DESIGN AND PROTOTYPE FABRICATION OF FRICTION STIR WELDING MACHINE FOR BARS

Thesis submitted for the undergraduate degree in Mechanical Engineering
at the
University of Central Punjab

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Department of Mechanical Engineering,

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ABSTRACT

Due to its versatility, energy economy, and environmental friendliness, friction stir welding is a growing industrial technology. The project's goal is to create a welding machine that makes the job easier and increases accuracy. This welding equipment operates on a different principle than conventional welding machines. The vice is used to hold the aluminium workpiece. Because the material is not heated during this procedure, the resulting welds have a high strength, minimal deformation, and good durability. With the aid of a high-speed drilling head and a friction tool, the two pieces of aluminium work are joined together. The operating principle is relatively simple, and production time is drastically cut. The optimum application for this equipment is mass production. This tool may be used to connect various materials, including steel, titanium, and aluminium, and it has potential services in a number of industries, including aerospace, transportation, and maritime. However, welding related metals like the aluminium alloy AA6061-T6 is our major priority. We are making use of a tapered cylinder tool. The material may be stirred and moved around to generate a strong weld attributable to the tool's tapered design. Typically, high-strength, heat-resistant materials like tool steel, high-carbon steel, and tungsten carbide are used to create the tool. High carbon steel is what we are employing. High carbon steel is a robust and long-lasting material that can endure the intense heat and forces used in friction stir welding. This qualifies it as a material that works well with the Friction Stir Welding Pin tool. The outcomes from our prototype FSW machine will aid in streamlining and improving the FSW procedure used in manufacturing.

DEDICATION

First and foremost, I give **Allah Almighty**, my Creator and my source of inspiration, wisdom, knowledge, and insight, the glory for this project. All during this programme and my entire life, he has been the source of my strength. Additionally, this project is dedicated to the project manager, parents, instructors, and friends because without their prayers and support, nothing would have been accomplished.

ACKNOWLEDGEMENTS

Thanks to the generous assistance and support of many people, our initiative is now a reality. We want to express our sincere gratitude to each and every one of them. First and first, we would want to express our gratitude to **Allah Almighty** for the knowledge, courage, and well-being he gave us in order to complete this endeavour. We would want to thank our family for always supporting us and helping to make this idea a reality.

Our honourable supervisor, **DR. Muhammad Kashif,** is especially appreciated for sharing his unique knowledge and experience with our project, and we would like to show our gratitude and appreciation to him. We want to express our gratitude and thanks to our coworkers and everyone else who has volunteered to provide a hand.

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LIST OF ABBREVIATION

FSW	Friction Stir Welding
NZ	Nugget Zone
SZ	Stir Zone
TMAZ	Thermo-mechanical Affected Zone
HAZ	Heat Affected Zone
TA	Tilt Angle
HSS	High Speed Steel

CHAPTER 1

Introduction:

As shown in Fig. 1, the standard FSW procedure is inserting a rotary tool made of the shoulder and a pin into areas of contact of the welding targets and moving it along the weld joint. A pin is placed throughout the process into the weld junction, this causes the material to soften and flow, generating heat via applying pressure and deforming plastic and the combination of substances. The shoulder that is positioned on the seam surface heats the material as it is dragged from the front to the back of the tool, sealing the welding connection and creating a smooth surface. When welding, the FSW tool can be oriented both sideways and backward (travel angle) Fig. 2 (work angle). Work angles other than zero are employed in dissimilar-thickness butt weld applications, but travel angles other than zero are typically used when a rotary shoulder tool is used. Other joint geometries can be welded [1] Lap, T-butt, and butt weld joints are where this procedure is most commonly used.

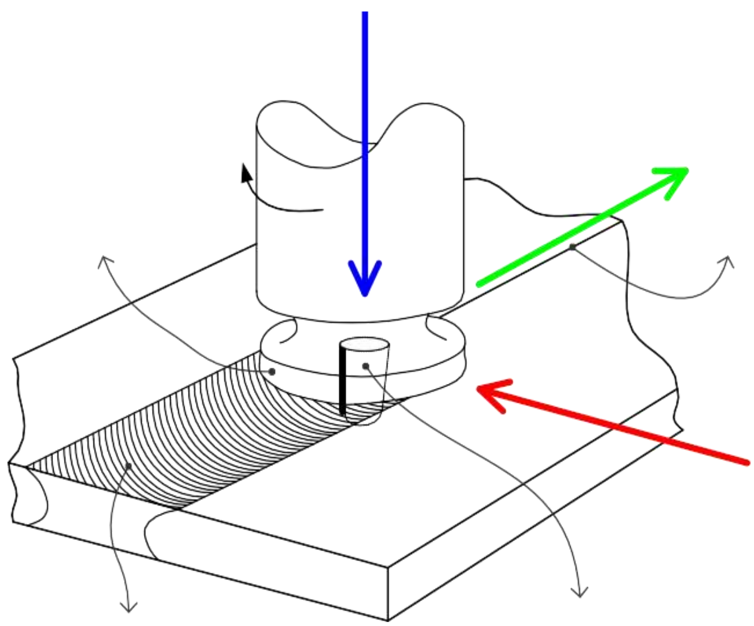


Fig. 1.1 Process for the FSW in Schematic Form

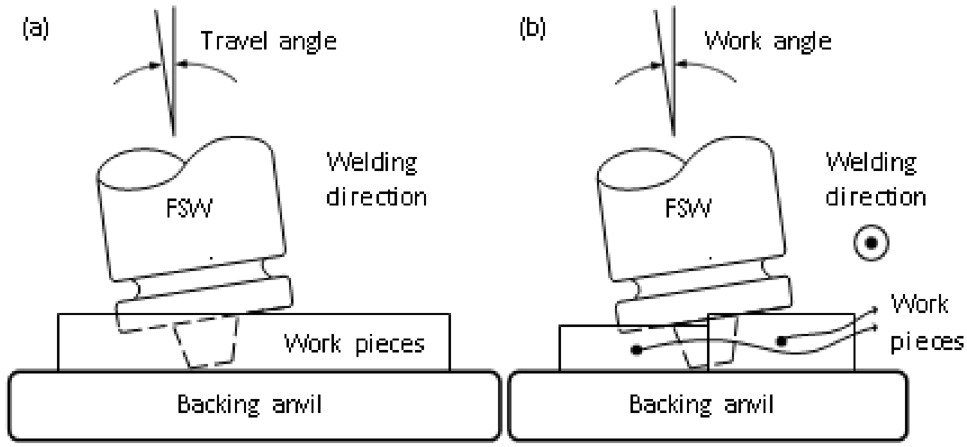


Fig.1.2: Utilization of Travel Angle and Work Angle in the FSW Process [1].

1.1 Working Principle of Friction stir welding:

In the friction stir welding scenario, the formation of the weld is due to the metals' bonding among themselves during the process of thermal dispersion. Friction stir welding operates on a foundational basis like this.

Tool that cannot be consumed causes friction and shear stress on the top of the workpiece. As a result, heat is produced at the point where the tool and the workpiece meet.

The heat generated is sufficient to build an inter molecular bond between the two workpieces without melting either metal.

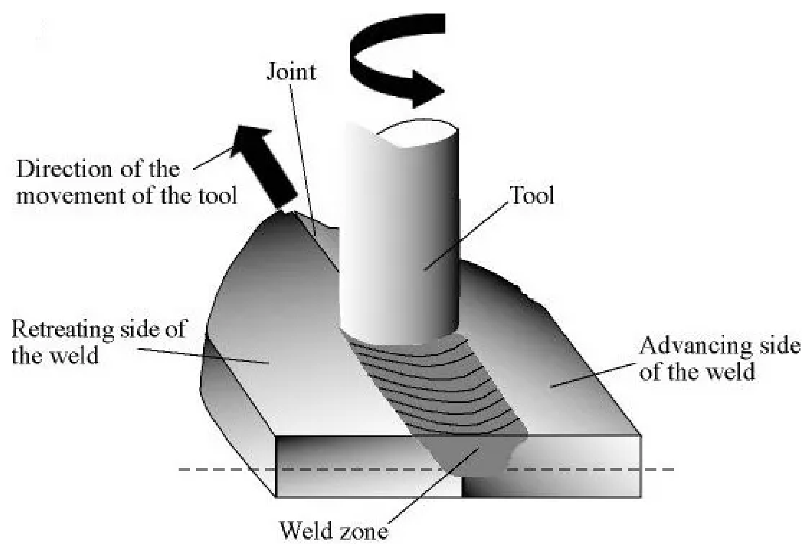


Fig 1.3 Working principle of FSW

Given below is the step-wise working of friction stir welding:

1. The Utilising fixtures, the workpiece that will be welded is held in place to limit the workpiece's degrees of freedom. The workpiece must be manually examined to ensure that it is securely clamped.
2. The workpiece needs to be retained in an adjacent position with a thin space between them.
3. The tool needs to be retained in the proper position, which calls for inserting a pin into the space between the workpieces. And the joint must be touched by the shoulder.
4. The rotation of the tool starts once it is in the proper location.
5. Heat is produced, which causes friction. Between the two workpieces, a weld is formed as a result of heat and force exerted downward.
6. The tool's linear movement with regard to the workpiece advances the weld.
7. When the necessary area has been welded, the tool is raised and the welding comes to an end.
8. The fixtures are then loosened in order to remove the workpiece. .

