

To Design and Construct a Friction Welding Attachment on Lathe, Conduct Experiment and to Study about Mechanical Behavior of Friction Welded Joints of Aluminum Rods

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Abstract— Friction Welding (FW) is a process of solid state joining which is used extensively in recent years, due to its advantages such as low heat input, production efficiency, ease of manufacture and environment friendliness. Friction welding can be used to join different types of ferrous metals and non-ferrous metals, which are not easy to be welded by traditional fusion welding processes. The process parameters such as friction pressure, friction time, forging pressure, forging time, and rotating speed play the major roles in determining the strength of the joints. The main objective of this investigation was to apply friction welding for joining of 10mm diameter aluminium 6063 similar joints in lathe. In the present study, an experimental friction welding setup was designed, in which continuous drive friction welding is used. Trial experiments were conducted to determine the working range. The parameters were chosen in such a way that the friction welded joints should be free from any visible external defects. In the second part of the study, the effect of welding parameters on welding strengths was investigated. Later the mechanical properties of joints were examined by using tensile test, SEM analysis, macro and micro structure analysis and Rockwell hardness test.

Keywords— Component; Formatting; Style; Styling; Insert

1. 1. INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position.

1.1. Different Type of Welding Processes

Based on the heat source used welding processes can be categorized as follows:

1.1.1. Arc Welding:

In arc welding process an electric power supply is used to produce an arc between electrode and the work-piece material to joint, so that work-piece metals melt at the interface and welding could be done. Power supply for arc welding process could be AC or DC type. The electrode used for arc welding could be consumable or non-consumable. For non-consumable electrode, an external filler material could be used.

1.1.2. Gas Welding:

In gas welding process a focused high temperature flame produced by combustion of gas or gas mixture is used to melt the work pieces to be joined. An external filler material is used for proper welding. Most common type gas welding process is Oxyacetylene gas welding where acetylene and oxygen react and producing some heat.

1.1.3. Resistance Welding:

In resistance welding heat is generated due to passing of high amount current (1000 –100000A) through the resistance caused by the contact between two metal surfaces. Most common types resistance welding is Spot-welding, where a pointed electrode is used. Continuous type spot resistance welding can be used for seam-welding where a wheel-shaped electrode is used.

1.1.4. High Energy Beam Welding:

In this type of welding a focused energy beam with high intensity such as Laser beam or electron beam is used to melt the work pieces and join them together. These types of welding mainly used for precision welding or welding of advanced material or sometimes welding of dissimilar materials, which is not possible by conventional welding process.

1.1.5. Solid-State Welding:

Solid-state welding processes do not involve melting of the work piece materials to be joined. Common types of solid-state welding are ultrasonic welding, explosion welding,

electromagnetic pulse welding, friction welding, friction-stir-welding etc.

Solid-State Welding:

Solid state welding is a group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing filler metal.

- 1.1.5.1. Cold welding (CW) is a solid-state welding process which uses pressure at room temperature to produce coalescence of metals with substantial deformation at the weld. Welding is accomplished by using extremely high pressures on extremely clean interfacing materials. Sufficiently high pressure can be obtained with simple hand tools when extremely thin materials are being joined. When cold welding heavier sections a press is usually required to exert sufficient pressure to make a successful weld.
- 1.1.5.2. Diffusion welding (DFW) is a solid-state welding process which produces coalescence of the faying surfaces by the application of pressure and elevated temperatures. The process does not involve microscopic deformation melting or relative motion of the parts. Filler metal may or may not be used. This may be in the form of electroplated surfaces. The process is used for joining refractory metals at temperatures that do not affect their metallurgical properties. Heating is usually accomplished by induction, resistance, or furnace. Atmosphere and vacuum furnaces are used and for most refractory metals a protective inert atmosphere is desirable.
- 1.1.5.3. Explosion welding (EXW) is a solid-state welding process in which coalescence is effected by high-velocity movement together of the parts to be joined produced by a controlled detonation. Even though heat is not applied in making an explosion weld it appears that the metal at the interface is molten during welding. This heat comes from several sources, from the shock wave associated with impact and from the energy expended in collision. Heat is also released by plastic deformation associated with jetting and ripples formation at the interface between the parts being welded. Plastic interaction between the metal surfaces is especially pronounced when surface jetting occurs. It is found necessary to allow the metal to flow plastically in order to provide a quality weld.
- 1.1.5.4. Forge welding (FOW) is a solid-state welding process which produces coalescence of metals by heating them in a forge and by applying pressure or blows sufficient to cause permanent deformation at the interface. This is one of the older welding processes and at one time was called hammer welding. Forge welds made by blacksmiths were made by heating the parts to be joined to a red heat considerably below the molten temperature. Normal practice was to apply flux to the interface. The blacksmith by skillful use of a

hammer and an anvil was able to create pressure at the faying surfaces sufficient to cause coalescence. This process is of minor industrial significance today.

