Experimental Evaluation on the Effect of Welding Speed and Tool Pin Profiles on Friction Stir Welded Joints on AA 6082-T6

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Abstract- **Friction stir welding (FSW) is a solid state metallic alloys joining process and has emerged as an alternative technology used in high strength alloys that are difficult to join with conventional techniques, in which the raltive motion between the tool and workpiece creates heat which helps the material of two edges being joined by plastic diffusion. In this research rotational speed, welding speed, axial force was taken as process parameters. The aim of the research is to evaluate the effects of different welding speeds (50, 65 & 80 mm/min), rotational speeds (1200& 1500 rpm) and tool pin profiles on the weld quality of AA6082-T-6. Straight cylindrical, taper threaded and hexagonal pin are used as tool pin profiles in this resarch. There is no visual effect found, consequently obtained results explian the stress variation as a functuion of strain. The friction stir welded plates of AA6082-T6 by using the hexagonal pin profile reaches the ultimate tensile strength of 72% of the base metal ultimate strength and there is very negligible eongation.**

Keywords – FSW, AA6082-T6 aluminium alloy, welding speed, and tool pin profile, mechanical properties.

I. INTRODUCTION

A method of solid phase welding which permits a wide range of parts and geometries to be welded and called Friction Stir Welding (FSW), was invented and patented by W. M Thomas et al. [1] of the Welding Institute in Cambridge, UK in 1991. Fricti on Sti r Wel di ng (FSW) is a process that has been shown to produce superior as-welded mechanical properties when compared to typical arc welding processes in other aluminum alloys such as 5083, 6061 and 2219.

FSW produces welds that are high in quality, strength, and also inexpensive to make. The other main advantage is that it produces no fumes during process and is energy efficient. FSW does not need any filler material as required in conventional welding process and is relatively easy to perform.

Defect-free welds with good mechanical properties have been made in a wide variety of aluminum alloys, even those previously thought to be "Unweldable," in thicknesses from less than 1 mm to more than 35 mm. In addition, friction stir welds can be accomplished in any position. Clearly, friction stir welding is a valuable new technique for butt and lap joint welding aluminum alloys.

However, the work piece should be rigidly clamped and welding speeds are low in order to avoid defects like porosity. For aluminum alloys such as the 2000, 5000, 6000, 7000, and 8000 series, the alloys can be easily welded by Friction Stir Welding. [2]

The goals of the FSW program were first to produce welds with equi valent strength and increased ductility compared to conventional arc welds, then to fabricate and test ballistic weld samples.

II. FRICTION STIR WELDING PROCESS

Friction stir welding is performed by a rotating non consumable tool which is plunged into the material to be welded. The tool is traversed along the joint line to create a solid phase weld. The material along the tool becomes softened and highly plasticized from the frictional heat generated during the process and is carried around the tool so that there is complete mixing of material from the two plates. The pin of the rotating tool hence provides the "stir" action in the material of the work piece. This result in a Heat Affected Zone (HAZ) with a better grain refinement required for a good weld joining.

A cylindrical, shouldered tool with different profiled probe (nib or pin) is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, until the shoulder of the tool forcibly contacts the upper surface of the material and the pin is a short distance from the back plate. The pieces are rigidly clamped onto a backing plate in a manner that prevents the abutting joint faces from being forced apart. The fixturing prevents the plates from spreading apart or lifting during welding. Frictional heat is generated between the tool shoulder and the work piece. This heat causes the latter to reach a visco-plastic state that allows traversing of the tool along the weld line. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase bond between the two pieces. [4]

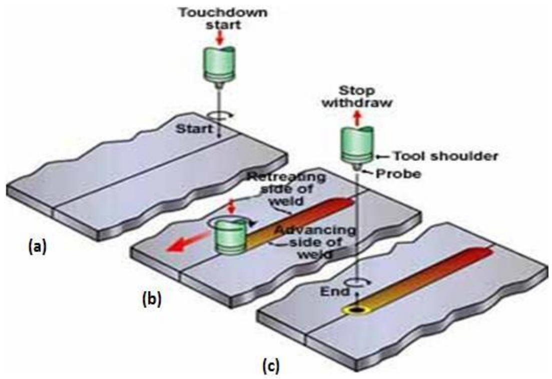

Fig. 1:- Process Overview of FSW (TWI)

Fig. 1 shows the step by step process description of Friction Stir Welding

Step 1: Tool rotates at constant rpm about its axis as shown in step (a) of figure 1.