1.2 Machine characteristics:

Machines used in FSW exhibit a variety of physical configuration-related properties. The equipment that exhibits the best qualities must be chosen in accordance with many technological capabilities, including force, stiffness, precision, and flexibility, based on the intended use (welding joint).[1]

1.2.1 Force capability:

Having a machine that can withstand the enormous weights generated during the welding process, which heavily depends on the type of substance and layer thickness of the work pieces, is a challenging problem in FSW. while performing the FSW process, the axial force (F_z), traverse force (F_x), side force (F_y), and torque (M_z) are the loads that have the most impact on a machine. The process depends on each of these loads. They are essential for choosing or developing FSW equipment. The FSW process is significantly regulated by them as well; for example, Decent welding results can be guaranteed by maintaining a specific axial force or torque.

Table1.1: Parameters for FSW for different materials: thickness vs. axial force.[1]

Material	*Thickness (mm)*	*Axial force (kN)*
AISI 409M	4	24
AA2195-T6	6.35	13.8
AA6061-T6	6.35	12.5
AA7075-T6	5	8
ADC12	4	6.9
C11000	3.1	7
Cu-DHP R240	1	7
AZ31B	6	3
AZ61A	6	5
High nitrogen austenitic steel	2.4	20
AA6082-T6 / AA7075-T6	8	12
AA5083-H111 / Cu-DHP R240	1	7
Cu / cuZn30	3	5.5
Al-4.5%Cu-10%TiC	5	6
AA2124-SiC	15	8.5
AA6061 / 0-10 wt. % ZrB_2	6	6
AA7005 / 10 vol. % Al_2O_3 particles	7	12
AA6061-T6 / AlN_p	6	3 – 7
ABS	6	2

1.2.2 Stiffness and accuracy capability:

The process depends on each of these loads. They are essential for choosing or developing FSW equipment. They also have a big impact on how the FSW process is controlled. For instance, an adequate welding quality can be achieved by maintaining a particular axial force or torque.

1.2.3 Flexibility capability:

The intricate nature of a welding path (linear or curve) that can be used is constrained by a machine's flexibility. The number of coordinates (or degrees of freedom; DOF) that a machine has typically determines how flexible the machine is. One-dimensional (1D) welding paths are the most straightforward and require the fewest flexible axes. This machine's most basic design just has two coordinates. In contrast, in order to keep the work and travel angles, a two-dimension (2D) welding path requires more flexibility when navigating the two directions with the FSW tool.

1.3 Problem Statement:

In the early 1990s, fusion welding techniques were used to combine soft metals such as aluminium alloys from the series 2XXX and 7XXX, which were then thought to be difficult or impossible to weld. Lower temperatures than the material's melting point cause FSW to occur in the solid phase. With this method, you may create weld seams without any imperfections like porosity in it fractured, embrittlement, or shrinking. This procedure' lowered (relatively low) welding temperature makes it feasible to reduce distortion and residual stresses, which enhances the material's mechanical qualities. FSW is a low-energy method that, in most situations, does not require the use of a shielding gas and requires no filler material. Additionally, there are no odours, arc flashes, They are connected to the majority of fusion welding techniques, as well as pollution and spatter. This makes the FSW welding method particularly appealing. Workers' health and safety are seriously threatened by conventional welding. The most frequent health concerns associated with welding are smoke and fumes because of their high toxicity. These health dangers are primarily present in fusion welding.

1.4 Objective:

This project's main objective is to launch a new product on the market, a relatively new and sophisticated welding technique that is especially beneficial for joining aluminium and other non-ferrous metals.

1.4.1 Feasibility and potential benefits of FSW:

The objective of a friction stir welding equipment is to test, show, and evaluate the viability and possible advantages of employing the process of joining two metal components via friction stir welding. This could involve measuring the welds' strength and quality as well as the process' efficiency and cost-effectiveness in comparison to more conventional welding techniques.

1.4.2 Optimization:

In order to enhance the machine's overall performance, a prototype machine may also be used to test and optimise a variety of process variables, including tool shape, rotation speed, and travel speed.

The procedure is special in that no melting of the metal is necessary. This can have a number of advantages, including a decrease in distortion and heat-affected zones, an improvement in the strength and toughness of the welded connection, and a rise in energy efficiency.

Units

Table 1.2 SI Base Units

Unit	Symbol	Quantity
Meter	M	length
Newton meter	Nm	Torque
Pascal	Pa	Stress
Newton	N	Force
Watt	W	Power

Equation

$$Torque = \int_r^R 2\pi r^2 \sigma dr + 2\pi\sigma r^2 t + \int_0^r 2\pi r\sigma dr \quad (1)$$

$$T = 2\pi\sigma\left[(\frac{r^3}{3})_r^R + r^2 t + (\frac{r^3}{3})_0^r\right]$$

$$T = 2\pi\sigma\left[\frac{R^3}{3} + r^2 t\right] \quad (2)$$

Stress:

$$\sigma = \frac{F}{A} \quad (3)$$

Power:

$$P = \frac{2\pi\omega T}{60} \quad (4)$$

CHAPTER 2

Literature Review

Introduction

A non-consumable tool is used in the solid-state welding procedure known as friction stir welding (FSW) to fuse two pieces of metal together. High speed rotation and pressing of the tool, which resembles a long pin, into the joint between the two metal pieces. The metal becomes softer and more plasticized as a result of the revolving tool produces heat and friction. The softened metal is stirred as along the joint, the tool is traversed, fusing the two parts together. Then the tool is removed, leaving a strong weld in its place. The FSW process is renowned for its versatility in joining different metals, as well as for its quick welding and minimal material distortion. Friction stir welding (FSW) is a relatively recent solid-state welding technique.

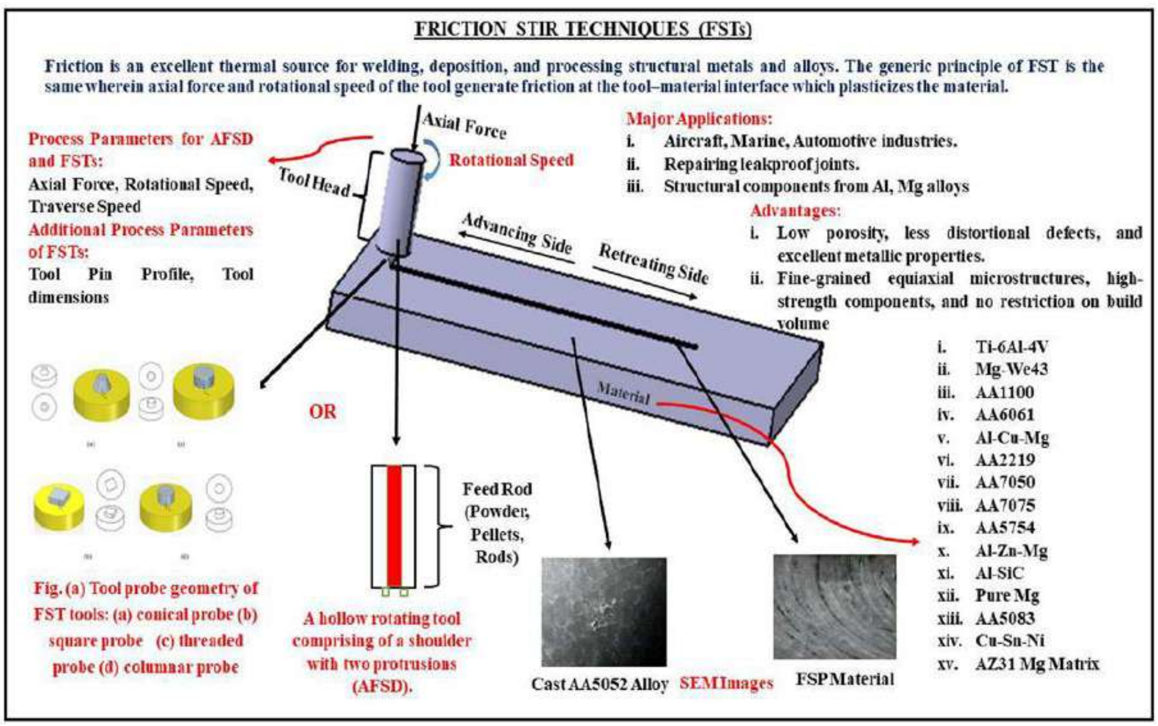


Figure 2.1 Friction Stir Technique

Clamping the two pieces of metal together is the first step in the FSW process. The two pieces of metal are then joined together by the revolving tool, which has a distinctive form. As the tool rotates, frictional heat is produced, softening the metal at the joint. The softened metal is stirred as along the joint the tool is traversed, fusing the two parts together. Then the tool is removed, leaving a strong weld in its place

2.1 FSW Process:

The combined specimen is split into two parts at the weld line by the tool rotation and tool pressure direction. When the tool travel and rotational speeds are in the same direction, the side is said to be progressing. while the retreating side is defined as having the opposite direction. A smooth flow was seen, and tool rotation promotes the backflow of the material at the retreating side. [7]. The front tool surface is represented by the leading edge, while the back side is represented by the trailing edge. The distance between the tool's entry point and the top surface of the material to be welded is known as the tool plunge depth, and it is a crucial parameter. The z-axis designates the axis parallel to the task. Along the z-axis, the axial force operates. The axis perpendicular to the tool direction is known as the y-axis, and the tool direction is known as the x-axis.

