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PARAMETRIC STUDY AND FORCE ANALYSIS OF FRICTION STIR WELDED AA-6063 JOINT

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ABSTRACT:
Important process parameters for Friction stir welding which mainly affect the quality of weld are tool rotational speed, welding speed, torque and tool geometry. Tensile strength, hardness, impact strength, weld appearance are the important quality parameters for weld. A lot of efforts have been made to optimize the FSW parameters. However, researches on measurement of forces which are acting on base metal in process are carried by some researchers but still lot of research in the field of force measurement technique and effect of tool pin profile on forces and its corresponding effect on mechanical properties of friction stir welding of AA6063 alloy is required. It is found that measurement of forces carried out using various methods such as by using Kistler dynamic dynamometer and by using strain gauges is costly. An experimental set-up has been prepared to measure force acting during friction stir welding. The effect of various tool pin profile on force acting during friction stir welding has been recorded. The corresponding effect on tensile and impact strength has been analysed. Regression model for forces in horizontal and vertical dirction along with Tensile and impact strength has been developed.

KEYWORDS: Welding; FSW, FSP, Weld, Microstructure, Processing.

INTRODUCTION:
At a low-temperature range of the metals being connected, Friction Stir Welding occurs. In December 1991, Wayne Thomas at TWI (The Welding Institute) devised Friction Stir Welding (FSW), and the first patent applications were filed in the United Kingdom. FSW may be used to fabricate materials that would otherwise be impossible to weld. Also, aluminium alloy welding using different welding methods is plagued by difficulties such as porosity, hot cracking, and stress corrosion cracking (SCC).

Solid-state Friction Stir Welding does not require the melting of the components to fuse them together [2]. This paves the way for a new era of welding innovation. Using FSW makes it feasible to weld alloys that were previously regarded unweldable and different from each other.

It is used in FSW when two sheets or plates of material are joined by a cylindrical shouldered tool with a profiled pin that is rotated and plunged into the joint region. To keep the joint faces from being pushed apart, the pieces must be firmly fastened together. The weld line may be traversed by the wear-resistant welding tool thanks to frictional heat between the tool and the workpieces, which causes the latter to soften but not melt. The trailing edge of the tool pin is forged by close touch with the contact area and pin profile, where the plasticised material is transmitted. A solid-phase bond is formed between the two workpieces when they cool down.

Welding aluminium plates and sheets without filler material or shielding gas is possible using friction stir welding [5]. Welding without porosity or internal cavities is possible on materials with a thickness range from 0.5 to 65 mm.

When two sheet or material plate pieces are welded together using FSW, a cylindrical-shouldered tool, with a cylindrical/profiled, tapped/untapped, threaded/unthreaded probe (pin) is spun at a consistent speed and moved at a constant traverse rate in the joint line. To keep the abutting joint faces from being pushed apart and to sustain the strong plunging pressures provided by the FSW machine head, the components must be fastened tightly onto a backing plate. It's important that the tool shoulder is in direct touch with the workpiece. A tilt angle of 2-4 degrees is used to increase pressure beneath the tool shoulder while the probe is submerged in the workpiece.

Due to frictional energy dissipation, heat is being produced on both shoulders and the tool's pin/work piece contact surfaces as it spins and travels over the butting surface [4]. Temperatures rise as a result of this, resulting in the material next to these surfaces softening. During the process of moving over the butting surfaces, the tool deforms the thermally softened material in front of it, which is then transmitted to the region behind it, where it is compressed and forged into a joint or weld (fig 1). It is important to remember that FSW may be utilised for lap and T joints in addition to butt joining.

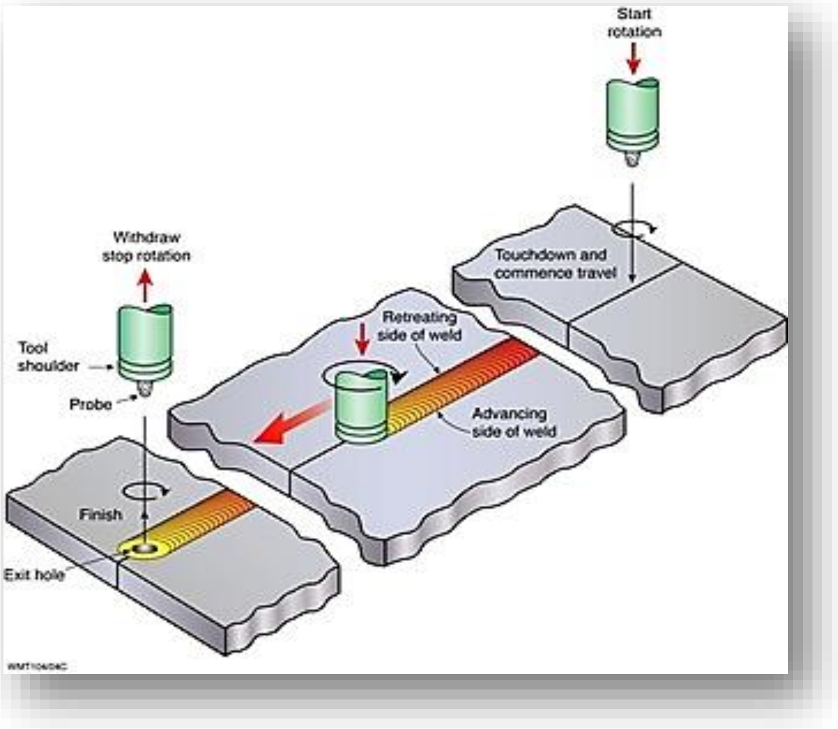


Figure1: Details of Friction Stir Welding Process

REVIEW OF LITERATURE:

The manufacturing industry has long been interested in this issue, and it has been extensively studied throughout the years. For example, tensile strength, microhardness, impact strength, surface roughness, and other mechanical qualities can be improved by adjusting process parameters. When it comes to weld qualities, this literature review focuses on force measuring methods and how different process factors (such as tool design or rotational speed) affect these attributes.