Step 2: Tool pin plunges into the abutting edges of the material to be joined due to the frictional heat between the tool pin and material. Tool shoulder contacts the material and plasticizes due to frictional heat between shoulder and material as shown in step (b) of figure 1.

Step 3: welding is made on the material and tool withdrawn from the plate as shown in step (c) of figure 1.

III. MICRO-STRUCTURAL FEATURES OF FRICTION STIR WELDS

The first attempt at classifying microstructures was made by P L Threadgill (Bulletin, March 1997). This work was based solely on information available from aluminium alloys. A more comprehensive scheme has been developed by TWI, and has been discussed with a number of appropriate people in industry and academia. This has also been accepted by the Friction Stir Welding Licensees Association. The system divides the weld zone into distinct regions as follows [2]

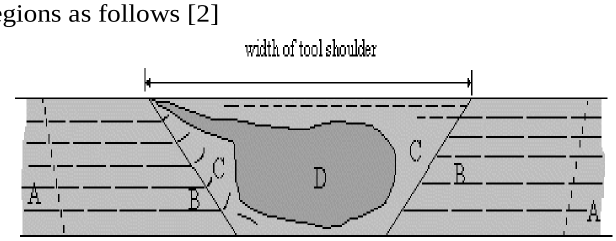

Fig: - 2 Micro Structural Study of Plate *(Copyright © 1997, TWI Ltd) [2]*

They are: (A) Unaffected parent material (B) Heat affected zone (HAZ) (C) Thermo mechanically affected zone (TMAZ) (D) Weld nugget (Part of thermo-mechanically affected zone). The formation of above regions is affected by the material flow behaviour under the action of rotating non-consumable tool. However, the material flow behaviour is predominantly influenced by the different tool pin profiles & tool geometry [6] and FSW process parameters like rotating speed [4,8] & welding speed [4,8]. The aim of present investigation is to study the effect of rotating and transverse speed on mechanical behaviour of AA6082-T6 welded plates of 6mm thickness.

IV. EXPERIMENTAL WORK

The friction stir welds have been carried out by a properly designed clamping fixture that allows the user to fix the two plates (150mm x 50mm x6mm) to be welded on a CNC vertical milling machine model HASS VF-0, which is transformed into friction stir welding machine by designing the fixture that makes the CNC machine capable for performing the friction stir welding.

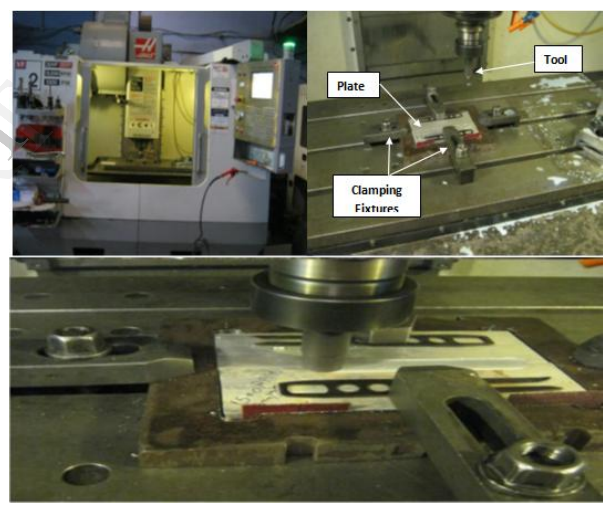

Fig: -3 Experimental Setup Describing Clamping and Welding of FSW Plates

In this investigation, the base materials, AA6082-T-6, which is a hardened aluminum alloy widely used in marine and aerospace applications due to its high strength was used. The welding parameters, mechanical and chemical properties of AA6082-T6 are shown in Table 1, Table 2 and Table 3 respectively. The parameters were selected on the trial bases.

