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Investigation of Variation in Tensile Strength of FSW Butt joints of Al 6082-T6 aluminum with Welding Speed and Tool Pin Profiles

Akshay Valate[1], Aniket Raut[2], Sudhir Salunke[3], Sumit Thombare[4], A.M. Umbarkar[5]

[1,2,3,4] *Student, Dept. of Mechanical Engineering, Smt. Kashibai Navale College Of Engineering, SPPU, Pune, India*
[5] *Assistant Professor, Dept. of Mechanical Engineering, Smt. Kashibai Navale College Of Engineering, SPPU, Pune, India*

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Abstract – *FSW is a solid state welding process for joining metallic alloys and has came up as an alternative technology used in high strength alloys which are difficult to join with conventional techniques. The applications of FSW process are found in various industries such as aerospace, rail, automotive and marine industries for joining the magnesium, aluminum and copper alloys. The Friction Stir Welding process parameters such as rotational speed, welding speed, axial force and Tilt angle plays an important role in the analysis of weld quality.*
The aim of this research is to find the effects of different welding speeds, rotational speeds and tool pin profiles on the weld quality of Al 6082-T6 aluminum alloy.. Taper cylindrical and cylindrical screw thread pin are used as tool pin profiles in this research. Evidently, the results obtained explain the variation of tensile strength for various welding speeds for two selected pin profiles. The FSW with cylindrical threaded pin profile have achieved 55-60% tensile strength that of the base metal.

Key Words: Friction stir welding, Al 6082-T6 Aluminum alloy, Tool pin profiles, Welding speed, Tensile strength

1. INTRODUCTION

The difficulty of making high strength, fatigue resistant welds in aerospace aluminum alloys, such as highly alloyed 2XXX and 7XXX series which has long inhibited the wide use of welding for joining aerospace structures. These aluminum alloys are commonly classified as non weld able because of poor solidification microstructure and porosity in the fusion zone. The loss of mechanical properties as compared to the base material is very significant. These factors make the welding of these alloys by conventional welding processes unattractive. [1].

Friction stir welding (FSW) is a joining process developed by The Welding Institute (TWI) of UK in 1991 and has came up as a welding technique used in high strength alloys for aerospace, marine and automotive applications that were difficult to weld with conventional welding techniques. This technique is attractive for welding high strength aluminum alloys as there is far lower heat input during the process compared with conventional welding methods such as Tungsten inert gas, Metal Inert Gas welding. This solid state joining process leads to minimal micro-structural changes and better mechanical properties than regular welding. The process was developed for aluminum alloys, but since then, FSW is a technique used for joining a large number of materials [2]. Various process parameters which affect the FSW process are welding speed, Rotational speed, axial force and angle of tilt of tool. The non-consumable FSW tool should be capable of generating sufficient amount of heat that can transfer metal into plastic state. Hence, tool material is also an important concern for FSW. Material selected for FSW tool should possess properties such as good resistance to wear, good strength, dimensional stability at ambient and elevated temperatures, low coefficient of thermal expansion, good thermal fatigue strength and Good machinability for manufacture of complex features on the shoulder and probe.

2. Friction Stir Welding Process

Friction stir welding is a simple process which consist of rotating cylindrical tool with shoulder and a profiled pin is plunged into the abutting plates to be joined and traversed along the line of joint [1]. The plates are tightly clamped on to the bed of the FSW equipment to prevent them from separation during welding. A rotating cylindrical tool at high speed is slowly plunged into the plate material, till the shoulder of the tool touches the upper surface of the plate material. A downward force is applied to maintain the contact between tool shoulder and upper surface of plate. Frictional heat generated between the tool and base material which causes the plasticized material to get heated and softened, without reaching melting point. As the tool is moved in the direction of welding, the leading edge of the tool forces the plasticized material, on both side of the butt line, to the back of tool (fig 1). In effect, the transferred plasticized material is forged by the direct contact of the shoulder and the pin profile. In order to achieve complete through-thickness welding, the length of pin should be slightly less

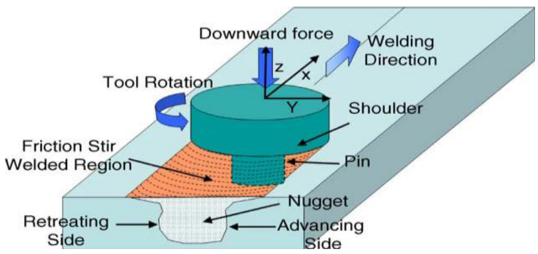

Fig- 1: Schematic drawing of FSW

than the plate thickness. The tool typically consist of a cylindrical shoulder with various profiled pin. The material or materials being welded can be called the work piece or plate. The joint where the samples are abutted will be referred to as the weld line. The part used to support and clamp the sample is called backing plate. Basically, the tool serves two primary functions: (a) heating of work piece and (b) movement of material to produce the joint.