- 1.1.5.5. Friction welding (FRW) is a solid-state welding process which produces coalescence of materials by the heat obtained from mechanically-induced sliding motion between rubbing surfaces. The work parts are held together under pressure. This process usually involves the rotating of one part against another to generate frictional heat at the junction. When a suitable high temperature has been reached, rotational motion ceases and additional pressure is applied and coalescence occurs.
- 1.1.5.6. Hot pressure welding (HPW) is a solid-state welding process which produces coalescence of materials with heat and the application of pressure sufficient to produce macro-deformation of the base metal. In this process coalescence occurs at the interface between the parts because of pressure and heat which is accompanied by noticeable deformation. The deformation of the surface cracks the surface oxide film and increases the areas of clean metal. Welding this metal to the clean metal of the abutting part is accomplished by diffusion across the interface so that coalescence of the faying surface occurs. This type of operation is normally carried on in closed chambers where vacuum or a shielding medium may be used. It is used primarily in the production of weldments for the aerospace industry. A variation is the hot isostatic pressure welding method. In this case, the pressure is applied by means of a hot inert gas in a pressure vessel.
- 1.1.5.7. Roll welding (ROW) is a solid-state welding process which produces coalescence of metals by heating and by applying pressure with rolls sufficient to cause deformation at the faying surfaces. This process is similar to forge welding except that pressure is applied by means of rolls rather than by means of hammer blows. Coalescence occurs at the interface between the two parts by means of diffusion at the faying surfaces.
- 1.1.5.8. Ultrasonic welding (USW) is a solid-state welding process which produces coalescence by the local application of high-frequency vibratory energy as the work parts are held together under pressure. Welding occurs when the ultrasonic tip or electrode, the energy coupling device, is clamped against the work pieces and is made to oscillate in a plane parallel to the weld interface. The combined clamping pressure and oscillating forces introduce dynamic stresses in the base metal. This produces minute deformations which create a moderate temperature rise in the base metal at the weld zone. This coupled with the clamping pressure provides for coalescence across the interface to produce the weld.

Ultrasonic energy will aid in cleaning the weld area by breaking up oxide films and causing them to be carried away.

1.2. Basic Mechanism of Friction Welding

Friction welding is a solid-state welding process. It makes use of frictional heat generated at the rubbing surfaces to raise the temperature at the interface high enough to cause the two surfaces to be forged together under high pressure. In the process, heat is generated by conversion of mechanical energy into thermal energy at the interfaces of the components during rotation under pressure without any energy from environment. Friction pressure, friction time, forging pressure, forging time and rotating speed are the most important parameters in friction welding. The parameters have to be selected properly in the experiments since these directly affect welded quality. Aluminum alloy strength must be adequate to resist denting at a thickness which offers cost effective weight savings over steel. Body structural components must be made from materials which absorb energy and fail gracefully during a crash. Designers of aircraft desire materials which will allow them to design lightweight, cost effective structures which have the performance characteristics of durability and damage tolerance. Increase in fuel economy because of lighter weight structure.

1.2.1. Types of Welding Current Used in Friction Welding

1.1.1.1. Rotary Friction Welding Process

Friction welding process is classified by the American Welding Society (AWS) as a solid state joining process in which bonding is produced at temperatures lower than the melting point of the base materials. All heating responsible by the union is mechanically generated by friction between the parts to be welded. This heating occurs due one part that is fixed, be pressed on the other that is in high rotation. The friction between the surfaces makes possible a rapid temperature rise in the bonding interface, causing the mass to deform plastically and flows depending on the application of pressure and centrifugal force, creating a flash. With this flash, impurities and oxides are removed from the surface, promoting the creation of a surface with excellent physical and chemical adhesion. The increase of temperature in the bonding interface and the application of pressure on that surface originate the diffusion between the two materials, and hence their union.