Researchers from SaeidAmini and colleagues (2015) examined the impact of pin position on tool shoulder during friction stir welding of aluminium 5083 [6]. An initial set-up, which included an abrasive tool, workpiece, and unique fixture, was carried out before the actual milling operation began. They used a tool with a pin coaxial with the axis of the tool shoulder to conduct a test, and the force in the joint region was measured as a result.

For thermoplastic sheets, Paoletti et al. (2015) studied the forces and torques generated during friction stir spot welding (FSSW) [3]. Measurements of tool and material temperatures were also made to better understand the FSSW process and its effect on the joint quality. Polycarbonate sheets were subjected to a series of tests.

Wang and colleagues gave Model-identification of axial force during robotic Friction Stir Welding (FSW) in 2015. Deformation of the robot is not negligible since the robot's intrinsic stiffness is insufficient for the enormous external force. They came up with two dynamic models of axial force based on the spindle axis positioning error and its rate of change.

Using Zhang et al. (2014)'s model for the computation of tool forces in FSW, they investigated how the tool design influences the temperature fields and tool forces along the welding direction. Temperature increases were shown to have a significant impact on the tool forces in FSW.

A rotating component dynamometer and a finite element model were used by D. Trimble et al. (2012) to study tool forces. Tool forces for different welding settings may be predicted using the model, indicating areas where tool failures are most likely to occur and identifying tool pin designs that can process the workpiece more effectively.

Several crucial features of FSW tools such as tool material selection, shape and load-bearing capabilities, processes of tool deterioration, and process economics were addressed by Rai et al (2011).

WELDING FORCES:

Forging forces are exerted on the plates to be welded by the tool's rotating and welding speeds during the FSW process [9] (Fig 2). Forces that include the thermal impact effect may cause the fixture and welded plates to distort, as well as wear out and break tools (Table 1). For this reason, the regulation of the force is essential for FSW and can have a significant impact on welding quality and productivity [7]. Benefits from maintaining a set welding force include:

• Developing better tool designs and clamp arrangements;

• Reducing complexity, size and power of machines and associated operational expenses while simultaneously improving productivity.

• Prevent tool breakage and limit excessive wear on both machineries as well as tools.

• Downward (axial) force (heat production, plastic flow, microstructure homogeneity, and mechanical characteristics) are all controlled by the downward force.

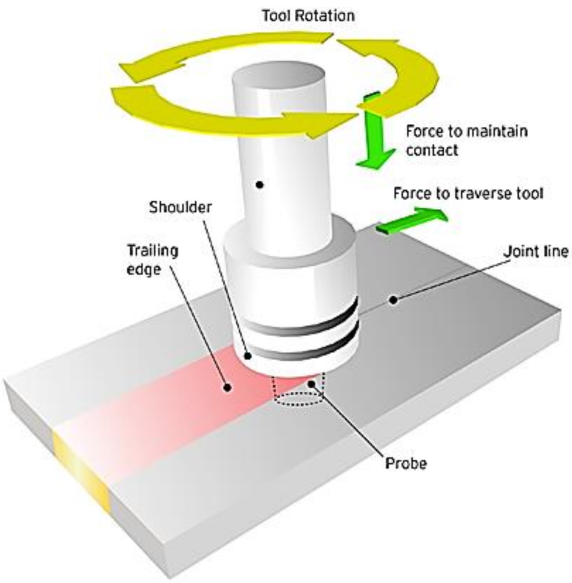


Figure 2: Welding Processes That Use Friction Stir

Force Sensor	Principle	s	Disadvantages
Spring	Hooke's Principle	Simple Rugged Good for static	Slow must also take into account the position of the vehicle.
The Crystals That Produce Piezoelectricity	Effect of piezoelectricity	Fast Unpowered	Static loads are not good. Fragile
Strain Gages	Change is resisted.	Cheap Available Easy to work with	Temperature sensitivity is really high.

Table 1: Force sensors used to measure force have both advantages and disadvantages that should be considered.

FSW TOOL DESIGN:

In order to have the best weld quality and the fastest feasible welding speed, the design of the tool is crucial. Figure 3 shows the two sections of the tool:

• Shoulder

• Pin.