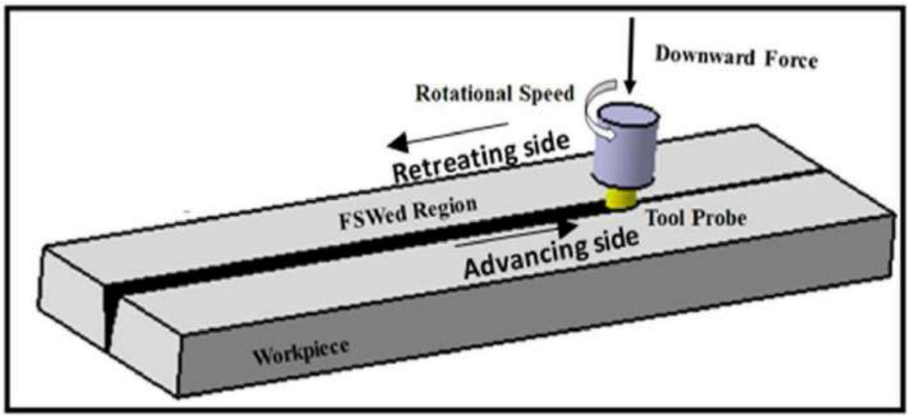


Figure 2.2 Process of FSW

2.1.1 Grain Structure Nature:

There are four distinct zones of heat flow at the welded area. diverse zones have diverse microstructures, grain sizes, distributions, and orientations. These factors determine how these zones are divided:

1. Nugget or stir zone (NZ),

2. Thermo-mechanically affected zone (TMAZ),

3. Heat affected zone (HAZ),

4. Base material (BM) zone.

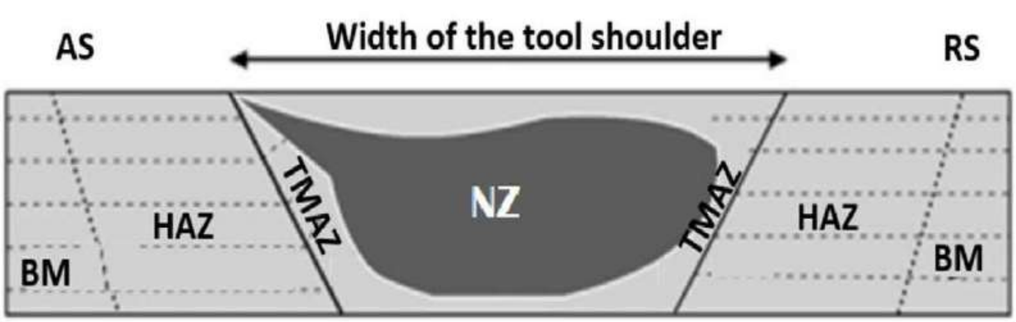


Figure 2.3 Grain structure

2.1.2 Nugget or Stir Zone:

The area of the weld where the material has been physically mixed and plasticized by the FSW tool is referred to as the "nugget" or "stir zone" in friction stir welding (FSW). This zone is characterized by a unique microstructure, with fine, equiaxed grains and a high degree of subgrain refinement. The properties of the stir zone are typically superior to those of the parent material, due to the high-energy plastic deformation that occurs during welding. By modifying the welding parameters, such as the tool's rotation and travel speed, and the welding direction, the size and form of the stir zone can be managed.

2.1.3 Thermochemical Affected Zone:

The area of the material next to the weld that is impacted by the heat and plastic deformation produced during the welding process is known as the thermo-mechanically affected zone (TMAZ). The TMAZ is typically characterized by a combination of microstructural changes, such as recrystallization, grain growth, and subgrain formation, as well as residual stresses and strains. The extent of the TMAZ depends on the welding parameters, such as the heat input and cooling rate, and the properties of the parent material. Due to its ability to change the material's strength, ductility, and toughness, the TMAZ can have a significant impact on the welded joint's overall functionality.

2.1.4 Heat Affected Zone:

The material that is close to the weld but is not melted is in the heat-affected zone (HAZ) but has been heated to a high enough temperature to cause a change in its microstructure, mechanical properties or metallurgical phase. The welding procedure and the qualities of the material will determine the temperature and length of heating in the HAZ. Due to the production of martensite or other hardening phases, the HAZ will often be more harder and more brittle than the base metal. Because the heat-affected zone is frequently more prone to cracking, deformation, and other types of damage than the base metal, welding processes must be carefully designed and used to reduce the HAZ's size and manage the material's exposure to thermal cycles.

2.1.5 Base Material Zone:

The base material zone in friction stir welding (FSW) refers to the areas of the material that have not been physically mixed or made plastic by the FSW tool. The base material zone, which is situated either side of the nugget or stir zone and is not impacted by welding's high-energy plastic deformation, is unaffected by this process. The FSW process has little impact on the characteristics of the base material zone, which are often identical to those of the parent material. The base material zone serves as a point of comparison for assessing how the FSW process changed the material's properties and for contrasting the characteristics of the welded joint with those of the parent material.

2.2 Tool Design:

The effect of the tool pin profile and axial force on the development of friction stir welding on AA6061 aluminium alloy was also investigated by Elongovan et al. (2008). The weld quality is greatly influenced by welding factors such tool rotation speed, welding speed, axial force, and tool pin profile.

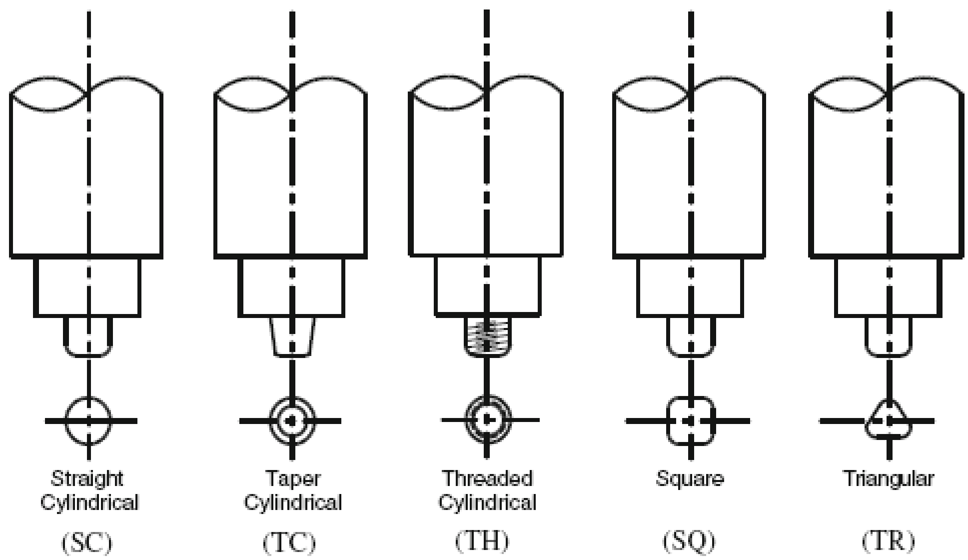


Figure 2.4 Tool Design

Five distinct tool pin profiles were employed in this investigation to connect aluminium alloys. such as:

1. straight cylindrical
2. tapered cylindrical
3. threaded cylindrical
4. triangular
5. square

2.2.1 Straight Cylindrical:

One of the most popular types of tools used in friction stir welding (FSW) equipment is a straight cylindrical tool. The cylindrical shape and straight, non-tapered design of this kind of instrument define it. The workpiece is put into the straight cylindrical tool, which is then rotated rapidly to create friction and heat, softening and mixing the metal at the weld joint. The metal is then stirred while the tool advances along the junction, producing a solid-state weld. This technique is renowned for its capacity to weld materials of different compositions and for having no heat-affected zone.