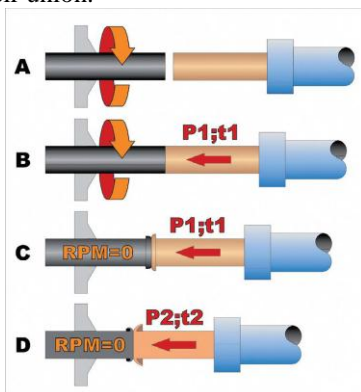


Figure 1.1: Phases of conventional friction welding process. (A) Period of approximation; (B) P1, t1 application; (C) end of

P1, t1 application, and braking of the machine (RPM = 0); (D) P2, t2 application and finish welding.

1.1.1.2. Linear Friction Welding

Linear friction welding (LFW) is similar to spin welding except that the moving chuck oscillates laterally instead of spinning. The speeds are much lower in general, which requires the pieces to be kept under pressure at all times. This also requires the parts to have a high shear strength. Linear friction welding requires more complex machinery than spin welding, but has the advantage that parts of any shape can be joined, as opposed to parts with a circular meeting point. Another advantage is that in most instances quality of joint is better than that obtained using rotating technique.

1.1.1.3. Friction Surfacing

Friction surfacing is a process derived from friction welding where a coating material is applied to a substrate. A rod composed of the coating material (called an mechtrode) is rotated under pressure, generating a plasticized layer in the rod at the interface with the substrate. By moving a substrate across the face of the rotating rod a plasticized layer is deposited between 0.22.5 millimeters (0.00790.0984 in) thick depending on mechtrode diameter and coating material.

1.3. Advantages of Friction Welding

- Enables joining of dissimilar materials normally not compatible for welding by other joining methods.
- Creates narrow, heat-affected zone.
- Consistent and repetitive process of complete metal fusion.
- Joint preparation is minimal saw cut surface used most commonly.
- Faster Turn-around Times compared to the long lead time of forgings, which are currently 6 months or longer.
- Greatly increases design flexibility choose appropriate material for each area of a blank.
- Suitable for diverse quantities from single prototypes to high-volume production.
- No fluxes, filler material, or gases required.
- Environmentally friendly process no fumes, gases, or smoke generated.

2. DESIGN AND FABRICATION

2.1 Basic Principle of Friction Welding

Traditionally, friction welding is carried out by moving one component relative to the other along a common interface, while applying a compressive force across the joint. The friction heating generated at the interface softens both components, and when they become plasticized the interface material is extruded out of the edges of the joint so that clean material from each component is left along the original interface. The relative motion is then stopped, and a higher final compressive force may be applied before the joint is allowed to cool. The key to friction welding is that no molten material is generated, the weld being formed in the solid state.

The principle of this process is the changing of mechanical energy into heat energy. One component is gripped and rotated

about its axis while the other component to be welded to it is gripped and does not rotate but can be moved axially to make contact with the rotating component. At a point fusion temperature is reached, then rotation is stopped and forging pressure is applied. Then heat is generated due to friction and is concentrated and localized at the interface, grain structure is refined by hot work. Then welding is done, but there will not occur the melting of parent metal.

Briefly the friction-welding process consists in bringing into contact two elements to be welded while one of the two is static and the other is rotated rapidly on its axis. As the soon as the heat generated by attrition at the interface is sufficient for solid state welding without melting, the rotation is stopped and the elements are forced together under pressure producing local forging which concludes the intimate joining and also expels at the joint all surface contamination and some of the upset material called flash.

In friction welding one component is rotated and one component is held stationary. The part that is rotated is brought into contact with the stationary component and when enough heat has been generated to bring the components to a plastic state and the desired burn off has been achieved, rotation is stopped. More axial force is then applied between the two components resulting in a solid-state bond at the interface forming friction welded joint.

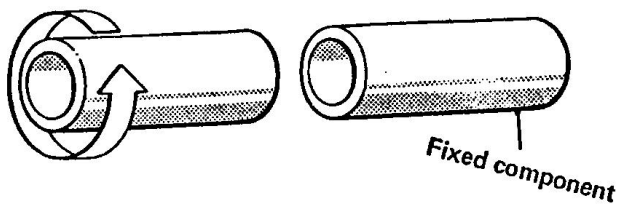


Figure 2.1: One component rotated rapidly, the other is stationary.

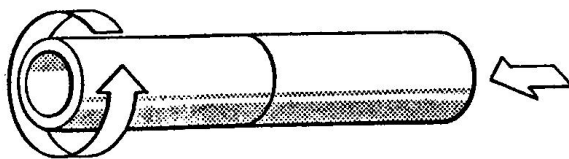


Figure 2.2: Rotating and stationary components brought together into contact and force applied.