Table: 1 Friction Stir Welding Parameters

Alloy	**Rotational Speed (rpm)**	**Welding Speed (mm/min)**	**Axial Load (KN)**
AA 6082-T6	1200 & 1500	50, 65, & 80	6

Table: 2 Mechanical Properties of Base Metal

Materia l	Tensile Strengt h (MPa)	Yield Strengt h (MPa)	Shear Strengt h (MPa)	% Elongatio n
AA 6082-T6	310-320	260	210	10-13

Table: 3 Chemical Composition of Base Metal (%)

Cu	M n	Si	Fe	Mg	Cr	Zn	Ti	Al
0. 1	0. 4- 1. 0	0.7 -1 .3	0.5	0.6 - 1.2	0.2 5	0.2	0. 1	Bal anc e

A. Configuration of Tool Geometry:

In this research, a tool made of H-13 tool steel heat treated to HRC50-52 with an 18mm shoulder diameter is used. Figure -4 shows the image of different tool pin profile used in this research in order to carried out joints. Three different tool pins are selected. These are presented as following:

(1). Straight Cylindrical Pin (SC) **(2)** Tapered Threaded Pin (TT) **(3).** Straight Hexagonal Pin (HT)

Fig: -4 Images of the Tool Pin Profiles Used In This Study

The primary function of the non-consumable rotating tool pin is to stir the plasticized metal and move the same behind it to have good joint. Pin profile plays a crucial role in material flow and in turn regulates the welding speed of the FSW process. The geometrical configuration and the chemical composition of the tools are shown in Table 4 and Table 5, respectively.

Table: 4 Tool Geometry

	Straight Cylindrical Pin	Tapered Threaded Pin		Straight Hexagonal Pin
Shank Length (mm)	80	80		80
Shank Dia (mm)	20	20		20
Shoulder Length (mm)	15	15		15
Shoulder Dia (mm)	18	18		18
Pin Length (mm)	5.7	5.7		5.7
Pin Dia (mm)	6	Major = 6	Minor = 4	6
Pitch	-	1mm		-

Table: 5 Chemical Composition of Tool (%)

	C	Si	M n	P	S	Cr	Mo	V
%	0.3 80	1.0 5	0.4 8	0.0 15	0.0 04	4.8 8	1.2 70	0.9 00

B. Welded Specimen

The weld joint size is 130 mm long. A tool tilt angle is 0°, because the bottom surface of the tool shoulder is flat. The tool rotational speed and welding speed were varied in the program according to the matrix designed. The tools were also accordingly changed. In this way 18 weld were made. Figure -5 shows the photographs of some friction stir welded specimens.

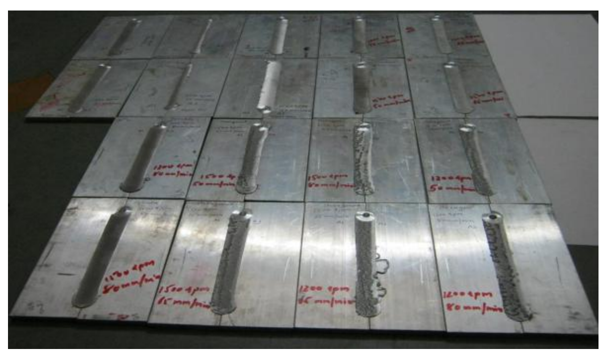

Fig: -5 FSW Joints of AA6082-T6

C. Specimen Preparation for Tensile Testing

Tensile tests were performed to determine the tensile properties of the weld material such as tensile strength and percentage of elongation. Transverse tensile test samples were prepared from joints according to ASME Sec-IX as shown in Figure-6. The tensile test of the welded joints was carried out on a Fie make Universal Testing Machine, UTE-40.

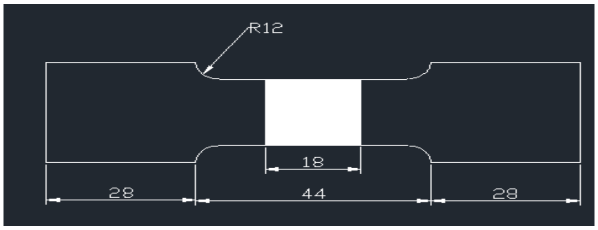

Fig: -6 Dimensions of Tensile Specimen

V. RESULT AND DISCUSSION

A. Visual Inspection

The welding was performed on rotational speed of 1200 and 1500 rpm and welding speed was 50, 65, & 80 mm/min. The weldment indicated no visible defects. The surface finish of weld sample welded at 1500 rpm was much better than weld sample welded at 1200 rpm. This confirms that as the tool rotation speed increases smooth surface is produced at the weldment. Figure 7 shows the weld sample.