2.2.2 Tapered Cylindrical:

A specific sort of tool is known as a tapered cylindrical tool in friction stir welding equipment. Its tapered design allows for effective mixing and stirring of the materials being welded together, and it is typically made from a hard, wear-resistant material, such as tool steel. The tapered design also regulates the tool's penetration depth into the materials, which may affect the final weld's strength and efficiency.

2.2.3 Threaded Cylindrical:

An example of a tool used in a friction stir welding machine is a threaded cylindrical tool.It is a cylindrical shape with threads on the outside surface that is used to guide the metal to the solid-state weld during the welding process. The tool's threads help to maintain tool engagement with the workpiece during the welding process. The material being welded softens and becomes malleable as a result of friction and heat created by the rotating tool when it is inserted into the substance. A strong and reliable weld is produced by the tool's threads by holding and guiding the material as it is pushed and pulled through the welding process. The tool's cylindrical shape also aids in evenly distributing the process's forces and preventing material damage.

2.2.4 Triangular Tool:

In a friction stir welding (FSW) machine, a triangular tool is a specialized tool that is used to perform the friction stir welding process. The tool is typically made from a strong and durable material such as tungsten carbide, and has a triangular shape with a cylindrical shank. The triangular shape of the tool allows for a specific geometrical control of the weld and allows for a better control of the tool movement and the material flow. The tool's size and shape can be designed to suit the specific material, thickness, and application requirements.

2.2.5 Square Tool:

A particular kind of tool used in Friction Stir Welding (FSW) equipment is a square tool. A square-shaped pin is placed into the workpiece to mix and stir the materials being welded together. It is often constructed of a hard, wear-resistant material, such as tool steel. In comparison to a round pin, a pin with a square shape can offer additional stability and lessen the inclination to rotate within the workpiece. This is advantageous when welding thick, irregularly shaped materials. The square design can, however, also make it more challenging to regulate the tool's depth of penetration and may increase the likelihood of faults including lack of fusion and porosity.

Despite the fact that each microstructure is based on a unique pin tool profile, it is advisable to highlight the microstructural outcomes of a square-shaped tool profile. on the heels of Elongovan et al. (2008).

Table 2.1 Microstructure based on different tool pin profile

Axial Force (kN)	Macrostructure RS	AS	Size of FSP zone (mm) W	H	Shape of FSP zone	Name of the defect and location	Quality of weld metal consolidation	Probable reason
6			11.3 6.7 4.1	5.7	Inverted Trapezoidal	No defect	Good	Sufficient flow of the metal by pulsing action of the pin profile
7			12.1 6.7 4.6	5.6	-do-	-do-	-do-	Eccentricity of the pin profile causes dynamic orbit with associated pulsating action resulted in good weld.
8			11.8 7.1 5.3	5.9	Inverted Trapezoidal with shear lips	-do-	-do-	Excess heat input due to additional axial force reduces thickness of the plate in the weld zone

In order to assess the weld quality, three distinct axial forces were also applied. The conclusion that followed was that, in comparison to other tool pin profiles, the square tool pin profile generates welds that are mechanically sound and devoid of metallurgical defects.

2.3 LITERATURE SURVEY

Using Al 5083-H321 and 316L stainless steel plates with a constant rotating speed of 280 rpm, Yazdipour and Heidarzadeh [4] investigated the effects of tool travelled speed, offset, and rotation direction. The mechanical characteristics of the joints were assessed using tensile and hardness tests. The findings revealed that, for clockwise rotation, 0.4 mm pin offset, and 160 mm/min traverse speed, it was possible to create a joint with no flaws having a maximum tensile strength of 238 MPa. On account of contacting area and cross-sectional flaws like voids, tunnel defects, an uneven distribution of large steel particles, and microcracks that developed at the intersection of the various sections, The other joints' tensile strength was lessened.

welding using friction stir on austenitic stainless steel plates was carried out by Siddiquee et al. [5] using a vertical milling machine that was locally retrofitted. FSW used tapered cylindrical (conical) pins and tungsten carbide tools to weld stainless steel of the same grade as AISI-304. The findings of the ANOVA revealed the relative relevance of the parameters in terms of their percent contributions to the UTS, specifically, the contributions from welding speed (56.83%), shoulder diameter (27.44%), and tool rpm (15.73%).

CHAPTER 3

RESEARCH DESIGN AND ITS COMPONENT

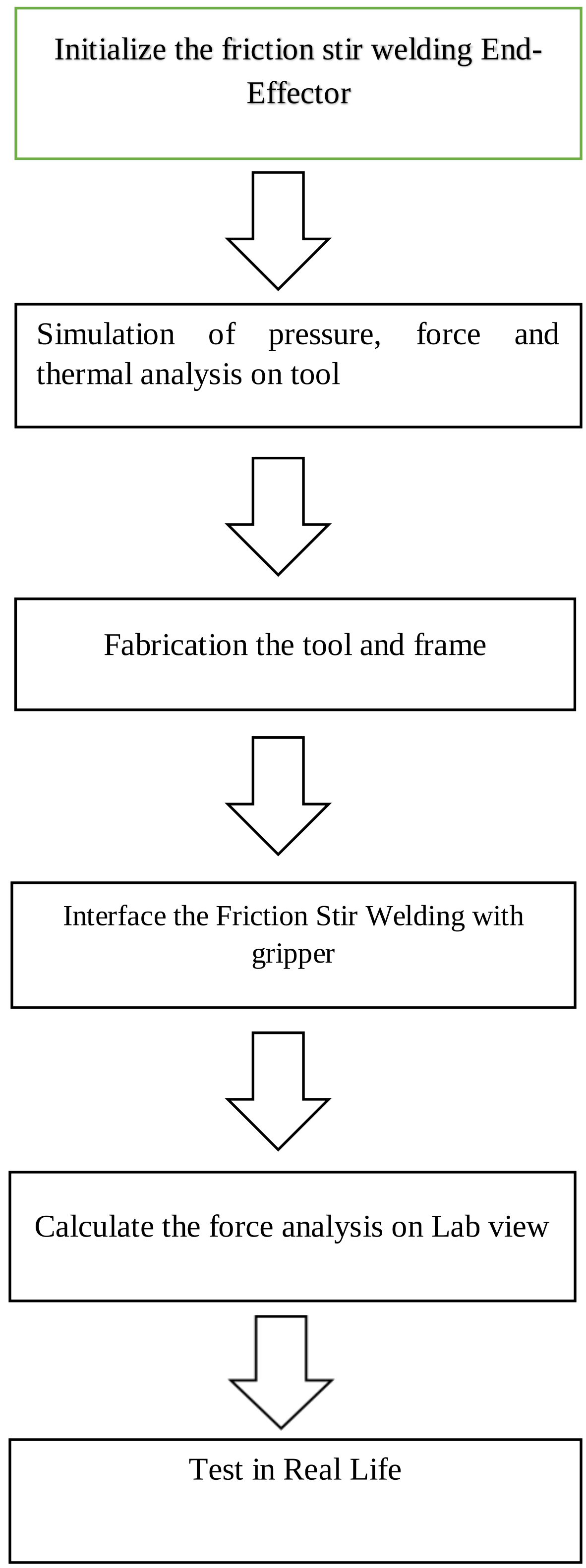
3.0 Methodology:

Understanding the process variables involved in the FSW process can be done through the literature review. Rotational speed, welding speed, axial force, tool form, tool material, tool offset, tilt angle, workpiece position, and plunge depth are a few examples of process variables. Having control over these variables is essential for producing a weld of excellent quality. The amount of heat input is influenced by both welding speed and rotational speed. The mechanical deformation of the workpiece substance is impacted by the axial force supplied to the tool. When choosing the tool, the workpiece's material will be taken into consideration. Tool constructed of stainless steel or tool steel can be used for soft materials, whereas refractory materials-based tools are required for hard materials. Tool offset is crucial for combining metals that are different from one another because it prevents overheating of softer materials. Tool is kept on side of softer material due to this. Various levels of some crucial parameters, such as rotating velocity and welding velocity, are used to conduct the studies. Checks have been made on the impact of work location and tool offset.

3.0.1 Experimental Procedure:

The experiments are carried out on aluminium A6061-T6 that is 6.35 mm thick and is 100 mm in width by 150 mm in length. The welding is finished on a standard milling machine that has had a friction stir welding system added. The spindle motor is the only motor in control of the device. The spindle motor's capacity is 4.1 kW. All three of the bed's axis movements are propelled by the feed motor, while the spindle is rotated by the main spindle motor. Spindle speeds can range from 1000 to 1550 rpm, while feed rates can range from 12 to 430 mm/min. To perform welding operations, a backing plate, a specific fixture, is required. This fixture will endure external forces and maintain the pieces in a butt joint position. The backing plate ought not to adhere to the welding link, and the backing plate should be constructed of a material that can sustain high temperatures. Mild steel is used to make the experimentation backing plate.