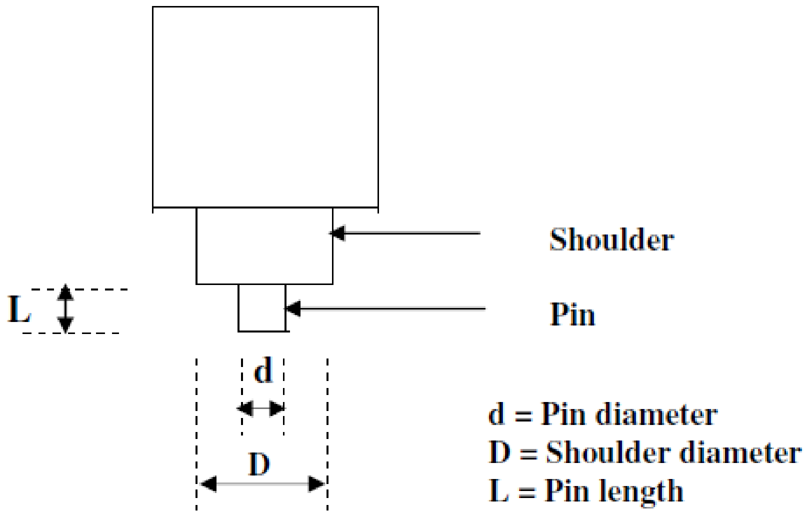


Figure 3: FSW Tool Dimensions

FSW research focuses mostly on the development of tool design. Effective tool design minimises the pressures necessary to push it through the material, hence decreasing energy costs and more critically permitting greater welding rates with reduced heat cycles [1]. It has also been found that several researchers have focused their attention on visualising the flow of materials around the FSW tool (2002). The movement of plastically deforming material from the front to the back of the FSW tool is well understood. In order to achieve ideal weld mechanical qualities, an effective tooling design must increase its usefulness. A comprehensive investigation of the influence of tool pin profile geometries on the FSW weld is thus required.

Therefore, in this study, we tested the tensile strength of welds using the following three instruments (Figure 4):

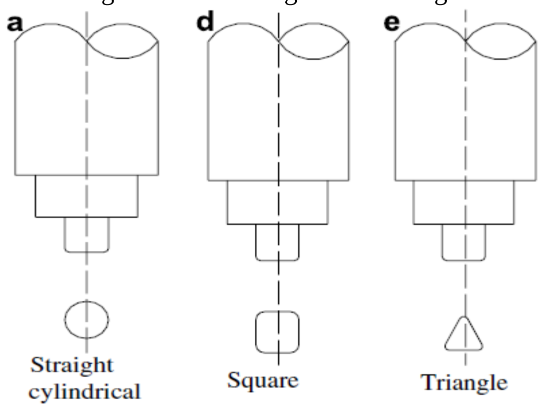


Figure 4: Tool Pin Profiles

The type of material to be welded dictates the type of tool to be used. To experiment, a high-speed steel tool was employed. According to our research, the thickness of the plate was a significant factor in determining pin length. To ensure that the needed amount of pressure is generated during welding, the shoulder-to-pin ratio was set at 3:1.

PERFORMANCE MEASURES:

For the current inquiry of FSW, the following performance measures or response variables are being studied:

- **Forces of Welding Applied in Both Directions**
- As part of the fixture design, a compression type load cell is used to monitor vertical forces required to keep the tool in place at or below the material surface.
- S-type load cells are used to measure the horizontal force, which is positive in the traverse direction and acts parallel to the tool motion. It is attached to the upper plate with a stopper plate that secures the plates that are to be welded in place.. The resistance of the material to the movement of the tool is what causes this force. Increasing the material temperature surrounding the tool will reduce this force.
- Forces that include the thermal impact effect may cause the fixture and welded plates to distort and wear out and break tools. For this reason, the regulation of the force is essential for FSW and can have a significant impact on welding quality and productivity [8].

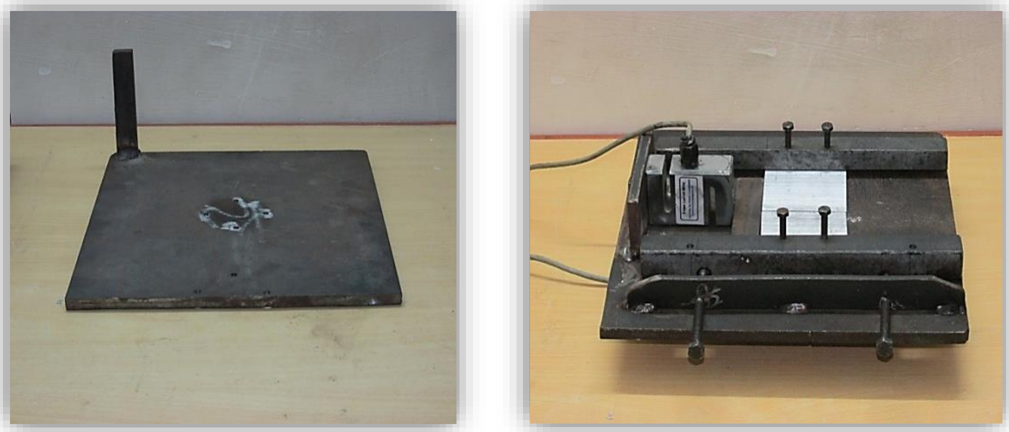
DESIGN OF FIXTURE

To carryout FSW operations on a milling machine, a proper fixture is required to hold the workpieces securely so that no gap forms between the plates during clamping, tool impinging and welding operation. It should also provide ease and safety of operation, with less setup time.