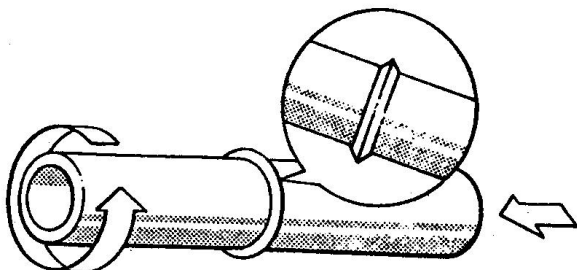


Figure 2.3: Axial force is increased to bring components into a plastic state at interface.

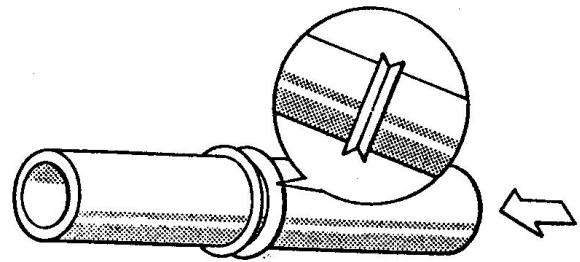


Figure 2.4: Rotation is stopped and more axial force is applied.

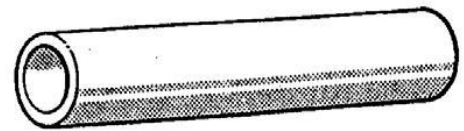


Figure 2.5: Result - A full cross sectional weld in the parent.

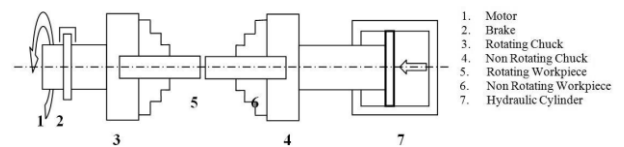
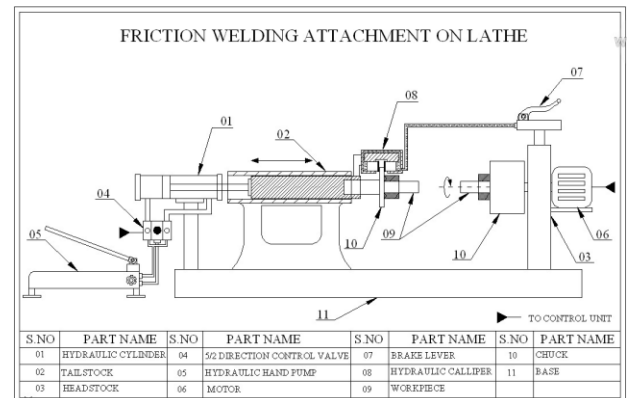


Figure 3.6: Layout.

3 DESIGN AND COMPONENTS



3.1.1 Components

3.1.1.1 Hydraulic Cylinder

- It is made up of cast iron.
- Used to pressurize the fluid.

3.1.1.2 Tail Stock

- It acts as the base of the attachment.
- Drill chuck, Disc plate, and Hydraulic cylinder are mounted on tail stock.
- Made up of cast iron, having centre height of 175mm from the lathe bed.

3.1.1.3 Hydraulic Brake

- Caliper type disc brake is used.
- The purpose is to keep the work piece stationary.
- Specifications
 - Brake fluid: Dot 3
 - Disc plate: 100mm diameter, Stainless steel

- 3.1.1.4 Hydraulic Hand Pump
 - It is employed for applying axial pressure on the work piece.
 - To pump fluid from reservoir to hydraulic cylinder, so that the required pressure can be achieved.
- 3.1.1.5 Pressure Gauge
 - The purpose of pressure gauge is to indicate the axial pressure.
 - Specification
 - Type: Bourdon tube pressure gauge
 - Range: 0-40 kg/cm²
- 3.1.1.6 Direction Control Valve
 - To control the flow in single direction.
- 3.1.1.7 Drill Chuck
 - To hold the stationary work piece.