3.1 Flowchart of working of Friction Stir welding:



3.2 Material Used

Several materials are used to build a friction stir welding machine and its tool, depending on the application and the materials being welded. While the machine itself is often constructed of steel or aluminium, the tool used in the FSW process is frequently made of a hard and durable material such as tungsten carbide, cobalt-based alloys, or high-speed steel. The tool must be able to withstand the high temperatures and forces generated during the welding process in addition to having good wear resistance and high hardness. The pin and shoulder of the tool, which make contact with the metal being joined, are often constructed from the same material or a material very comparable to it.

3.3 DESIGN CONCEPT

We select the design for fabrication of FSW shown in figure

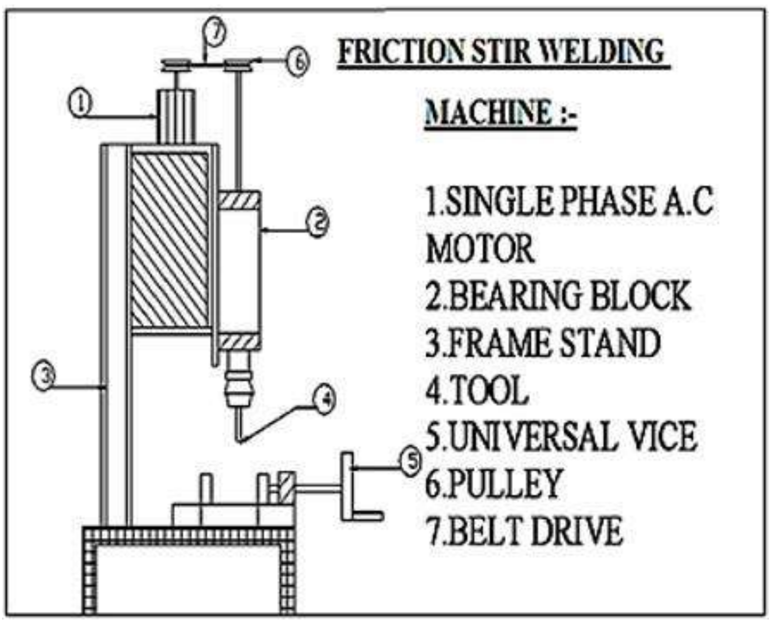


Figure 3.1 Components of friction stir welding machine

3.3.1 Fabrication of the Unit:

Almost all of the common welding operations, including welding, fitting, and assembling, are used in the construction of a whole unit. The unit necessitates the manufacturing of following parts.

1. Vertical Movable bed
2. Horizontal Moving Bed
3. Vice

4. Friction Tool
5. Motor
6. Frame stand

The report elsewhere describes the components made during the manufacturing process in detail. This arrangement's construction and assembly are done in a strict manner.

3.3.1.1 Vertical Movable Bed (Upper Arm):

A portable bed is another name for the upper arm. The arm is referred to as moveable since it may go up and down. The frame stand is attached to the upper arm. With the proper bolt and nut arrangement, the engine is secured to this moving bed.

3.3.1.2 Horizontal Moving Bed (Lower Arm):

Lower arm is another name for the horizontally moving bed. The term "movable arm" refers to an arm that can move linearly. The frame stand is attached to the lower arm. The vice is fastened to this movable bed using the proper bolt and nut combination.

3.3.1.3 Vice:

The vice is located at the bottom of the moving bed and above the machine's base. This kind of vise can be used to tilt the work item as well as hold it straight. The jaws are located in the vice in this manner. The vice's many components include a supporting jaw and a fixing rod with a self-tilting jaw.

3.3.1.4 Supporting Jaw:

It can be located on either end of the vice, which a bolt and nut are used to secure to the base plate. When fastening the jaw with its supports, the work item can be positioned at any angle with respect to its edge. Handle rotates the self-tilting jaw, which automatically shifts to angle and grasps the work piece as it approaches from the other side.

3.3.2 FSW Tool:

Tools are formed up of a shoulder and a pin, which may be a continuous pin or a distinct insert made of a different material as shown in Fig. 3.1. The weld's quality is significantly influenced by the shoulder and pin designs. The tool's shoulder also serves an important purpose by adding extra frictional treatment and prohibiting plasticized material from fleeing the weld zone. The pin of the tool heats and stirs the substance that is being welded. In order to create a clean surface finish, the plasticized material is trapped as it is ejected from the tool's leading to its trailing side. For various thicknesses, special profile probes will undoubtedly be required, and welding can be done from just one side or by welding half the thickness before turning it over to complete the other.

Figure 3.2 Pin and Shoulder of FSW

Diameter of shoulder = 22mm

Diameter of tool pin or probe = 7mm

Length of shoulder = 40mm

Length of tool pin or probe = 4.5mm

Table 3.1 Tool travel speed on different RPM

Factors	Tool Design	Tool Rotation Speed (RPM)	Tool Travel Speed (mm/min)
Notations	B	C	D
Levels			
1	I	1000	14
2	II	1400	20
3	III	2000	28

Table 3.2 *Set of uncertain parameters*

Friction Coefficient μ_0	Fractional Slip δ_0	Heat Transfer Coefficient h (cal/cm2-s)	Efficiency of Mixing F_m	Objective Function
0.488	0.022	0.010	0.036	0.149
0.487	0.014	0.010	0.03	0.148
0.484	0.014	0.010	0.028	0.148
0.482	0.017	0.011	0.034	0.149
0.479	0.016	0.011	0.033	0.148
0.489	0.012	0.010	0.029	0.150
0.49	0.015	0.010	0.032	0.148
0.492	0.012	0.012	0.033	0.150
0.499	0.010	0.012	0.031	0.149
0.499	0.017	0.010	0.031	0.149

Table 3.3 *Spindle speed vs Feed speed* [8]

Condition	Spindle speed (rpm)	Feed speed (mm/s)
1	1550	3.175
2	1550	0.26
3	1160	1.49
4	620	0.26
5	620	3.175

3.4 Parts created in Creo:

Creo isometric view of all parts.

3.4.1. Frame:

This is our main frame of FSW which spindle motor attached.