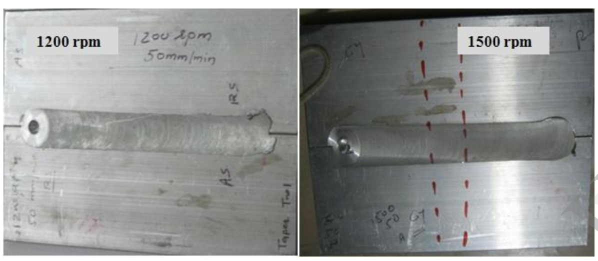

Fig: -7 Welded Specimen at 1200 and 1500 rpm

B. Tensile Properties

Tensile properties such as tensile strength and percentage of elongation have been evaluated for welded plates and compared with base metal. For rotational speed 1200 rpm and 1500 rpm and welding speed 50, 65, 80 mm/min, specimen was tested and the results of the specimens are presented as the outcome of this study. The results are given in Table 6. The results are plotted as graphs and they are displayed in figure 8 to 13.

Table: 6 Tensile Test Result

Exp. No.	**Tool Pin Type**	**Speed N rpm**	**Welding Speeds mm/min**	**UTS (MPa)**	**UTL (KN)**
1	Straight Cylindrical (SC) Tool Pin	1200	50	125.09	15.66
2		1200	65	102.772	12.68
3		1200	80	132.019	16.34
4		1500	50	114.991	14.26
5		1500	65	90.11	11.28
6		1500	80	126.897	15.64
7	Taper Threaded (TT) Tool Pin	1200	50	133.002	16.58
8		1200	65	144.252	18.02
9		1200	80	135.579	17.08
10		1500	50	108.275	13.36
11		1500	65	115.354	14.32
12		1500	80	113.852	13.34
13	Straight Hexagonal (SH) Tool Pin	1200	50	140.133	17.34
14		1200	65	151.900	18.72
15		1200	80	150.271	18.56
16		1500	50	141.130	17.74
17		**1500**	**65**	**173.496**	**19.94**
18		1500	80	150.012	18.66
19	**Base Plate**		**%El=13.5**	**241.735**	**21.30**