3.2 Experimental Setup

- 3.2.1 Lathe Specification
 - Centre height: 175 mm.
 - Swing diameter over bed: 350 mm.
 - Maximum speed: 750 RPM.
 - Distance between centers: 680 mm.
 - Drive: Belt drive.
- 3.2.2 Chemical Composition of Aluminum 6063

COMPONENT	WEIGHT %
Aluminium	97.5
Chromium	0.1
Copper	0.1
Iron	0.35
Magnesium	0.45 - 0.9
Manganese	0.1
Silicon	0.2 - 0.6
Titanium	0.1
Zinc	0.1
Others	0.15

Table 2.1: Chemical composition of aluminum6063

3.3 Working

Fix the friction welding attachment on the lathe. Ensure that the tail stock will not move backwards while applying the friction and forge pressures. Hold the 10mm diameter Aluminum work piece on both the chucks. To avoid the vibrations, length of the work piece extending from both the chucks minimized as possible. Make sure that both the work piece should be in contact with in the stroke length of hydraulic piston. Drill chuck is kept stationary under the application of hydraulic brake. Switch on the lathe and allow the lathe chuck to rotate at desired speed. Apply initial axial pressure by using hydraulic pump, to make both the work piece in contact. Before

pumping we have to ensure that sufficient amount hydraulic fluid (2T oil) in the oil sump and priming has to done to avoid air bubbles in the oil.

Then apply friction pressure in desired friction time. Friction pressure and friction time are predetermined values. For example, at a speed of 1400 RPM and friction pressure 65 MPa, friction time is 3 seconds. As friction pressure increases, friction time also increases as 5 seconds, 7 seconds for 104 MPa and 156 MPa friction pressure.

After desired heat generated, switch off the lathe to decrease the rotational speed and apply upset pressure in upset time. At this time as the welding progresses release the hydraulic brake, then allow the weld joint to cool down.

4 TESTING

4.1 Hardness Testing

Rockwell hardness testing was done to measure the variation in hardness across the weld zones of aluminium joints. A minor load of 10 kg is first applied, which causes an initial penetration and holds the indenter in place. Then, the dial is set to zero and the major load of 90 kg is applied. Upon removal of the major load, the depth reading is taken while the minor load is still on. The hardness number may then be read directly from the scale. Location1 (Loc1) is at the center of the weld (for welded pieces) or 2mm away from the end which is tried to be welded (for pieces which couldn't be welded) Loc2 is 5mm away from the Loc1 and Loc3 is 10mm away from the Loc1. The experimental results are shown in Table 3.1

Speed	Scale Used	Indenter Used	Minor Load (kg)	Major Load (kg)	RHN		
					Loc 1	Loc 2	Loc 3
600	B	1/6 ball	10	90	13	12	11
1000	B	1/6 ball	10	90	19	17	16
1400	B	1/6 ball	10	90	19	17	16

Table 3.1: Experiment result of hardness test

As speed is increases hardness strength increases up to a certain level and attains saturation, there after decreases on further increase of speed.

4.2 Tensile Testing

To know the breaking load and breaking stress tensile test has done on the rotary welded specimens at different rotational speeds. Breaking load test is only conducted for the specimen which is perfectly welded during friction welding experimentation. The experimental results are shown in Table 3.2

Speed	Dia	Breaking Load (kg)	Breaking Stress (MPa)
600	10	1300	162.37
1000	10	1600	199.84
1400	10	1590	198.6

Table 3.2: Experiment result of tensile test

The stress is calculated using above equation.

$$S = (P \times g) \div (\pi D^2 / 4)$$

As speed is increases breaking strength increases up to a certain level and attains saturation, there after decreases on further increase of speed.

4.3 Dye Penetrant Inspection

A clean surface is essential for successful dye penetrant inspection. The surface to be examined and adjacent area should be free of such contaminants as ultrasonic couplants, welding flux, weld spatter, scale, rust, paint, oil and grease.

Spray dye penetrant (SKL-SP1) on a clean, completely dry surface. Let it remain for 5 minutes or more. If especially tight cracks are suspected, if there is reason to believe defects are contaminated and not free of soil, or if the substrate is cold (below 600F), the dye penetrant should dwell on the surface for a longer time.

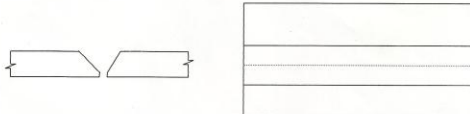

LIQUID PENETRANT TESTING SPECIMENS RECORD OF DISCONTINUITY LOCATIONS						
Specimen Master Reference Number:	-					
Specimen Length:	PCN Weld Group Ref:					
Joint Type & Configuration:						
Equipment Used:	Portable Penetrant Kit:					
Reference Block Type:						
Type of Penetrant Used:	SKL-SP1	White Light Intensity:	600 lux			
Dwell Time Used:	9 min	Black Light Intensity:				
Type of Developer Used:	SKD-52					
Developing Time:	9 min					
Operator -	1					
Reflector Location Sketches: (Use additional Sheets if required)						
						
SUMMARY OF REFLECTORS' (DEFECTS) LOCATION						
Sl. No.	Distance from '0'	Type	Length	Location	Orientation	Note *
1.					Centreline	Center
2.					Porosity	Center
Remarks: Two defects noted.						
Tested By	Signature		Date			
						

Figure 3.1: Result of Dye penetrant test.

