Design and Experimental study of Friction stir welding of AA6061-T6 Alloy for optimization of welding parameters by using Lathe Machine

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Abstract - *Friction stir welding is a new solid state welding process for joining metallic alloys and it is useful in serve industries for joining aluminium, magnesium and copper alloys. The various parameter such as rotational speed, transverse speed and tool tilt angle play important roles in FSW process and quality weld. The aim of this study is to know the relation between the effects of different transvers speed and tool profile on the weld quality of AA6061-T6 aluminium. The geometry of the pin tool along with the process parameters plays an important role in dictating the path that the material takes. The tool geometry was carefully chosen and fabricated to have a nearly flat welded interface pin profile. In this work, an attempt has been made to analyze the effect of various tool profiles on mechanical properties of aluminium alloy. Various tool profiles have been used to fabricate joints by using varying thickness work piece of Aluminium alloy. Numerical techniques particularly, the finite element method for the simulation of FSW for thermal, mechanical and thermo-mechanical modelling has been investigated. The current studies also aim to understand mechanical properties during the FSW.*

*Key Words***:** Friction Stir Welding, Transient Thermal Analysis, Al6061, Process parameter, Tool Profile

1.INTRODUCTION

Friction Stir Welding process is relatively a new joining process that is presently attracting considerable interest. Since the joint can be obtained below the melting temperature, this method is suitable for joining a number of materials those are extremely difficult to be welded by conventional fusion techniques. The process is solid state in nature and relies on the localized forging of the weld zone to produce the joint.

A constantly rotated non consumable cylindrical tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding a top the work surface.

Frictional heat is generated between the wear resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting.

FSW is actually performed in different steps as shown in figure 1. The probe primary function is to mix the material under the tool shoulder, which can be enhanced by threads. First, the probe is plunged into the joint formed by the two sheets to be welded, until the shoulder gets in contact. As the tool rotates at a high velocity, the sheets are heated up by plastic deformation and friction. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material. Figure 1 shows process of tool traversing along the weld line. [1], [2]
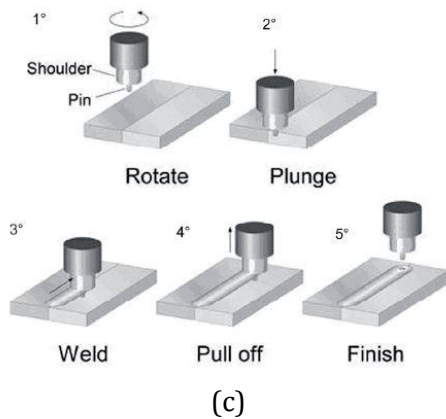

(a)

(b)

(c)
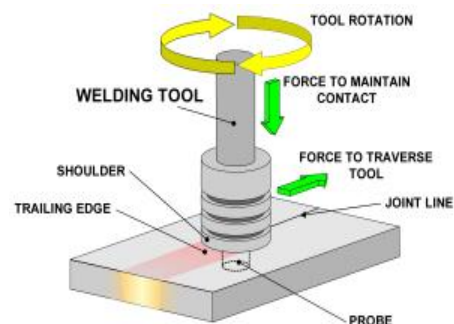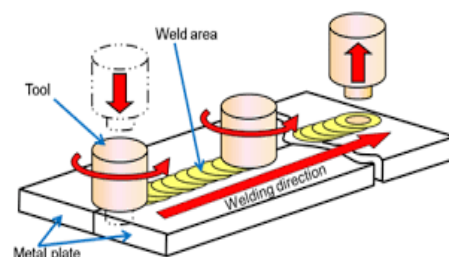
Fig -1: Schematic representation of FSW process

1.1 Key of Benefits

In contrast to the traditional friction welding, which is usually performed on small axisymmetric parts that can be rotated and pushed against each other to form a joint, FSW can be applied to various types of joints like butt joints, lap joints, T butt joints and fillet joints.