The developed fixture is highly useful for carrying out FSW operations in a vertical milling machine. The fixture has two main components, fabricated individually with all appropriate features. The various parts of the fixture shown in figure 4.6 are top plate, bottom plate.

The bottom plate shown in figure 5.6 (a) of the fixture is made up of mild steel of thickness 10 mm along with four holes at centre which is used to mount compression type load cell to measure vertical force generated by tool on plates during welding. Also one small plate is welded at corner of bottom plate which is used to prevent rotation of top plate along the axis of load cell during welding.

The top plate shown in figure 5.6 (b) of fixture is also made up of mild steel of 10mm thick which is provided with two rectangular bars, one is fixed while other one is movable which we can slide in slots to hold workpieces according to its dimensions. M16 bolts are provided on rectangular bars provided to apply vertical tightening force on welding plates to hold them tight.



(a) Bottom Plate (b) Top plate

Figure 5.6: Fixture Plates

At one end of plate, a 100×30 mm dimension plate is provided to hold S-type of load cell which is used to measure horizontal force and to arrest the linear movement of the workpiece along the direction of welding.

The complete assembly of the developed fixture is shown in Figure 5.7.The developed fixture holds the workpiece securely, without any gap formation between the interface, during tightening as well as during FSW operation. It does not allow the workpiece to move along the direction of tool travel, due to horizontal force, nor does it allow any misalignment of the workpieces. Most importantly, for similar products as in a batch or mass production process, there is no need to align the workpiece with respect to the tool every time before welding.

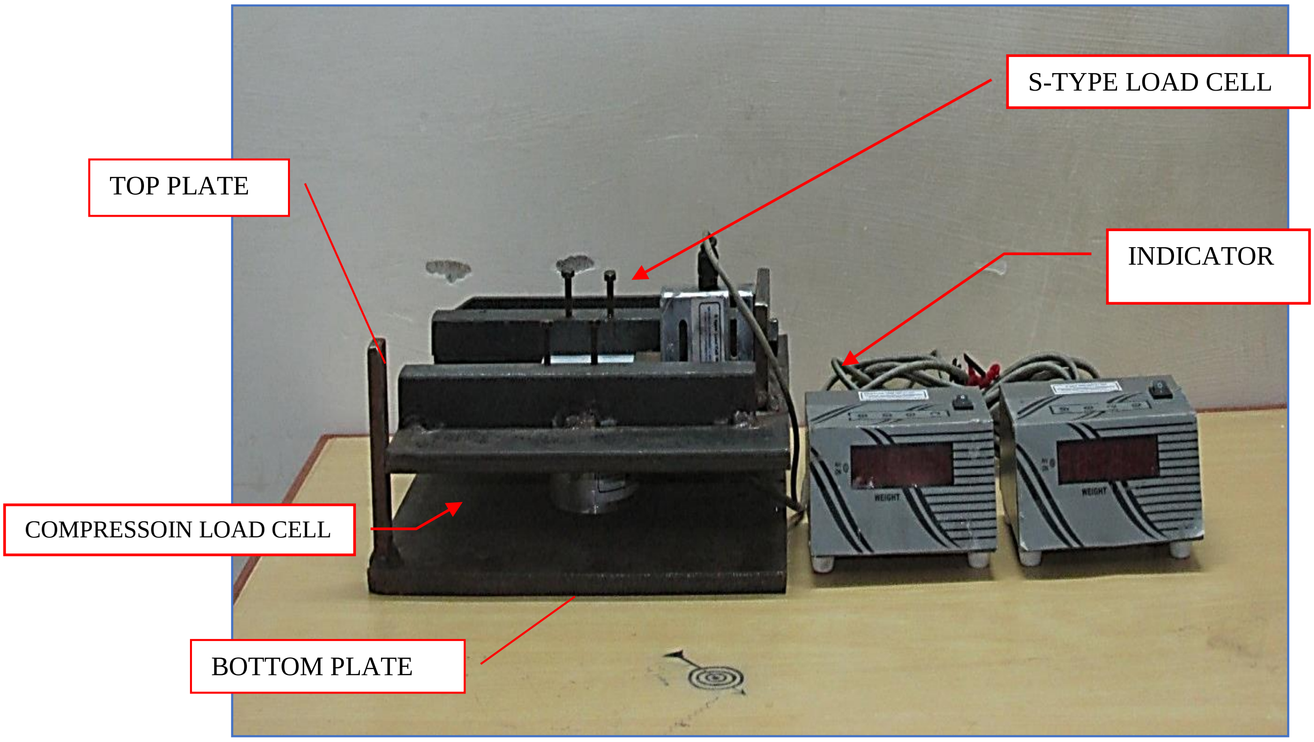


Figure 5.7: Force Measurement System Used For Experimental Study

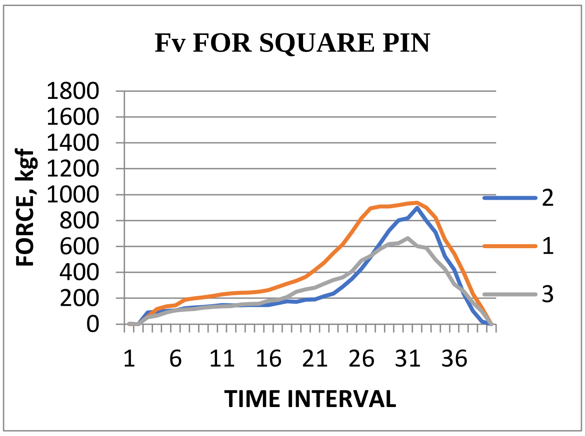
Once the tool movement is aligned with the joint line, it takes very little time for the next job, which will reduce the overall setup time.