Dye penetrant is removed from the inspection surface by manually wiping with a towel or cloth. First, wipe the surface with a clean, dry cloth or towel to remove the majority of the surface dye penetrant. Smooth surfaces may wipe clean with a dry cloth and may not require further processing. Remove any remaining surface dye penetrant film with a towel pre-moistened by spraying with Cleaner/Remover. The result of dye penetrant inspection is shown in fig 3.1.

4.4 SEM Analysis

To confirm the visual inspection of failure, the fracture analysis was done. For that scanning electron microscope (SEM) of JEOL model No. JSM-6610LV. The SEM analyses were carried out to show the fracture behavior of tensile test which justifies the visual inspection results of brittle and ductile failures. The magnified images were captured at the fractured locations taken at 100x, 500x and 1000x magnification. The effect of tensile strength has been observed on the fractured surface appearance. It is observed from the SEM fractography images Fig.3.1 is less dimpled pattern. This is may be due to dimples associated with high ductility because the material is softened due to coarsening and dissolution of precipitates constituent particles presented in alloys. Coarsening occurred by heat generated force followed by air cooling. The ductile fracture mechanism is normally identified by dimples. The brittle fracture mechanism is identified by a relatively featureless fracture surface that may include cleavage.

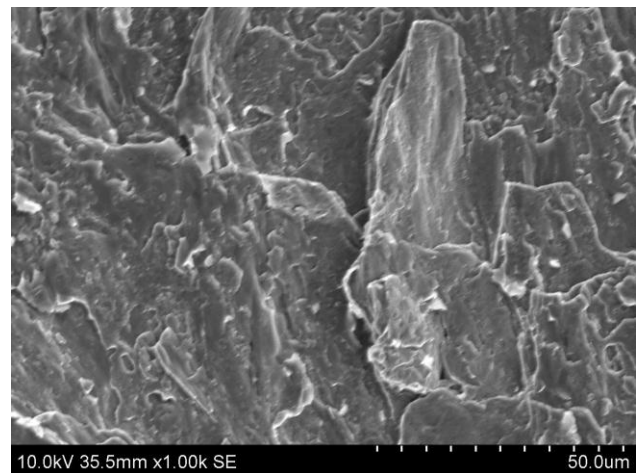


Figure 3.2: Friction welded similar joints of aluminium rods at 1000x magnification.

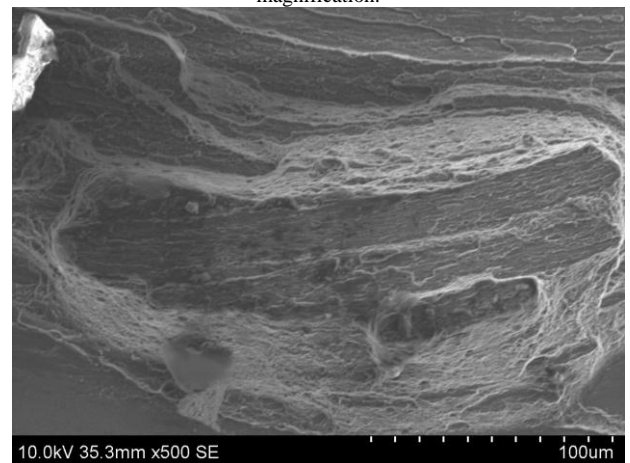


Figure 3.3: Friction welded similar joints of aluminium rods at 500x magnification.

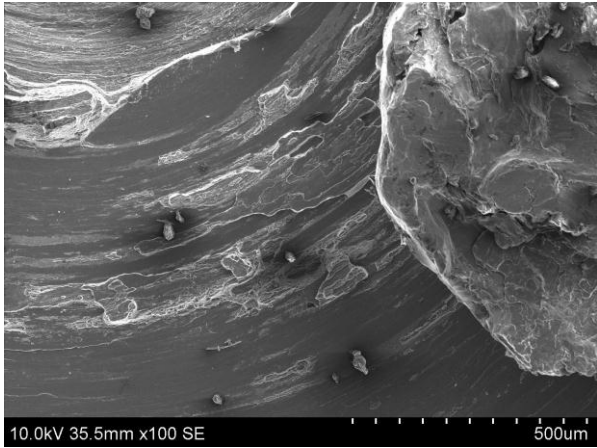


Figure 3.4: Friction welded similar joints of aluminium rods at 100x magnification.