Table -1: The key benefits of FSW Process

Metallurgical benefits	Environmental Benefits	Energy benefits
Solid phase process	No shielding gas required	Reduction in weight
Good dimensional stability and repeatability	Eliminate grinding waste	Decrease fuel consumption
No loss of Alloying elements	Eliminate solvents required for degreasing	
Excellent metallurgical properties in the joint area	Consumable materials saving such as rugs , wire or any other gases	

1.2 Comparison of friction stir welding to other welding processes

Comparison of FSW to other welding processes is typically done within the context of justifying the use of the process over other, more conventional techniques. Successful application of FSW depends upon a clear misunderstanding of the characteristics of the process, so favorable technical and economic justification can be developed.
The unique, favorable characteristics of FSW compared to traditional arc welding methods provide several sources for technical justification for use of the process. [3], [4]
The main points for technical justification of FSW compared to arc welding processes are;
- Improved weld ability
- Reduced distortion
- Reduced residual stress

- Improved cosmetic performance
- Elimination of under matched filler metal
- Improved static strength and ductility
- Mechanized process
- High robustness and few process variables

2. DESIGN APPROACH

Generally, Friction stir welding is performed on the Milling or Radial cum drilling machine. But our main objective is to perform operation onto Lathe Machine. So for that an attachment is required to hold a welding plate on a lathe machine. [9], [10]

2.1 Basic Requirement of machine:

The performance test on Lathe machine for the FSW Technique is analyzed for the different parameters.

2.1.1 Light duty lathe machine specification:

Fig- 2: Lathe Machine

Table-2: Light duty lathe machine specification

| Sr no	Features	Values
1	Swing over bed	90 mm
2	Swing over carriage	45 mm
3	Distance between center	430 mm
4	Overall length	820 mm
5	Overall width	220 mm
6	Overall height	200 mm
7	Shipping weight	140 kg
8	Hole through spindle	10 mm
9	Spindle speed range	575-900 rpm

2.1.2 Lathe attachment

Now for holding a welding plate on lathe machine an additional attachment is required for mounting purpose. Figure 3 show CAD Geometrical view of lathe attachment for holding of welding plate.
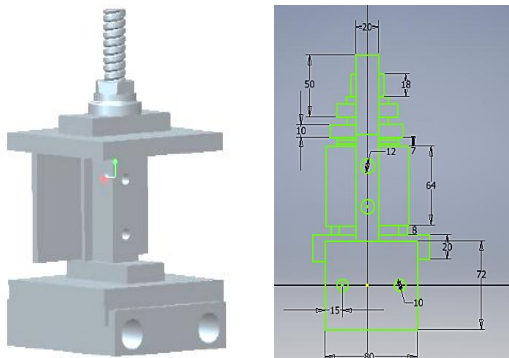
Fig-3: CAD Geometrical view of Lathe Attachment (All dimensions are in mm)

2.2 Basic requirement of tool geometry

A novel pin is design for friction stir welding tools that can penetrate more apply into work pieces to form a thicker weld joint without overloading the tool. The pin is providing with cylindrical and taper face on surface of tool. The diameter of the tool shoulder to the diameter of the tool pin (D_s/D_p) are chosen based on the literature survey. The shoulder of tool is designed to produce heat on the surface of the work pieces. The tool shoulder accounts for majority of the deformation and frictional heat generation between the work pieces. Due to large surface area, friction increases, which in turn increases the amount of heat generated. [6], [7], [8]
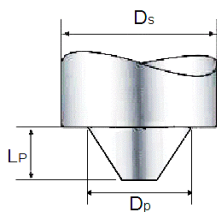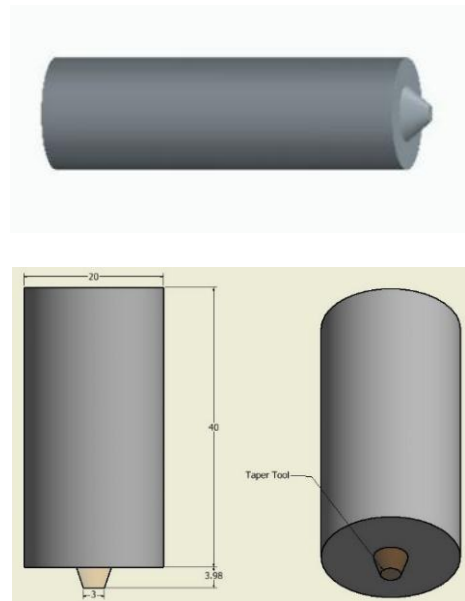

