
P	<0.0030
S	<0.0030
Cr	13.30
Mo	<0.0050
Ni	0.0499
Cu	0.0103
Al	0.00798
Co	<0.005
Nb	<0.01
Ti	0.0114
V	0.028
Fe	84.2

2. Tool Design for FSW

The FSW tool Nomenclature used for the friction stir welding of 6082 T6 Aluminium alloy and the fabricated FSW tool for friction stir welding of aluminium alloy plates are shown in the Figure.

Three types of friction stir welding tools were designed and fabricated for use in this investigation are as listed below:

Tool 1: Cylindrical Pin Profile
Tool 2: Square Pin Profile
Tool 3: Combined polygon and taper cylindrical Pin Profile

Tool 1: Cylindrical Pin Profile

The FSW tool with Cylindrical Pin Profile to weld Aluminum 6082 T6 plates is shown in Figure 5.

Tool 2: Square Pin Profile

The FSW tool with square pin profile to weld Aluminum 6082 T6 plates is shown in Figure 5. The pin for this tool has square shape with a cylindrical shoulder.

Tool 3: Combined tool profile

The FSW tool is obtained by cutting a hexagonal pin profiled tool with a suitable tapered angle for welding of Aluminium 6082 T6 plates is shown in figure 5.

Fig. 5 Tools For FSW Process

C) Selection of Process Parameter

There are number of process parameter in friction stir welding as shown in figure.

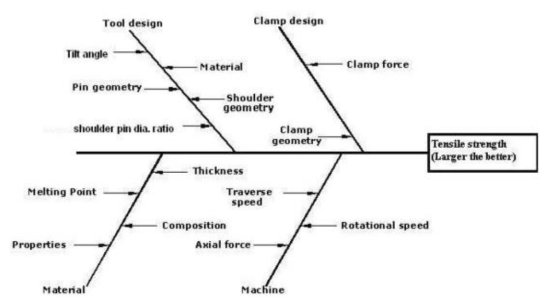

Fig 6. Cause and effect diagram of influencing friction stir welding

From the above process parameter, we have selected following parameter by keeping other parameter constant.

2) **Tool Rotation Speed-** Frictional heat, stirring, oxide layer breaking and mixing of material.
3) **Welding Speed-** Appearance, heat control.
4) **Tilt Angle-** Confine material, maintaining contact conditions.

1. Selection of Response Variables

For this investigation weld strength is selected as response variable.

D) Experimental Details

The parameters and their levels are selected for trail experimentation and by using Design of Experiments by Taguchi Method, L9 orthogonal array is selected for trail experiments.

TABLE IV. PARAMETER SELECTION

Process Parameter	Levels		
	1	2	3
Pin profile	Cylindrical	Square	Hexagonal with tapered cut
Tool rotational speed(rpm)	700	910	1035
Welding speed(inch/min)	2	3	4
Tilt angle (^{0})	2	3	4

TABLE V. L9 ORTHOGONAL ARRAY

Trial No.	**A (Tool)**	**B (rpm)**	**C (Welding Speed)**	**D (Tilt Angle)**	**Avg. UTS (N/mm2)**
1	1	700	2	2	
2	1	910	3	3	
3	1	1035	4	4	
4	2	700	3	4	
5	2	910	4	2	
6	2	1035	2	3	
7	3	700	4	3	
8	3	910	2	4	
9	3	1035	3	2	

E.Testing of Welded Plates

After welding, we are going to cut the FSW plates perpendicular to the welding direction for tensile testing and tensile specimen will be prepared according to the IS 1608: 2005.

Fig. 6 Tesile Test Specimen According to IS1608:2005

VI. RESULTS AND DISCUSSION

Table VI shows the tesile strength of weldments for different pin profiles.

TABLE VI. TENSILE STRENGTH OF WELDMENTS

Sr. No.	**Condition**	**UTS (N/mm2)**		**Avg. UTS(N/mm2)**
		Trial 1	**Trial 2**	
1	Tool 1-700-2-2	210.469	221.374	215.921
2	Tool 1-910-3-3	193.566	192.203	192.884
3	Tool 1-1035-4-4	223.282	184.297	203.789
4	Tool 2-700-3-4	193.293	172.028	182.660
5	Tool 2-910-4-2	187.296	194.657	190.976
6	Tool 2-1035-2-3	216.467	209.106	212.786
7	Tool 3-700-4-3	221.647	216.194	218.920
8	Tool 3-910-2-4	227.372	221.647	224.509
9	Tool 3-1035-3-2	230.371	185.932	208.151

From the above it is clear that the hexagonal tool with tapered cut shown the best results at 910 rpm, 2 inch/min and at 4 degree parameters.

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