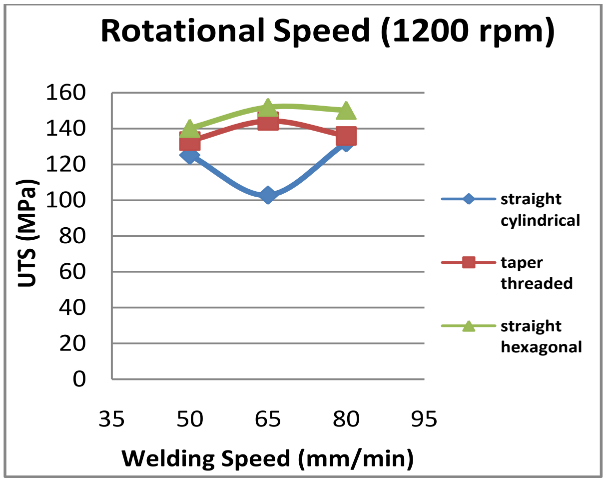

Fig: -8 Effect of Tool Pin Profile and Welding Speed on UTS at 1200rpm

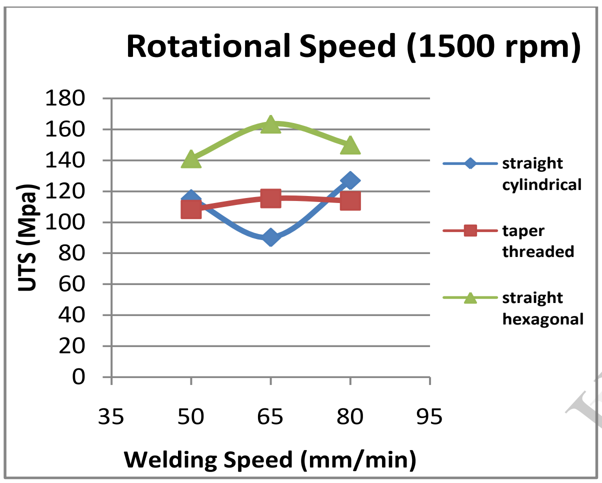

Fig: -9 Effect of Tool Pin Profile and Welding Speed on UTS at 1500rpm

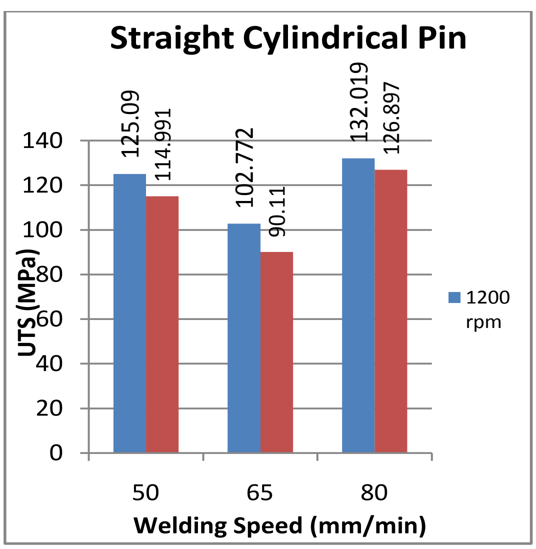

Fig: -10 Effects of Straight Cylindrical Pin Profile and Welding Speed on UTS

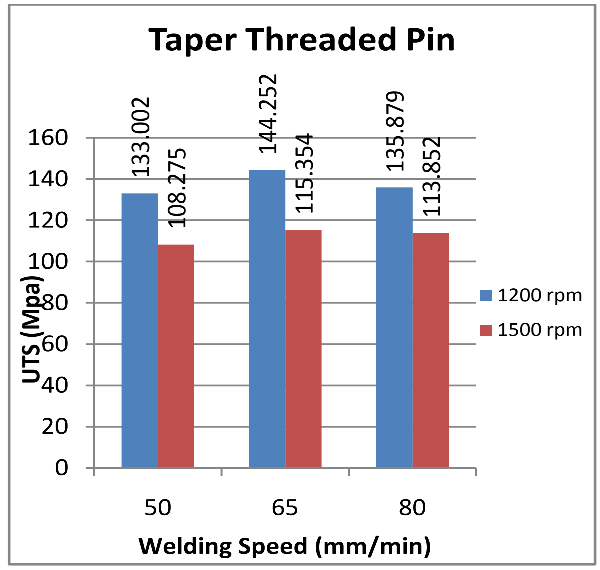

Fig: - 11 Effect of Taper Threaded Pin Profile and Welding Speed on UTS

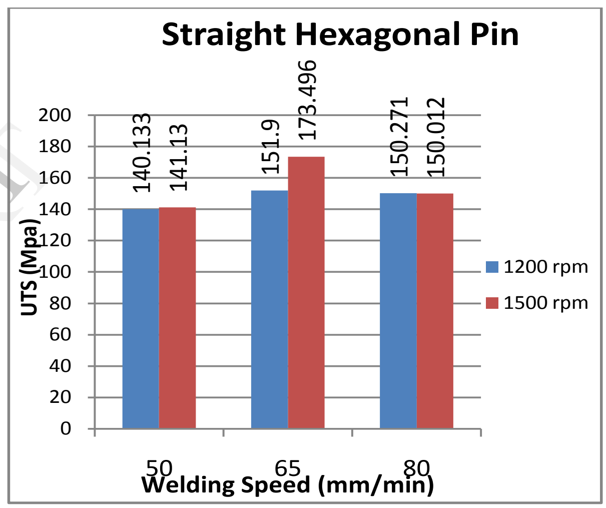

Fig: - 12 Effect of Straight Hexagonal Pin Profile and Welding Speed on UTS

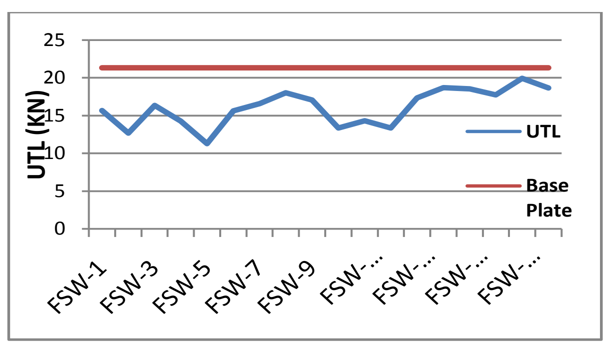

Fig: - 13 Comparison of UTL of all Fabricated Joints with UTL of Base Metal

VI. CONCLUSION

In this research, AA6082-T6 alloy was welded by using FSW process, and three tools of different pin profiles were designed to study the influence of the pin geometry on the mechanical properties. Also, the effect of different welding speed and rotational speed is investigated. From the experiment, the following conclusions are derived.

- The effect of rotational speed and welding speed on the appearance of the weld is presented and no obvious defect was found. The surface finish of weld sample welded at 1500 rpm was better than weld sample welded at 1200 rpm. This confirms that as the tool rotation speed increases smooth surface is produced at the weldment.
- The results indicate that the pin profile effect on the mechanical properties of welded joints.
- Among the eighteen joints in this experiment, the joints produced using the straight hexagonal pin profiled tool at a rotational speed 1500 rpm and welding speed 65 mm/min showed the best tensile properties.
- The tensile strength of the straight hexagonal pin at 1500 rpm and 65 mm/min reaches to 71.77% of the base metal ultimate strength, but the UTL reaches 93.61% of the base metal UTL.
- The straight cylindrical and taper threaded ultimate strength goes to 35.38% and 44.61% respectively of the base metal ultimate strength.