Fig-4. Tool Geometry

TABLE 3. Tool design parameter [15]

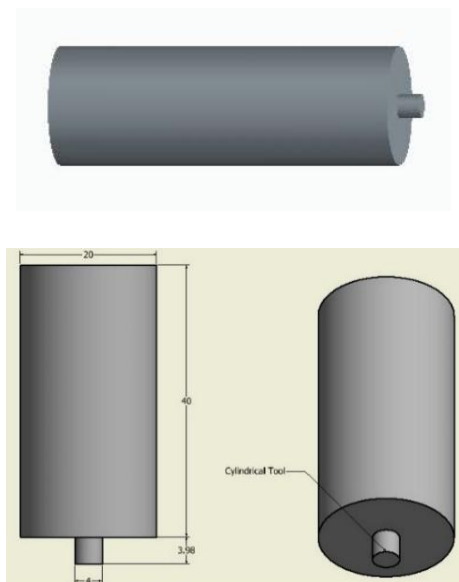| Weld tool Geometry	AL	TI	Steel (HMTM)
D_S/D_P	2.4	1.2-3.8	2.3-2.4
D_P/L_P	1.5	1.4-1.9	1.7-2.0
Pin surface	Treads	Smooth	Smooth
Taper	0	30-60	30-60

2.2.1 Types of tool

❖ Taper tool:

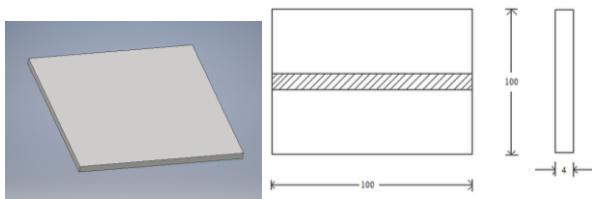**Fig- 5:** CAD geometry of Taper Tool (All dimensions are in mm)

❖ Cylindrical tool:

Fig- 6: CAD geometry of Cylindrical tool (All dimensions are in mm)

2.2.2 Base plate

The welding regime in the FSW procedure is defined by speed of rotation and the translational speed of tool, all of which depend on the thermo-physical properties of the material and the thickness of plates. [12]

Fig- 7: CAD Geometrical Dimension (All dimensions are in mm)

3. SIMULATION BASED APPROACH

Three-dimensional thermo mechanical model and the thermo mechanical effect of the welded material is developed for the FSW of an Al-alloy, in order to build qualitative framework to understand the thermo mechanical process in FSW. In this analysis work below figure shows the total deformation and temperature graph for a cylindrical tool geometry. The prediction and the measurement show that the maximum temperature gradients in longitudinal and lateral directions are located just beyond the shoulder edge. To simulate this kind of welding process, a fully coupled thermo-mechanical solution has been adopted to simulate the FSW process. [11], [13]
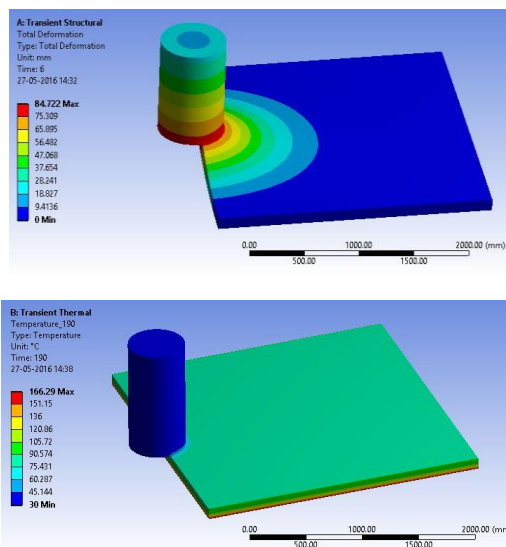
Fig- 8: Total deformation and Temperature profile