5 TAGUCHI OPTIMIZATION

5.1 Selection of Friction welding parameters and their levels:

Welding process where metallic bonding is produced at temperatures lower than the melting point of the base metals. Friction time, friction pressure, forging time, forging pressure and rotation speed are the most interesting parameters in the friction welding method. Friction pressure (MPa), Friction time (s), Forging pressure (MPa), Forging time (s) Rotational speed (rpm), Work piece diameter (mm). The main variables in direct drive friction welding.

- Rotation speed
- Forging pressure (MPa)
- Friction time

Chemical and Mechanical properties composition of aluminum alloy 6061 which was used in the experiments are shown in Tables 4.1 and 4.2.

AA	Si	Zn	Mg	Mn	Fe	Cu	Ti
6061	0.60	0.01	0.97	0.02	0.15	0.19	0.01

Table 4.1: Chemical composition of AA6061 aluminum alloy

Base Material	Tensile Strength(MPa)	Elongation (%)	Yield Strength (MPa)
AA 6061	297	13.6	85

The process parameters workable range for the experiments was chosen in order to control the weld seams quality including defects in the root, the type of defect more difficult to eliminate in sound welds. Therefore, three levels of the FS welding parameters were selected as shown in Table 4.3.

Parameters	Factors	Level		
		1	2	3
Speed	A	600	1000	1400
Forging Pressure	B	100	120	140
Friction Time	C	8	9	10

Table 4.3: Friction welding parameters and level

5.2 Selection of Orthogonal array

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. For example, a three-level process parameter counts for two degrees of freedom. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for the two process parameters.

Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study, an L9 orthogonal array was used. A total of nine experimental runs must be conducted, using the combination of levels for each control factor as indicated in Table 4.4.

COMPONENT	WEIGHT %
Aluminium	97.5
Chromium	0.1
Copper	0.1
Iron	0.35
Magnesium	0.45 - 0.9
Manganese	0.1
Silicon	0.2 - 0.6
Titanium	0.1
Zinc	0.1
Others	0.15

Table 4.4: Orthogonal Array

The selected parameters are listed in Table 4.2 along with their applicable codes and values for use in the Taguchi parameter design study.

5.3 Signal to Noise Ratio (S/N)

To implement robust design, Taguchi advocates the use of an inner array and outer array approach. The inner array” consists of the OA that contains the control factor settings; the outer array consists of the OA that contains the noise factors and their settings which are under investigation. The combination of the inner array and outer array constitutes what is called the product array or complete parameter design layout the product array is used to systematically test various combinations of the control factor settings over all combinations of noise factors after which the mean response and standard deviation may be approximated for each run using the following equations.

Mean Response _

$$\bar{Y} = \frac{1}{4} \sum_{i=0}^n Y_i$$

The preferred parameter settings are then determined through analysis of the signal-to-noise (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal. There are three standard types of SN ratios depending on the desired performance response.

Smaller the better (for making the system response as small as possible):

$$SN_S = -10 \log\left(\frac{1}{4} \sum_{i=0}^n Y_i^2\right)$$

The better (for making the system response as large as possible):

$$SN_L = -10 \log\left(\frac{1}{4} \sum_{i=0}^n \frac{1}{Y_i^2}\right)$$

where,

- i = Experiment number
- u = Trial number
- Ni = Number of experiment

Experiment Run	Level			Tensile Strength	S/N Ratio
	A Speed	B Forging Pressure	C Friction Time		
01	600	100	8	162.30	44.21
02	600	120	9	170.2	44.61
03	600	140	10	184.5	45.31
04	1000	100	9	180.4	45.12
05	1000	120	10	199.84	46.01
06	1000	140	8	210.2	46.45
07	1400	100	10	198.6	45.95
08	1400	120	8	190.4	45.59
09	1400	140	9	200.2	46.02