ANALYSIS OF DATA

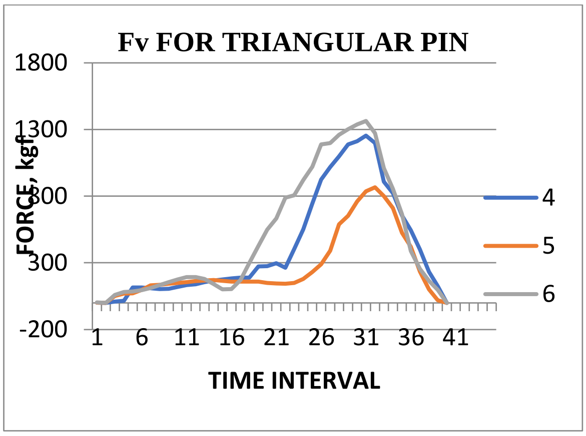
The effect of process parameters on the response characteristics under consideration have been discussed in this chapter. After completion of the trials according to the design matrix, the data of force obtained through indicator are plotted and organized. Total data for each weld is collected for 40 s. Figures 6.1 and 6.2 show the variation of vertical force and horizontal force with time for different tool pin profiles.

Figure 6.1 (a,b,c) shows the variation of vertical force with time. Vertical force increases steeply during plunging, indicating the softening of the material beneath FSW tool with heat generation. After complete plunging of pin, a sudden increase in force indicates the rubbing of tool shoulder with weld plate indicative of softening of material with heat generation. From the graphs it can be observed that vertical force during welding by square tool pin is less compare to the vertical force during welding by triangular and cylindrical tool pins.

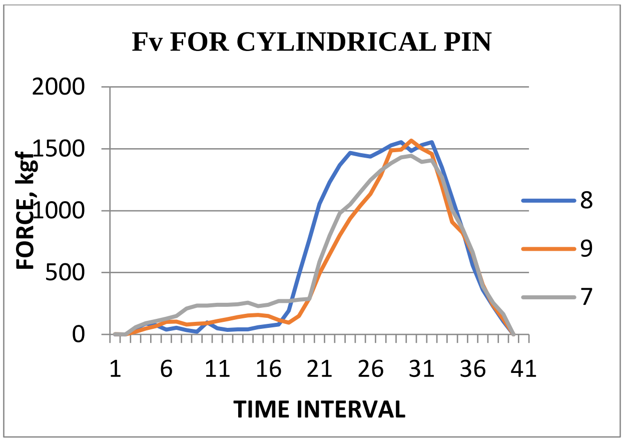
Figure 6.1 (d,e,f) shows the variations of horizontal force with respect to time. From the graphs it can be observed that horizontal force during welding by square tool pin is less compare to the horizontal force during welding by triangular and cylindrical tool pins.



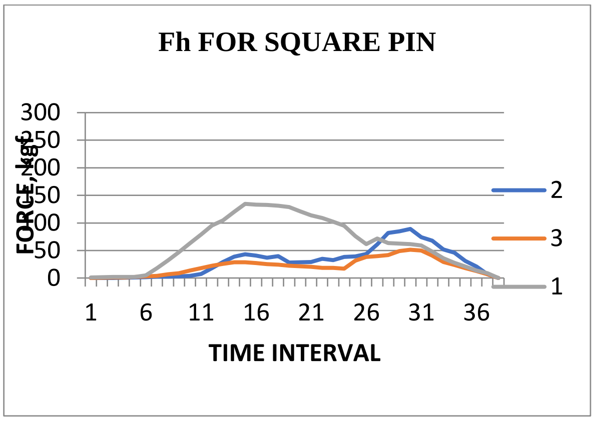
(a)



(b)



(c)