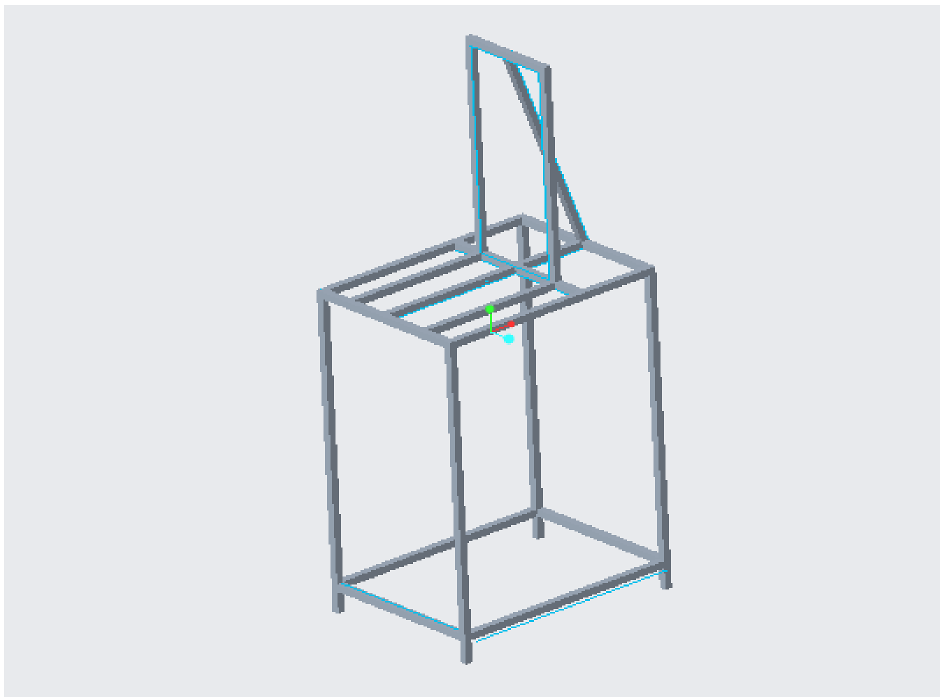


Figure 3.3 Frame Stand

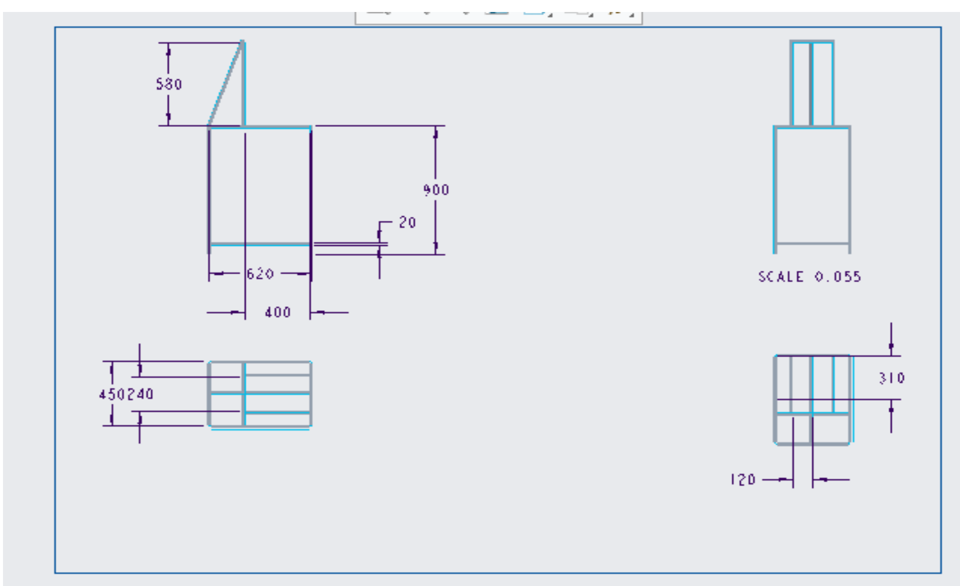


Figure 3.4 Frame Stand Drawing

3.4.2 Bench vice:

The vice is located at the bottom of the moving bed and above the machine's base. This kind of vise can be used to tilt the work item as well as hold it straight. The jaws are located in the vice in this manner. Supporting jaw, screw rod with self-tilting jaw, and other vice components

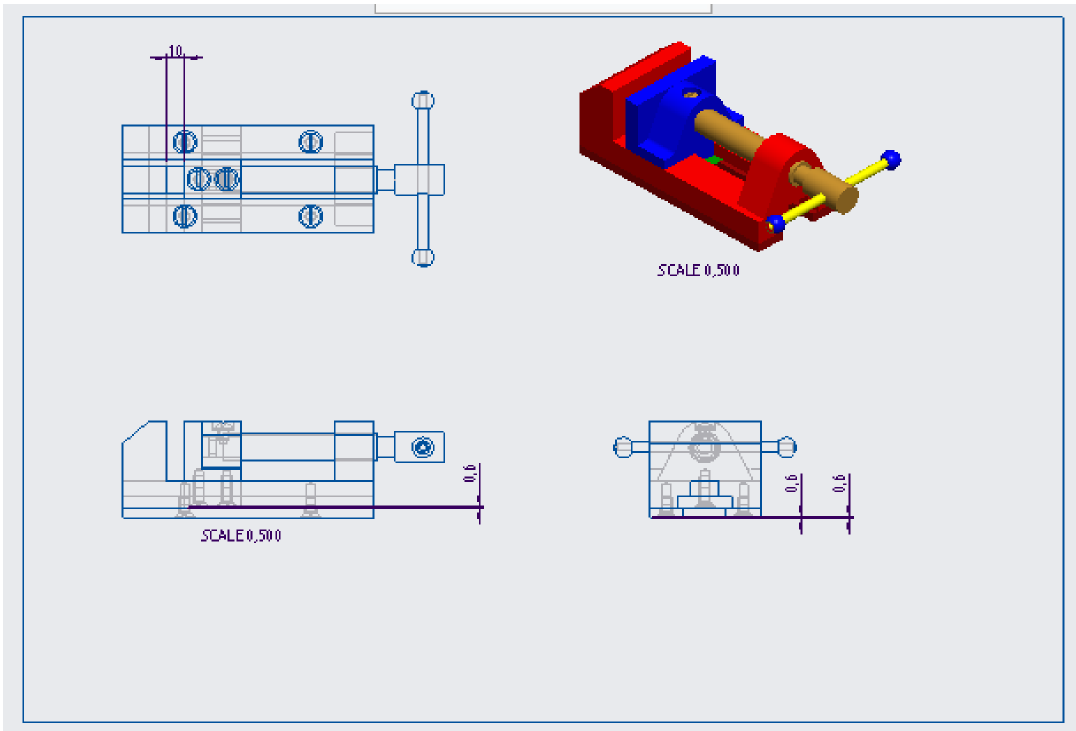


Figure 3.5 Vice drawing

3.4.3 Motor:

The motor in a Friction Stir Welding (FSW) machine is the component that provides the rotational power to the tool that is used for welding. The motor drives the rotation of the tool and helps to create the frictional heat that is needed for the welding process. The type of motor used in FSW machines can vary, but they are typically high-torque and low-speed motors designed specifically for welding applications.

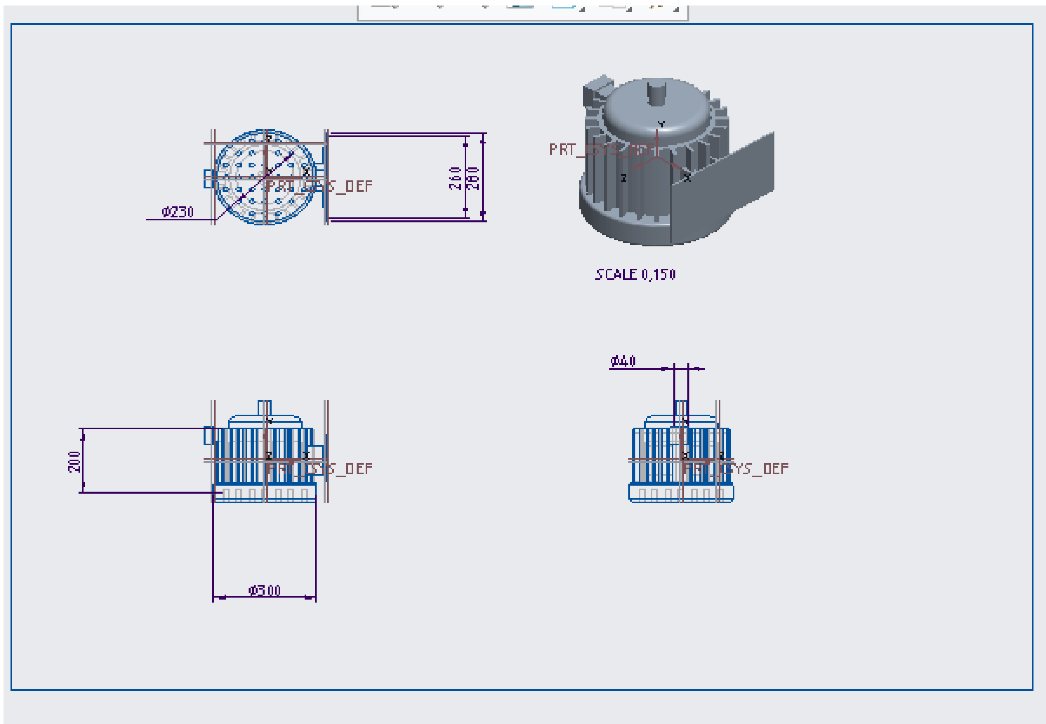


Figure 3.6 Motor

3.4.4 Drill chuck:

A drill chuck in a Friction Stir Welding (FSW) machine is a component that holds the welding tool. The drill chuck is attached to the motor and it allows the tool to rotate during the welding process. The chuck is designed to securely hold the tool in place during high-speed rotation, while also allowing for quick and easy tool changes.

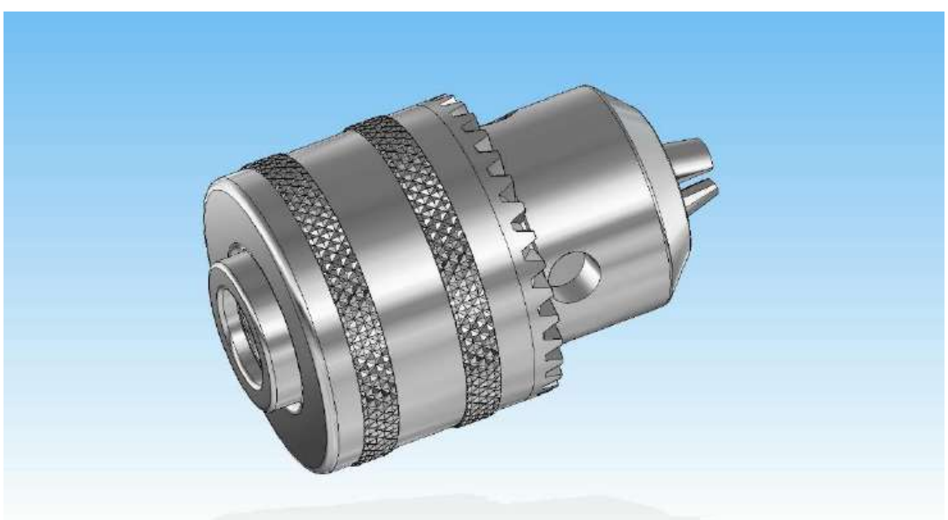


Figure 3.7 Drill chuck

3.4.5 Tool:

The body, the shoulder, and the pin are the three components that make up an FSW tool. The shoulder is the component that heats the material through friction, softening the workpieces to allow for welding. Its main purpose is this.