Table 4.5: Mean Response Table

5.4 Response Graph of S/N Ratio:

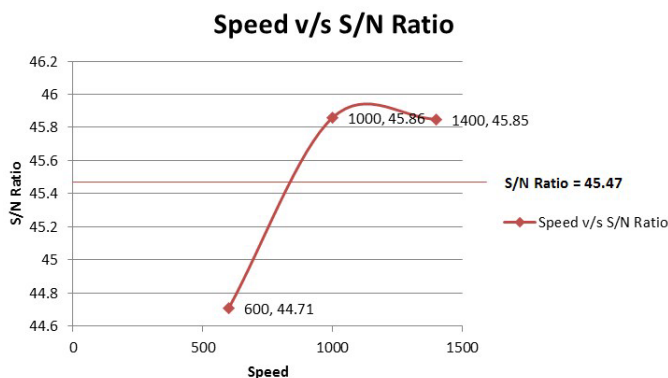


Figure 4.1: Speed Vs S/N Ratio

Forging Pressure v/s S/N Ratio

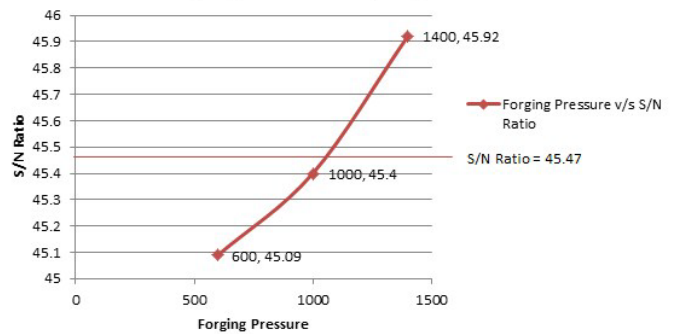


Figure 4.2: Forging pressure Vs S/N Ratio.

Friction Time v/s S/N Ratio

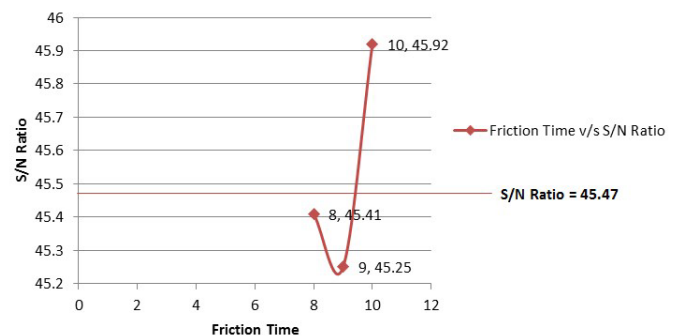


Figure 4.3: Friction Time Vs S/N Ratio.

6 CONCLUSION

In the present study, similar joints of aluminum alloys (AA6061) were welded successfully. The welding process was investigated by tensile testing, SEM fractography analysis, micro structure analysis and Rockwell hardness test observations with the following results.

1. As speed is increases hardness strength increases up to a certain level and attains saturation, there after decreases on further increase of speed.
2. As speed is increases breaking strength increases up to a certain level and attains saturation, there after decreases on further increase of speed.
3. From the microstructure test, it is observed that friction welded similar joints of AA 6061 has low ductility.

The results of this study have fundamental importance for the understanding and comprehension of the main characteristics of friction welding process, the bonding mechanisms between similar joints and the feasibility of applying this process. From Taguchi optimization, it is understood that S/N Ratio is maximum for experimental run 06 with a tensile strength of 210.2 MPa, working parameters of speed 1000 RPM, forging pressure 140 MPa and friction time 8 seconds.

REFERENCE

- [1] J.T. Staley and D.J. Lege. (1993), Advances in aluminum alloy products for structural applications in Transportation, Journal de Physique, vol. 3, pp.179-190.
- [2] Sammaiah , G.R.N. Tagore , G.R. Madhusudhan (2009), Effect of parameters on Mechanical Properties of Ferritic Stainless steel (430) and 6063 Al-Alloys by FrictionWelding, Journal of Advanced Manufacturing Technology, vol.3 (1), pp. 21-34.

- [3] K. Sandeep, K. Rajesh, and S.K. Yogesh. To study the mechanical behavior of friction welding of aluminum alloy and mild steel, In. J. Mech.eng. & Rob. Res. Vol. 1, pp. 43-50, October 2012.
- [4] A. Moarrefzadeh. Study of Heat Affected Zone (HAZ) in Friction welding process, J. Mech. Engineering. Vol. 1, pp. 11-18, January 2012.
- [5] J.Wannasin, R.A. Martinez and M.C. Flemings. A novel technique to produce metal slurries for semi-solid metal processing, SSP. Vol. 116-117, pp. 366-369, October 2006.