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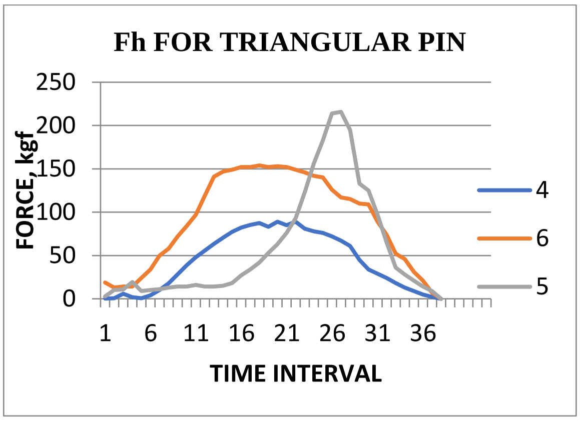
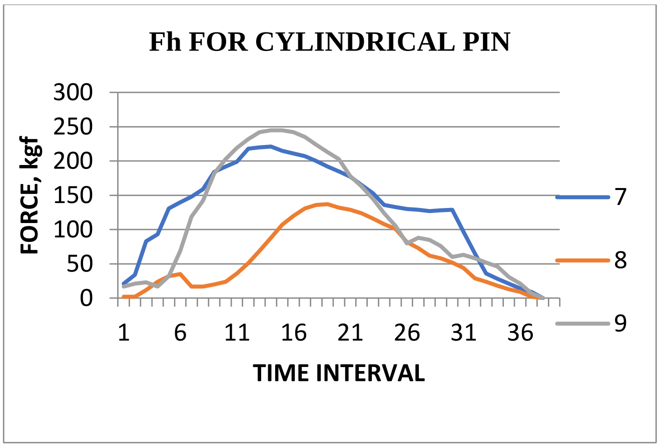
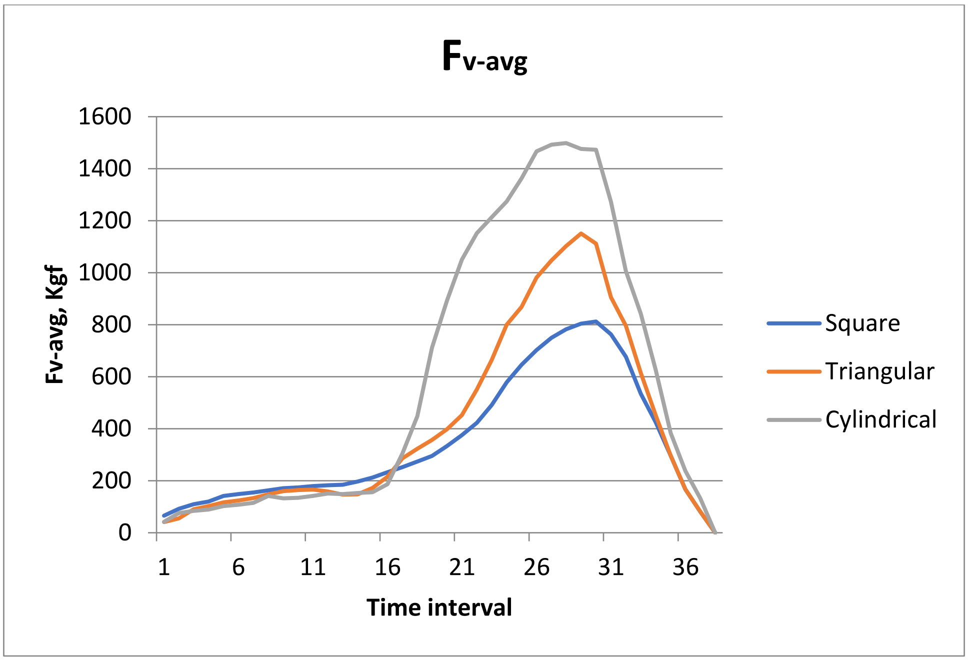


(e)

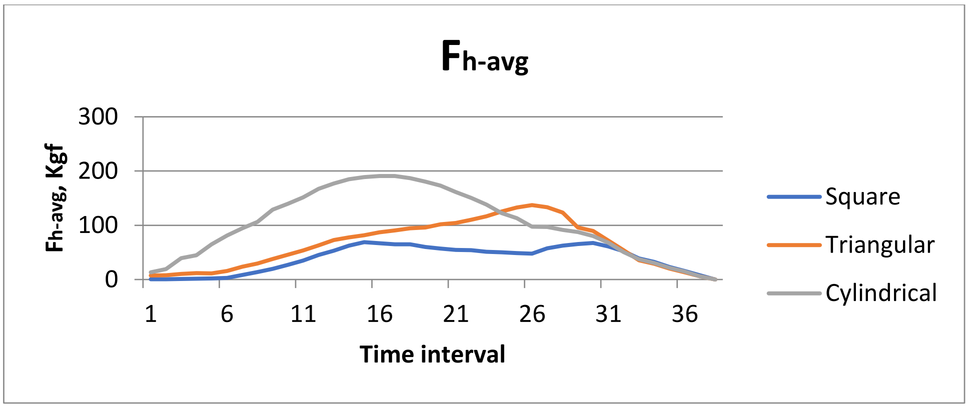


(f)

Figure 6.1: Variation of Vertical and Horizontal forces with time during welding.



(a)



(b)

Figure 6.2: Average Force Graphs for Vertical and Horizontal Force

Figure 6.2 shows graphs for average vertical and horizontal forces for square, triangular and cylindrical tool pin profiles. Graphs clearly show that square tool pin profile require minimum vertical and horizontal force.