Figure 8 show the Total deformation and temperature profiles in the work piece during the welding operation for $N_2=900$ rpm; $T_2 = 3.16$ mm/min and for a cylindrical tool profile for the size of 4 mm thickness plate. [14], [16]

4. EXPERIMENTAL WORK

Experimental setup was recognized using a light duty lathe machine. No extra setup is required for friction stir welding except tool and fixture, so as to place piece in proper position during welding. The different process parameters

are discussed below which are effecting for the Analysis on FSW. [15]

4.1 Process parameter

The various process parameters play important roles in FSW process and quality weld.

Table 4: Main FSW process variables

| Tool design variables	Machine variables	Other variables
Shoulder and pin material	Welding speed	Anvil material
Shoulder diameter	Spindle speed	Anvil size
Pin diameter	Plunge force or depth	Work piece size
Pin length	Tool tilt angle	Work piece properties
Thread pitch		
Feature geometry		

There are so many parameters are effecting for the analysis on friction stir welding as shown in Table 4. As many parameters are important in the friction stir welding but in this experiment main two parameters are selected for analysis by using lathe machine;
   (1) Tool speed
   (2) Transvers speed
The proper choice of tool rotation and transverse speed will produce a good quality weld. The material use for base plate is Al alloy 6061 and the material use for the tool geometry is EN8.

4.2 Process step for friction stir welding on lathe machine

The experimental study includes the butt joining of aluminum plates. The welding method is carried out on light duty lathe machine as shown in Figure 2. Tool is hold in tool arbor as shown in Figure 9. Welding jigs and fixtures are designed to carry two plates as shown in figure 9. [5]
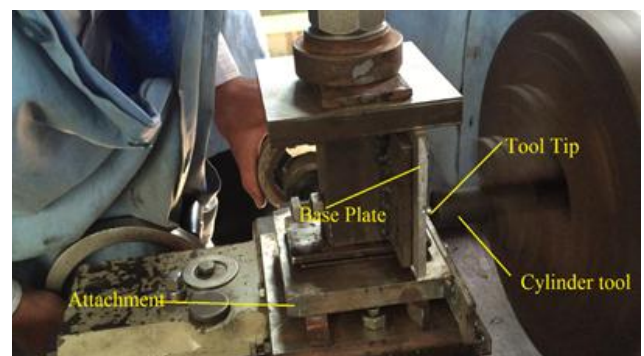
Fig-9: Process steps for FSW Experiment

In the present work, different FSW butt welds were obtained by varying the process parameters within the range and the optimal values are drawn based on the trend of the values. In this experiment it is observed that the process parameters like tool design, tool rotational speed, welding speed and materials are the main parameters to produce the effective butt joint by friction stir welding. [17]

4.3 Observation table

Table 5: Experiment data

| Sr No	Material Aa-6061	RPM (n)	Transvers Speed (mm/min)	Pass	Material size (mm)	Tool
1	Plate no:2	N_2=900	T_2=3.16 mm/min	P_1	S_2=100*45*4	C
2	Plate no:9	N_9=900	T_9=3.37 mm/min	P_2	S_9=100*45*6	C
3	Plate no:8	N_8=575	T_8=7.35 mm/min	P_1	S_8=100*45*4	C
4	Plate no:3	N_3=575	T_3=8.16 mm/min	P_2	S_3=92*45*6	C
5	Plate no:6	N_6=900	T_6=4.41 mm/min	P_1	S_6=100*45*4	t
6	Plate no:4	N_4=900	T_4=6.15 mm/min	P_2	S_4=100*45*6	t
7	Plate no:7	N_7=575	T_7=4.50 mm/min	P_1	S_7=100*45*4	t
8	Plate no:5	N_5=575	T_5=4.49 mm/min	P_2	S_5=100*45*6	t

Where;

Plate no 2: (P1N2T2S2C); Cylindrical Tool = C; Tapper Tool = t; RPM = N; Transvers speed = T; Material size = S; Single pass = P_1; Double pass = P_2

4.4 Tensile Tests: -

Tensile strength, along with elastic modulus and corrosion resistance, is an important parameter of engineering materials used in structures and mechanical devices.