- There is no elongation shown in the weld region.

REFERENCES

[1] W M Thomas, E. Nicholas, J. Needham et al. Friction Stir Butt Welding. International patent application, No. PCT/GB92/02203 and GB patent application, No. 9125978.8, (1991).
[2] FU Zhi-hong, HE Di-qiu, WANG Hong. "Friction Stir Welding of Aluminum Alloys", Journal of Wuhan University of Technology-Mater. Sci. Ed., Volume 19, No.1, (March-2004).
[3] J. Adamowski and M. Szkodo, "Friction Stir Welds (FSW) of aluminium alloy AW6082-T6", Journal of Achievements in Materials and Manufacturing Engineering, Volume-20, Issues-1-2, PP 403-406, (January-February 2007).
[4] H. S. Patil, P. D. Ahir and S. N. Soman, "Influence of Process Parameter on Tensile Properties of Friction Stir Welded Butt Joints in 6082 Aluminium Alloy", Elixir Mech. Engg. 30, PP 1823-1825, (January-2011).
[5] Dr.A.K.Shaik Dawood, M.Karthikeyan, "Influence of Tool Design on the Mechanical Properties and Microstructure in Friction Stir Welding of AA6351 Aluminium Alloy", IRACST- Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol. 2, No. 2, PP 233-237, (April 2012).
[6] R.S. Mishra, Z.Y. Ma, "Friction Stir Welding and Processing", Materials Science and Engineering R, published by ELSEVIER, available on Science Direct, 50, PP 1-78, (2005).
[7] Kudzanayi Chiteka, "Friction Stir Welding/Processing Tool Materials and Selection", International Journal of Engineering Research & Technology, ISSN: 2278-0181, Vol 2, Issue 11, PP 8-11, (November-2013).
[8] H. S. Patil & S. N. Soman, "Experimental Study on The Effect of Welding Speed and Tool Pin Profiles on AA6082-O Aluminium Friction Stir Welded Butt Joints", International Journal of Engineering, Science and Technology, published by Multicraft, Volume- 2, No. 5, PP. 268-275, (2010).
[9] V. Balasubramanian, "Relationship between Base Metal Properties and Friction Stir Welding Process Parameters", Materials Science and Engineering A, published by ELSEVIER, 480, PP 397–403, (2008).