The main effect i.e. the effect of process parameter on the response characteristics when they change from one level to another level are calculated and plotted as response curves. The response curves are the average value of the response and average S/N values versus level of process parameters. The response curves are used as aid to visualize the effect of process parameters on the selected performance measure (response) curves characteristics

Table 6.3: Experimental Results

Sr No.	A	B	C	$F_{vertical}$ (Kgf)	$F_{horizontal}$ (Kgf)	Tensile strngth (MPa)	Impact Strength (J)
	Tool Pin Profile	Tool Rotational Speed (rpm)	Welding Speed (mm/min0				
1	1	1000	30	730	56.6	132	38
2	1	1200	45	690	49	138	40
3	1	1400	60	549	132	128	33
4	2	1000	45	1002	86	113	26
5	2	1200	60	862	152.5	124	29
6	2	1400	30	1072	168.1	120	21
7	3	1000	60	1174	215	115	18
8	3	1200	30	1384	134	127	20
9	3	1400	45	1244	240.5	109	16

Table 6.4: S/N values for Response Parameters

Tool	S/N Fv	S/N Fh	S/N Tensile	S/N Impact
1	-57.2665	-57.2665	42.4115	31.5957
1	-55.5919	-55.5919	42.7976	32.0412
1	-58.5884	-58.5884	42.1442	30.3703
2	-59.5545	-59.5545	41.0616	28.2995
2	-58.0618	-58.0618	41.8684	29.2480
2	-60.2567	-60.1720	41.5836	26.4444
3	-61.4081	-61.4081	41.2140	25.1055
3	-60.8672	-60.8672	42.0761	26.0206
3	-62.0761	-62.1442	40.7485	24.0824

The equations in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. The equation in terms of actual factors is shown below

$$Fv = 697.9 + 305.5 A - 0.0342 B - 6.678 C$$

$$Fh = -233.6 + 58.6 A + 0.1525 B + 1.564 C$$

$$\text{Tensile Strength} = 147.6 - 7.83 A - 0.0025 B - 0.133 C$$

$$\text{Impact Strength} = 57.28 - 9.50 A - 0.01000 B + 0.0111 C$$

- **Tensile Strength**

The greatest stress that a weld can bear while being stretched or pushed before failing or breaking is known as the ultimate tensile (UTS) of a weld. Stress is calculated in terms of force applied for calculating tensile strength.

In the Welding Metallurgy lab of SLIET, LONGOWAL, tensile strength was measured using the Bi-00-201 "Plug 'n' Play" testing equipment depicted in figure 5. This mechanical testing system tests strength, fatigue, and fracturing in the 5 to 25 KN force range.

Figure 5: BI-00-201 TESTING SYSTEM

- **Impact strength**

It is possible to measure the material's capacity to withstand a sudden application of force by looking at its impact strength. Both the Izod impact strength test and the Charpy impact test evaluate how much energy it takes to shatter a sample in order to use this test method.

Figure 6: Pendulum Impact Testing Machine

The pendulum impact testing machine depicted in figure 6 was used to assess impact strength in the Metallurgy lab of SLIET, LONGOWAL.

RESULTS:

- **Assigning parameters to the orthogonal arrays:**

The three process parameters, each at three levels, have been selected for the current experiment. To get a realistic picture of the study's output parameters, it's best to have three minimums of process parameters. They have been renamed factors and are listed in the next column. Listed in Table 2 are all of the process parameters and variables.

Factors	Parameters	Levels		
		L1	L2	L3
A	Tool Pin Profile	Square	Triangular	Cylindrical
B	Tool Rotational Speed(rpm)	1000	1200	1400
C	Welding Speed(mm/min)	30	45	60

Table 2: Process Parameters and their Levels

In Taguchi parameter design, there are 18 conventional orthogonal arrays. Three layers of each of the three criteria were taken into account in this study. This is why the L9 (3^3) orthogonal array was chosen for multi-performance optimization in this study. Table 3 depicts the experimental design matrix.

Run	**Coded levels**			**Uncoded lecvels**		
Std.				**A**	**B**	**C**
No.	**A**	**B**	**C**	**Tool Pin Profile**	**Rotational Speed**	**Welding Speed**
1	**1**	**-1**	**-1**	**1**	**1000**	**30**
2	**1**	**0**	**0**	**1**	**1200**	**45**
3	**1**	**1**	**1**	**1**	**1400**	**60**
4	**1**	**-1**	**0**	**2**	**1000**	**45**
5	**1**	**0**	**1**	**2**	**1200**	**60**
6	**1**	**1**	**-1**	**2**	**1400**	**30**
7	**1**	**-1**	**1**	**3**	**1000**	**60**
8	**1**	**0**	**-1**	**3**	**1200**	**30**
9	**1**	**1**	**0**	**3**	**1400**	**45**

Table 3: Design matrix (3 parameter and 3 levels)

DISSCUSSION:

- **Effect of tool pin profile:**

For the most part, the non-consumable spinning tool pin is used for stirring and movement of the plasticized metal, which is necessary for an excellent connection. Material flow is regulated by the pin profile, which affects the welding velocity of the Fsw. Flat and threaded surfaces are common on pins with cylindrical plain or frustum tapered surfaces. Eccentricity is connected with flat pin profiles (square and triangular). Allows incompressible materials to travel around the pin profile as a result of this eccentricity. Dynamic orbits are connected to the rotational object's eccentricity. FSW uses a dynamic orbit, and the dynamic orbits for different pin profiles are shown in Table 4. The flow of plasticized material from the lead edge to the trailing edge of the spinning tool is determined by the connection between the static volume and dynamic volume. 1.56 for square and 2.3 for triangular pin shapes have a ratio of 1 to 1.

To add to this effect, a pulsing stirring motion is created by the flat faces of the triangular and square pin shapes. A tool with a square pin profile generates 80 pulses per second, while a tool with a triangle pin profile generates 60 pulses per second (Table 4). When using cylindrical pin profiles, the pulsing action is absent. Increased stirring activity in the stir zone of square pin shaped tools generates a finer microstructure with evenly dispersed precipitates, which results in a higher strength and hardness of the finished product. Without this pulsing motion, the plasticized material is permitted to extrude on the sides of a straight or other pin shape without flat faces, resulting in inferior strength.