- *Tensile test specimen geometry*
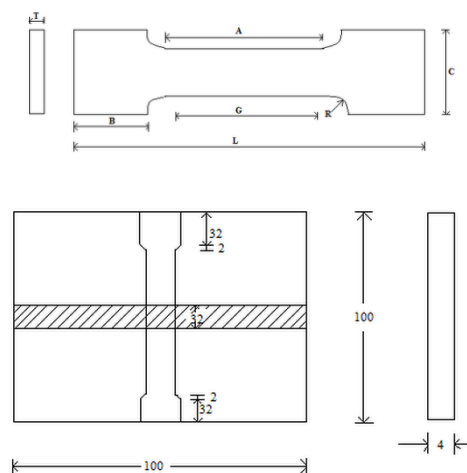
Fig-10: Tensile test specimen (All dimensions are in mm)

- *Sub size specimen:*

G: Gauge length: 25 + 0.08mm
W: Width: 6.25 + 0.05mm
T: Thickness: Thick of material plate
R: Radius of fillet: 6 mm
L: overall length: 100mm
A: Length of reduced section: 32mm
B; Length of grip section: 32mm
C: Width of grip section: 10mm

4.5 Tested plate and results

Fig- 11: Tested plate (All dimensions are in mm)

The process parameters selected were mainly tool rotational speed, welding speed and tool geometry etc. Tests are performed as per the ASTM Standards at TCR Advance Engineering at Vadodara. A machined specimen is placed in the testing machine and load is applied to measure the resistance of a Material. The result for tensile strength for sample specimen is shown in Table 6.

Table 6: Tensile strength of sample specimen

Sr no	Plate no	Force (KN)	Area (mm²)	Ultimate tensile strength (N/mm²)
1	P₂	15440	158.35	98
2	P₉	7640	163.11	47
3	P₁₀	5679	87.95	65
4	P₁₁	4420	98.57	45

Figure 12 shows the load vs displacement graph for varying thickness of plate on Tensile strength.
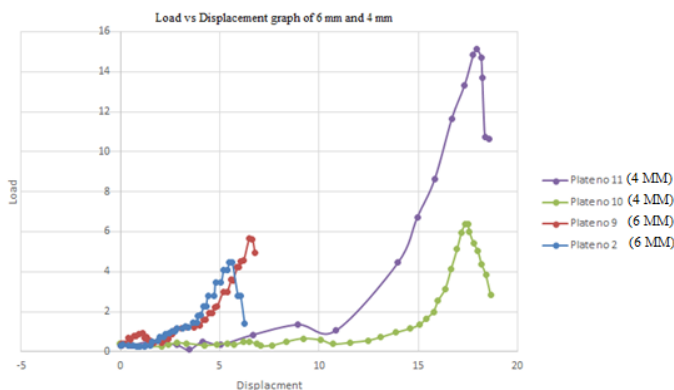
Fig-12: Tensile test graph (6 mm & 4 mm)

5. CONCULUSION

Important process parameters that control the quality of the weld are rotation speed (575 - 900 rpm) and traverse speed (3.16 - 8.16 mm/min) were performed to obtain defect free welded joints.

The following various conclusions summarize the present paper;

- From this investigation, it has been found that tool profile cylindrical tool, transvers speed 3.37 mm/min and rotational speed is 900 rpm produced good tensile strength.
- Mechanical properties of the joints increase with increase in tool rotational speed and reaches maximum at 500 to 575 rpm but again deceases with further increase in tool rotational speed.
- The heat input from the tool shoulder was assumed to be the frictional heat. The coefficient of friction was

continuously adjusted to keep the calculated temperature from exceeding the material melting point.