FSW is considered to be the most significant development in metal joining and is a green technology due to its energy efficiency, environment friendliness and versatility. As compared to conventional welding methods, FSW requires considerably less amount of energy. No cover gas or flux is used, thereby making a process environmental friendly. The joining does not involve any use of filler metal and hence any aluminum alloy can be joined with no concern for compatibility of composition, which is an issue in fusion welding. In FSW Process, desirable, dissimilar aluminum alloys and composites can be joined with equal ease. In contrast to the conventional friction welding, which is usually performed on small axis symmetric part that can be rotated and pushed over each other to form a joint, friction stir welding can be applied to various types of joints like butt joints, lap joints, T-butt joints and fillet joints [1].

3. Experimental Work

3.1 Selection of base material

FSW is a solid state process which can be used to join all common aluminum alloys, including 2xxx, 5xxx, 6xxx, 7xxx and 8xxx series which are generally challenging or impractical to weld by fusion processes [2]. Aluminum alloy Al 6082 is a medium strength alloy with good corrosion resistance. It has the highest strength of 6xxx series alloy. It is also known as structural alloy. The addition of a large amount of manganese controls the grain structure which in turn result in a stronger alloy. In this experimentation, base materials, Al 6082-T6, which is a precipitation hardened aluminum alloy widely used in aerospace applications due to its high strength is used. Plates of 110 × 60 × 6 mm are used.

3.2 Selection of Tool material & Tool Pin Profiles

Friction stirring is a thermo-mechanical deformation process where tool temperature approaches the solidus temperature of base metal. Making a choice in selection of FSW tool material has become an important task which determines the quality of weld produced. Material should have properties like good thermal fatigue strength, good fracture resistance & toughness, low coefficient of thermal expansion, good machinability, resistance to wear and no harmful reactions with weld metal. Tool material should be harder than work material Al 6082-T6. The tool is carried for the hardening process. Here we are choosing High Carbon High Chromium (HCHCr) Steel (C 1.55%, Si 0.40%, Mn 0.30% and Cr 11.5%).

Fig.2–(a) Taper Cylindrical Tool **(b)** Cylindrical Threaded Tool

Tool pin profiles which are selected for experimentation are Taper cylindrical and cylindrical threaded (Fig. 2(a) and Fig. 2(b)).

3.3 Tool Specifications and Fixture

Tool 1: Taper Cylindrical profiled pin

- Material: HCHCr
- Tool Dia: 15 mm
- Shoulder Dia: 12 mm
- Pin Dia: 4 mm
- Length of Pin: 4.8 mm
- Length of Tool: 60 mm
- Hardness: 56 HRC

Tool 2: Cylindrical Threaded pin

- Material: HCHCr
- Tool Dia: 16 mm
- Shoulder Dia: 12 mm
- Pin Dia: 4 mm
- Length of Pin: 5.2 mm
- Length of tool: 60 mm
- Hardness: 58 HRC

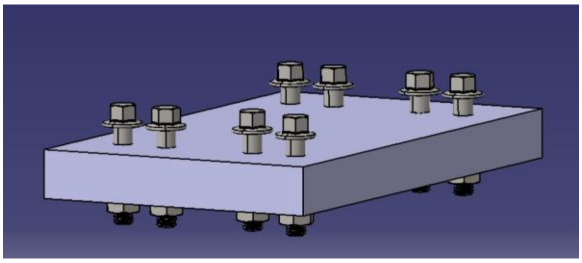

Fig-3: CAD Model for Fixture

Wooden Fixture is used for holding plates while performing FSW operation. Dimensions 200×120×15 mm of Fixture are selected based on base metal plate dimensions and milling working Table dimensions (Fig. 3).

3.4 Experimental Setup

Experiment is carried out on Vertical milling machine as shown in Fig. 4

Fig-4: FSW setup

3.5 Design of Experiments

Table-1 shows the values of selected machining parameters, two factors with three levels of each factor. By using Design

Table-1: Process Parameters and Their Levels

Process Parameter	Levels		
	1	2	3
Tool Rotation Speed (rpm)	800	1000	1200
Welding Speed (mm/min)	30	60	80

of experiments by Taguchi method, (Table-2) L9 orthogonal array is selected for Experiments.

Table-2: L9 orthogonal array for Experimentations

Tool Rotational Speed (rpm)	Welding Speed (mm/min)
800	30
800	60
800	80
1000	30
1000	60
1000	80
1200	30
1200	60
1200	80

Design of experiment is a method of designing experiments, in which only selected number of experiments are to be performed. Using design of experiments method, only 9 experiments are required to be performed. On the basis of these experiments, the significance and optimal levels of each parameter is obtained.

4. Results and Discussion

Tensile Strength of welds obtained by FSW process are measured using Universal Testing Machine (UTM). The response variable i.e. tensile strength in this case are analyzed using ANOVA and Interpreted.