Flow patterns and the thicknesses of deformed aluminium lamellae are significantly dependent on the tool geometry, welding temperature, and axial force, which in turn affects the amount of material mixing and inter-diffusion. When the weld temperature rises, material flow stress decreases, resulting in a difference in measured forces.

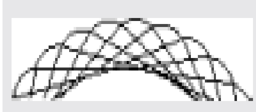
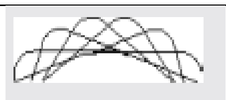
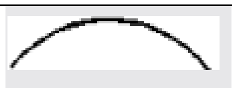
Pin Profile	Portion Of Dynamic orbit	No. of Pulses per Second (no. of faces * rotational speed, 20 rps)
Square		80
Triangular		60
Cylindrical		0

Table 4: Result of pin profile on dynamic orbit and pulsating action

- **Welding speeds have an impact on the rotational speed:**

Faulty tensile characteristics were caused by a lack of friction stir during the friction stir processing zone due to decreased rotating speeds and greater welding speeds. Slower cooling rates in the weld zone caused grain development as a result of greater rotating speeds and lower welding speeds. Using a square pin shaped tool with a welding speed of 30mm/min and a rotating speed of 1200 rpm, a junction with improved tensile qualities was created. The rotating speed affects the amount of shoulder force applied at a certain point in time. The initial axial force decreased as the rotating speed increased over time.

CONCLUSION:

With the help of nine experimental trials, we investigated the influence of input parameters (tool pin profile and rotational speeds and welding speeds) on the response parameters of AA-6063 aluminium alloy during friction stir welding (FSW). Analysis of input factors' effects on response parameters has been carried out using the Taguchi based design. The study's most important findings are presented in the following paragraphs:

- One of the advantages of the new fixture is that it's easy to operate and cost-effective. Holding the workpieces in place without gaps, it measures vertical and horizontal forces with precision.
- It is possible to anticipate the reactions of a given factor at a certain level by using the formulas in terms of the actual factors.
- According to the Taguchi approach, the tool pin profile seems to be the most significant element for all response characteristics.
- The square pin-shaped tool produces good quality, high strength welds that need the least amount of vertical and horizontal force, regardless of welding speed and rotating speed, among the three-pin profiles employed in this experiment to create the joints.
- It was found that joints made at the highest tool rotational speed, 1200 rpm, had greater tensile and impact strength, requiring less horizontal force to construct.
- The joints formed at 60 mm/min welding speed had the best characteristics of the three welding speeds tested.

REFERENCES:

1. X. Z. X. Zhao, P. Kalya, R. G. Landers, and K. Krishnamurthy, “Design and Implementation of a Nonlinear Axial Force Controller for Friction Stir Welding Processes,” *2007 Am. Control Conf.*, pp. 5553–5558, 2007.
2. K. Kumar and S. V. Kailas, “On the role of axial load and the effect of interface position on the tensile strength of a friction stir welded aluminium alloy,” *Mater. Des.*, vol. 29, no. 4, pp. 791–797, 2008.
3. A. M. Eramah, M. P. Rakin, D. M. Veljic??, S. S. Tadic??, N. A. Radovic??, M. M. Zrilic, and M. M. Perovic??, “Influence of friction stir welding parameters on properties of 2024 T3 aluminium alloy joints,” *Therm. Sci.*, vol. 18, no. December 1991, pp. S21–S28, 2014.
4. W. R. Longhurst, A. M. Strauss, G. E. Cook, and P. A. Fleming, “Torque control of friction stir welding for manufacturing and automation,” *Int. J. Adv. Manuf. Technol.*, vol. 51, no. 9–12, pp. 905–913, 2010.
5. G. Singh, K. Singh, and J. Singh, “Effect of process parameters on microstructure and mechanical properties in friction stir welding of aluminum alloy,” *Trans. Indian Inst. Met.*, vol. 64, no. 4–5, pp. 325–330, 2011.
6. A. Astarita, A. Squillace, and L. Carrino, “Experimental Study of the Forces Acting on the Tool in the Friction-Stir Welding of AA 2024 T3 Sheets,” *J. Mater. Eng. Perform.*, vol. 23, no. 10, pp. 3754–3761, 2014.
7. K. W. F. L. G. Abba, “Dynamic Model Identification of Axial Force in Robotic Friction Stir Welding ⋆,” *15th IFAC Symp. Inf. Control Manuf.*, pp. 2010–2015, 2015.

8. C. B. Smith, W. Crusan, J. R. Hootman, J. F. Hinrichs, R. J. Heideman, and J. S. Noruk, "Friction stir welding in the automotive industry," *2001 TMS Annu. Meet. Automot. Alloy. Join. Alum. Symp. (Aluminum 2001)*, pp. 175–185, 2001.
9. A. Paoletti, F. Lambiase, and A. Di Ilio, "Analysis of forces and temperatures in friction spot stir welding of thermoplastic polymers," *Int. J. Adv. Manuf. Technol.*, vol. 83, no. 5–8, pp. 1395–1407, 2016.