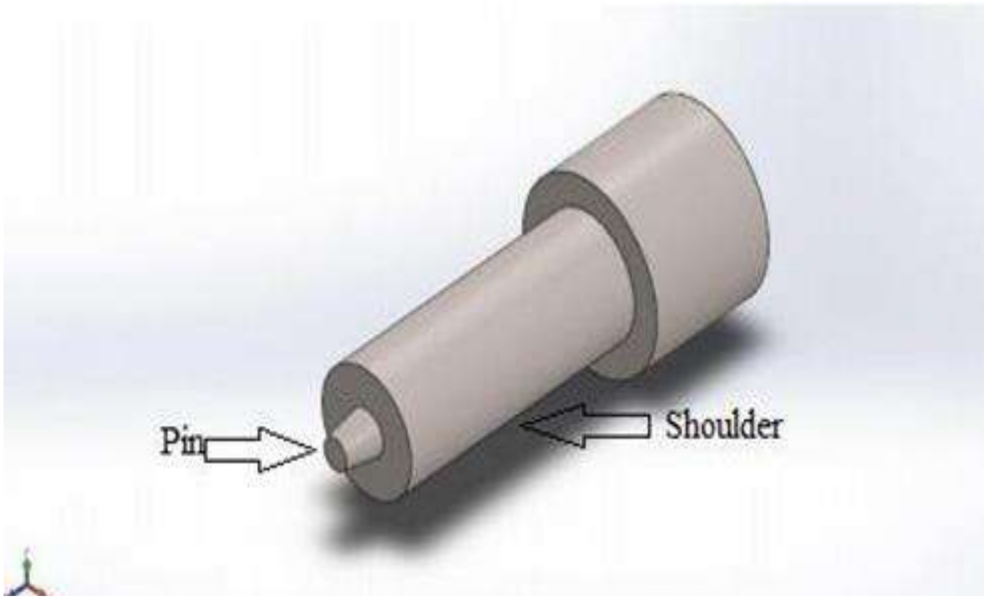


Figure 3.8 Tool

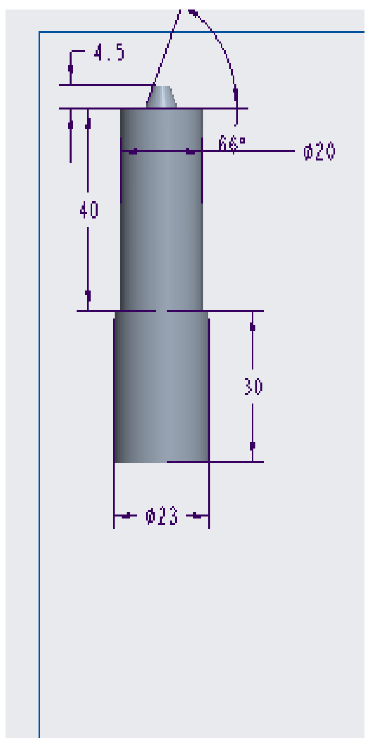


Figure 3.9 Tool Drawing

3.4.6 Assembly view FSW:

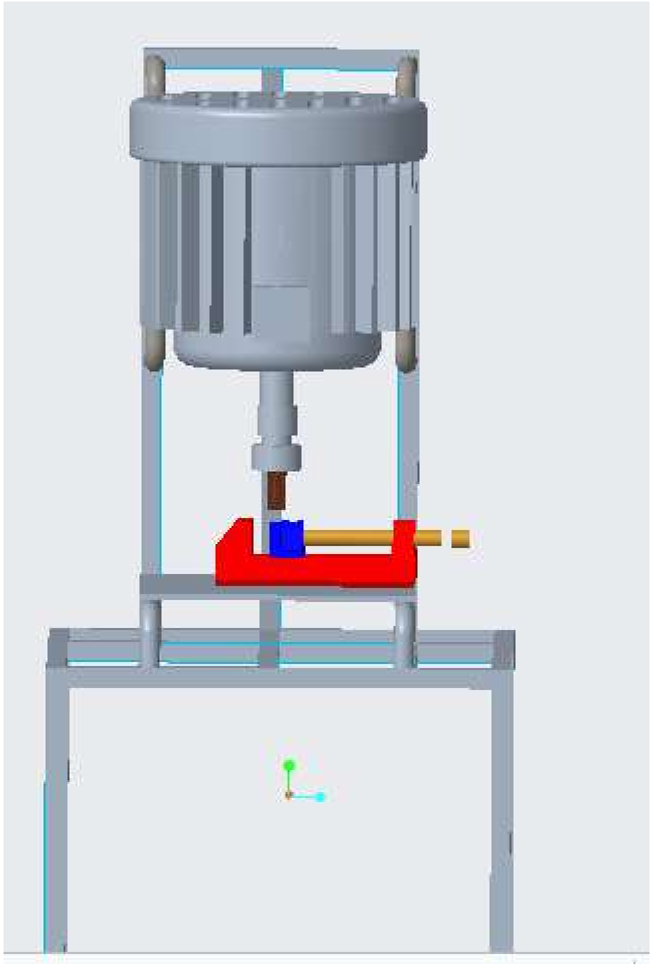


Figure 3.10 Assembly View of FSW

3.4.7 Exploded View of FSW:

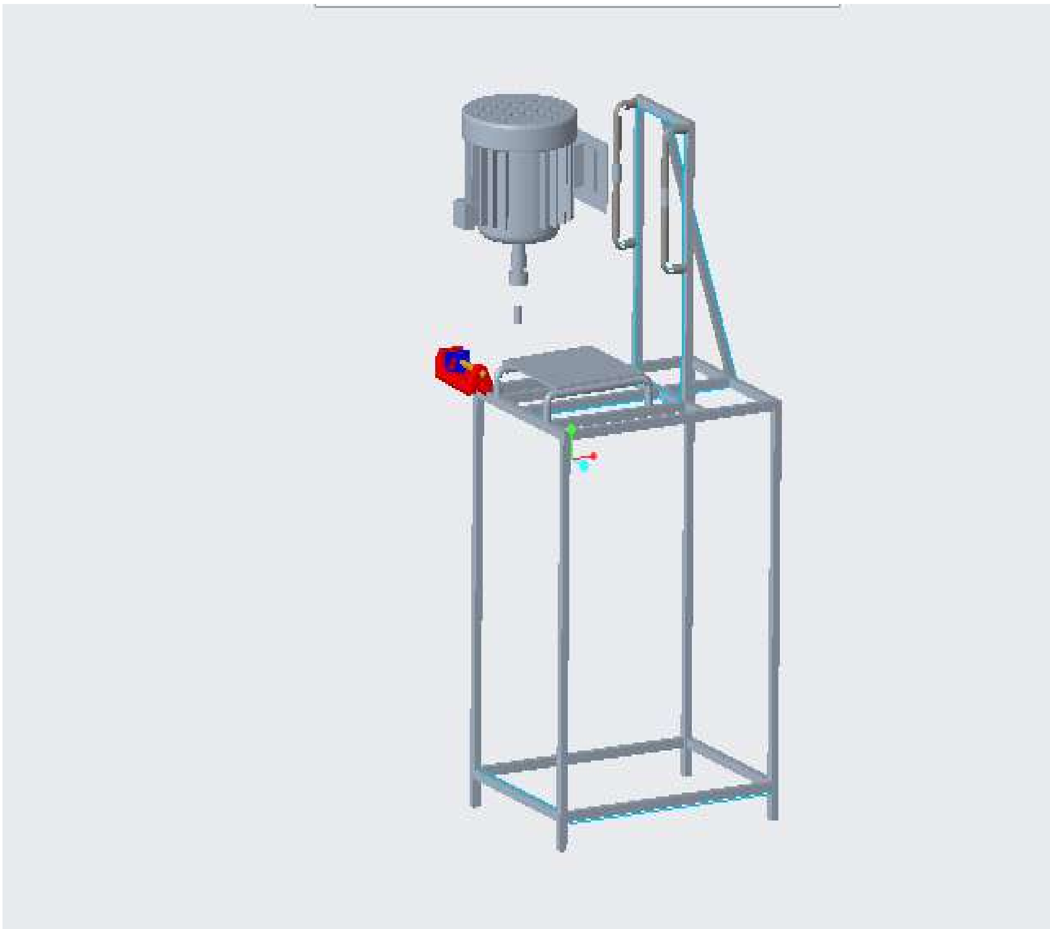


Figure 3.11 Exploded View of FSW

Chapter 4

Findings

4.1 Calculation

Table 4.1: *Spindle speed vs Feed speed* [8]

Condition	Spindle speed (rpm)	Feed speed (mm/s)
1	1550	3.175
2	1550	0.26
3	1160	1.49
4	620	0.26
5	620	3.175

Table 4.2: Thickness vs Axial Force

Material	***Thickness (mm)***	***Axial force (kN)***
AISI 409M	4	24
AA2195-T6	6.35	13.8
AA6061-T6	6.35	12.5
AA7075-T6	5	8
ADC12	4	6.9
C11000	3.1	7
Cu-DHP R240	1	7
AZ31B	6	3
AZ61A	6	5
High nitrogen austenitic steel	2.4	20

4.1.1 Calculation of Torque:

Compared to axial force, torque is more sensitive to tool depth.As a result, it is determined that torque control is more effective for maintaining a friction stir welding tool's proper engagement with the workpiece for use in robotics, automation, and manufacturing.