Table-3: Orthogonal array of Experiment and Results for Tool 1

Sr. No.	Rotational Speed (rpm)	Welding Speed (mm/min)	Tensile Strength (N/mm^2)
1	800	30	29.84
2	800	60	56.02
3	800	80	48.93
4	1000	30	20.51
5	1000	60	62.23
6	1000	80	59.99
7	1200	30	22.05
8	1200	60	28.99
9	1200	80	18.28

Analysis of Experimental data is done using MINITAB-16 software. The effect of input parameters on output responses will be analyzed using analysis of variance. Analysis of variance (ANOVA) test is performed to identify the process parameters that are statistically significant and which affect the tensile strength of FSW joints. The ANOVA results for tensile strength S/N ratio are given in Table-5 and Table-6 for Tool 1 and Tool 2 respectively.

Table-4: Orthogonal array of Experiment and Results for Tool 2

Sr. No	Rotational Speed (rpm)	Welding Speed (mm/min)	Tensile Strength (N/mm^2)
1	800	30	64.95
2	800	60	60.87
3	800	80	52.91
4	1000	30	63.74
5	1000	60	59.41
6	1000	80	57.50
7	1200	30	77.59
8	1200	60	59.26
9	1200	80	49.47

The value of F ratio is greater than 4 for rotational speed in case of tool 1 while it is greater than 4 for traverse speed in case of tool 2

Table-5: ANOVA of Tensile Strength for Tool 1

Source	DF	Adj SS	Adj MS	F	P
Rotational Speed	2	1082.0	541	4.11	0.107

Welding Speed	2	1000.6	500	3.80	0.119
Error	4	526.5	131.6		
Total	8	2609.2			

Table-6: ANOVA of Tensile Strength for Tool 2

Source	DF	Adj SS	Adj MS	F	P
Rotational Speed	2	10.38	5.191	0.15	0.868
Welding Speed	2	361.61	180.806	5.12	0.079
Error	4	141.35	35.336		
Total	8	513.34			

Interaction plots are drawn to see effect of combination of process parameter on tensile strength (Fig. 5 and Fig. 6 for tool 1 & 2 resp.).

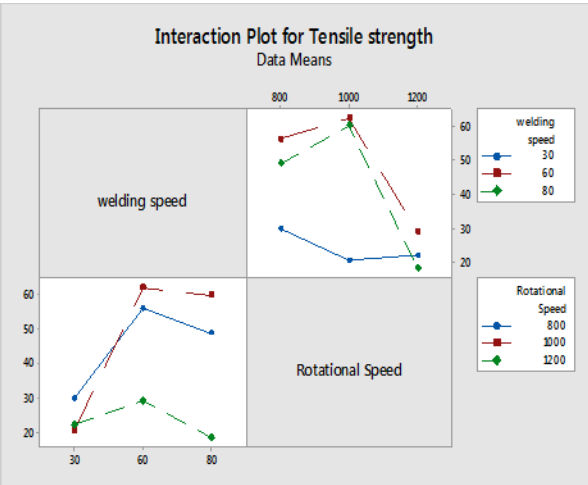

Fig-5: Interaction Plot for Tensile Strength of Tool 1

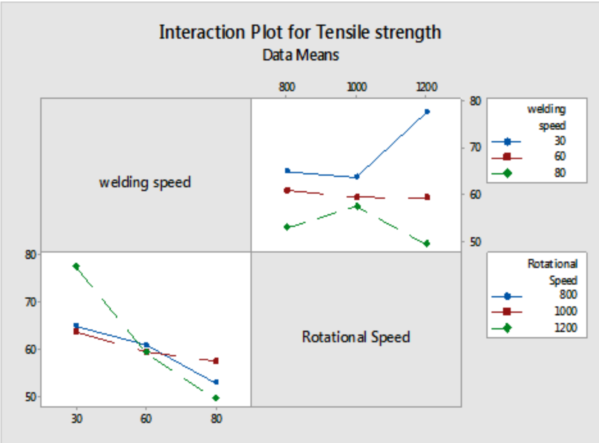

Fig-6: Interaction Plot for Tensile Strength of Tool 2

5. Conclusion

In this paper, Al 6082-T6 alloy was welded by using FSW process. Two selected friction stir pin profiles were designed to study the influence of pin geometry on the weld shape and mechanical properties. Also, the effect of different welding speed is investigated in this research. From this research, the following conclusions are obtained:

- The results indicate that pin profile has significant effect on the weld quality and the mechanical properties.
- It is found that the joint fabricated using Cylindrical threaded pin exhibits superior tensile properties compared to Taper Cylindrical pin irrespective of welding speed.
- Tensile strength of Cylindrical Threaded reaches to 55-60 % of the base metal tensile strength.
- Taper Cylindrical joints fabricated at welding speed 60 mm/min have demonstrated more tensile strength in comparison with other welding speed of 30, 80 mm/min.
- Cylindrical Screw Threaded joints fabricated at welding speed of 30 mm/min show superior tensile properties compared to 60, 80 mm/min.

Finally, we conclude that the friction stir welded plates of Al 6082-T6 by using Cylindrical Screw Threaded pin profile at welding speed 30 mm/min and rotational speed of 1200 rpm reaches the tensile strength of 55-60% of the base metal tensile strength.

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