- Increase in pin length decreases penetration depth on the back side of welded plate. It is also observed that more than 6 mm thickness of work piece is possible to weld by friction stir welding butt. The condition is to design a different tool for different thickness. While designing tool, the tool tip length should be less than the thickness of the base material i.e less than 0.25 to 0.8 times of the base the material thickness.

REFERENCES

[1] Chunlin Dong (2009), "Microstructure and mechanical properties of friction stir welded joints in 2219-T6 Aluminum alloy", Materials and Design 30, page 3460–3467.

[2] Aritoshi, M., and Okita, K. 2002, "Friction welding of dissimilar metals" Journal of Japan Welding Society 71-6(2002): 432-436.

[3] Sakayama, T.; Naito, Y.; Miyazakki, Y.; Nose, T.; Murayma, G.; Saita, K.; Oikawa, H, "Dissimilar metal joining technologies for steel sheet and aluminum alloy sheet in auto body", Nippon Steel Tech. Rep. 2013, 103, 91–98.

[4] Nandan, R.; DebRoy, T.; Bhadeshia, H.K.D.H, "Recent advances in friction stir welding Process", weldment structure and properties. Prog. Mater. Sci. 2008, 53, 980–1023.

[5] Mishraa, R.S.; Ma, Z.Y, "Friction stir welding and processing"; Mater. Sci. Eng. 2005, 50, 1–78.

[6] Fujii, H.; Cui, L.; Maeda, M.; Nogi, K, "Effect of tool shape on mechanical properties and microstructure of friction stir welded aluminum alloys", Mater. Sci. Eng. 2006, 419, 25–31.

[7] R. Rai, A. De, H. K. D. H. Bhadeshia and T. DebRoy, "Review on friction stir welding tools, Science and Technology of Welding and Joining", (2011) VOL16 NO4 325.

[8] Y. N. Zhang, X. Cao, S. Larose and P. Wanjara, "Review of tools for friction stir welding and processing", Canadian Metallurgical Quarterly, (2012) VOL 51 NO 3.

[9] Akos Meilinger and Imre Torok, "The importance of friction stir welding tool", Production Processes and Systems, vol. 6. (2013) No. 1. pp. 25-34.

[10] Cerri, E.; Leo, P, "Influence of high temperature thermal treatment on grain stability and mechanical properties of medium strength aluminum alloy friction stir welds", J. Mater. Process. Technol. 2011, 213, 75–83.

[11] Reynolds A.P., Lockwood W.D., Seidel T.U. 2000. Processing - Property Correlation in Friction Stir Welds. Material Science Forum. 331-337. pp. 1719-1724.

[12] Frigaard Grong, Midling O.T. 1998, "Modeling of the Heat Flow Phenomena in Friction Stir Welding of Aluminum Alloys", Proceedings of the Seventh International Conference Joints in Aluminum-INALCO '98, Cambridge, UK, April 15-17. pp. 1189-1200.

[13] Chen C.M., Kovacevic R. 2003, "Finite Element Modeling of Friction Stir Welding-Thermal and Thermo-Mechanical Analysis", International Journal of Machine Tools and Manufacture. 43: 1319-1326.

[14] Colegrove P. A. and Shercliff H. R. 2003, "Experimental and Numerical Analysis of Aluminum Alloy 7075-T7351 Friction Stir Welds", Science and Technology of Welding and Joining. 8, 5, IoM Communications Ltd. pp. 360-368.

[15] Buffa G., Huaa J., Shivpuri R., Fratini L. 2006. "A continuum based FEM model for friction stir welding-model development", Journal of material science and engineering, A419. pp. 389-396.

[16] Chao Y.J. and Qi X. 1998, "Thermal and Thermo mechanical Analysis of Friction Stir Joining of AA6061-T6", Journal of Mat. Process and Manufacturing. Sci. pp. 215-233.

[17] Chao Y.J., Qi X., Tang W. 2003, Heat Transfer in Friction Stir Welding-Experimental and Numerical Studies. ASME J. Manuf. Sci. and Eng. 25: 138-145.

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