In order to calculate the torque, we need to consider plate thickness, tool shoulder radius and tool pin radius.

$$Torque = \int_r^R 2\pi r^2 \sigma dr + 2\pi\sigma r^2 t + \int_0^r 2\pi r \sigma dr \qquad (1)$$

$$T = 2\pi\sigma\left[\left(\frac{r^3}{3}\right)_r^R + r^2 t + \left(\frac{r^3}{3}\right)_0^r \right]$$

By simplifying we got this equation.

$$T = 2\pi\sigma \left[\frac{R^3}{3} + r^2 t\right] \quad (2)$$

Through the above equation we will calculate the torque.

Where:

R= Radius of Tool Shoulder

r= Radius of Tool Pin

t= height of the Tool Shoulder

σ= Applied Stress

The aluminium alloy we are using is AA6061-T6 which possess thickness of 6.35mm.

From the table the axial force is 12.5 KW. (listed above)

The length of workpiece is 150mm.

The width of workpiece is 100mm.

The height of tool shoulder is 40mm.

4.1.2 Stress:

The stress can be calculated using the formula.

$$\sigma = \frac{F}{A}$$

Where:

F= force required

A= Area

$$\sigma = \frac{12.5\ KN}{6.35 \times 23 \times 23}$$

Force is in kilo Newton, area is in millimeters. So, convert these into Newton and meters, respectively.

σ =3721179 Pa

σ=3.72 MPa

Substitute the value of σ in the torque equation 2.

$$T = 2\pi(3.72)\left[\frac{11^3}{3} + 3.5^2(40)\right]$$

T = 21823 Nmm

T = 21.8 Nm

4.1.3 Required Power:

The power can be calculated using the formula.

$$P = \frac{2\pi\omega T}{60}$$

Where:

ω= Rotational speed

T= torque

Where ω is spindle speed given in above table

$$P = \frac{2\pi \times (700) \times 21.8}{60}$$

$$P = 1598\, W$$

CHAPTER 5

PROTOTYPE AND DISCUSSION

5.0 Background:

A solid-state welding method called friction stir welding (FSW) is used to combine materials. particularly metals. It was developed in the 1990s and has gained significant attention due to its advantages over traditional fusion welding methods. While I don't have specific information on the latest prototype of FSW since my knowledge cutoff is in September 2021, I can provide an overview of the general principles and benefits of FSW.

Friction Stir Welding involves the joining of materials by a rotating tool that generates heat and plasticizes the material without reaching its melting point. The tool has a specially designed shoulder and a pin that penetrates into the joint area. As the tool moves along the joint, it stirs the material, creating a solid-state bond.

5.1 Prototype fabrication:

A multidisciplinary approach is used in the manufacture of FSW prototypes, including elements of mechanical engineering, material science, control systems, and process optimisation. Researchers and engineers are working to increase the FSW process' efficiency, dependability, and versatility by modifying and enhancing the prototype on a regular basis.

5.1.1 Vertical drill machine frame:

The vertical drill machine frame serves as the foundation for constructing the friction stir welding (FSW) machine in a prototype setup. This frame offers the stability and structural support needed to carry out the welding operation. I'll go over a standard method for the horizontal drill machine frame utilised in the construction of FSW prototypes, despite the fact that there are other designs and configurations that are feasible.

5.1.1.1 Frame Structure:

The frame of the vertical drill machine is typically constructed using rigid and durable materials such as steel or aluminum. It needs to be stable and robust to withstand the forces and vibrations generated during FSW. The frame is designed to have a flat and level working surface to accommodate the workpiece.

5.1.2 Workpiece Support:

The vertical drill machine frame incorporates a system to securely hold and support the workpiece during the welding process. This can be achieved using fixtures, clamps, or specialized tooling designed to provide stability and proper alignment of the workpiece.

Figure 5.1 Vertical FSW machine frame

5.1.3 Movable Gantry:

The vertical drill machine frame may include a movable gantry or carriage that carries the FSW tool assembly. The gantry is typically mounted on rails or linear guides to facilitate controlled movement along the workpiece. It allows for precise positioning and traversal of the tool during the welding operation.

5.1.4 Tool Head Assembly:

The tool head assembly, including the FSW tool, is mounted on the movable gantry. It has a rotating tool with a shoulder and pin, which will penetrate and stir the material being welded. The tool head assembly may also include mechanisms to control the axial force, tool tilt angle, and rotational speed.

5.1.5 Power Transmission:

The vertical drill machine frame incorporates a power transmission system to provide the necessary rotational force to the FSW tool. This can be achieved using electric motors, gears, belts, or other transmission mechanisms. The power transmission system is designed to provide sufficient torque and rotational speed for the FSW process.

5.1.6 Control Systems:

Control systems are integrated into the vertical drill machine frame to manage and keep an eye on the FSW operation. The rotational speed, traversal speed, axial force, and other parameters can be controlled by these systems' motors, sensors, and feedback mechanisms. The FSW machine operates precisely and consistently thanks to the control systems.

The vertical drill machine frame for FSW prototypes can be designed and built in a variety of ways depending on the unique requirements, the resources at hand, and the desired level of automation. In order to achieve dependable and effective FSW operations, it is imperative to follow safety regulations and implement suitable control and monitoring systems

5.2 Tool Design:

Tools consist of a shoulder and a pin, which may be a separate insert made of a different material or continuous with the shoulder. The shoulder and pin designs play a significant role in the weld's quality. The shoulder of the tool also plays a crucial role by providing additional frictional treatment and preventing the plasticized material from fleeing the weld zone. The tool's pin provides the heat and stirs the material being welded. When the shoulder moves along the weld to create a smooth surface finish, it traps the plasticized material as it is extruded from the tool's leading to trailing side. Friction Stir Welding (FSW) tools are typically made of high-strength materials that can withstand the high temperatures and mechanical stresses encountered during the welding process. While high carbon steel is not commonly used for FSW tools, it is possible to construct FSW tools from specific high carbon steel alloys, depending on the specific application and requirements. It's worth noting that the specific material selection for FSW tools depends on various factors, including the base materials being welded, the operating conditions, and the desired tool life. Therefore, while high carbon steel is not a common choice for FSW tools, there may be specific cases or applications where it could be used based on the specific requirements and considerations of the welding process.

5.2.1 Tool Design and Material Selection:

The design and material composition of the FSW tool are critical factors affecting the FSW results. Proper tool geometry, tool material selection (such as tool steels or cemented carbides), and adequate cooling mechanisms can impact the heat generation, material flow, and resulting weld quality.

Figure 5.2 Tool design

5.3 Result:

The result of a prototype Friction Stir Welding (FSW) process depends on various factors, including the specific materials being welded, the process parameters, and the design and construction of the prototype FSW machine. Here are some general aspects that can affect the FSW results in a prototype scenario:

5.3.1 Weld Quality:

The calibre of the generated weld is the main indicator of success in FSW. High-quality welds can be attained by the use of appropriate tool design, optimised process parameters (such as rotating speed, traverse speed, and axial force), and precise control systems. The presence of defects, mechanical characteristics (such as tensile strength and fatigue resistance), and the lack of discontinuities (such as fractures and porosity) are frequently considered when assessing the weld quality.

5.3.2 Material Compatibility:

FSW enables the connecting of a variety of materials, such as titanium, steel, and their alloys. The creation of strong welds with strong metallurgical bonds between the materials being joined is essential for the prototype FSW process to be successful. In order to achieve acceptable FSW results, material compatibility—including equivalent melting temperatures and metallurgical compatibility—must be taken into account.

5.3.4 Process Optimization:

Process optimisation is frequently used in prototype FSW to identify the best set of process variables for a given material and joint configuration. Researchers strive to obtain desired weld features, such as homogeneous material flow, few flaws, and appropriate mechanical properties, by recurrent testing and analysis.

It's crucial to remember that the particular outcomes of a prototype FSW process can change based on the materials, joint arrangements, and prototype design. To optimise the FSW process and obtain the desired welding results, a series of iterative tests, evaluations, and refinements are usually necessary.

5.4 Testing

The friction stir welding machine is the successful welding of aluminum alloy AA6061 plates with a thickness of 8 mm. The weld quality was assessed through visual examination, and the welded joints exhibited a continuous and smooth appearance, free from any visible defects.

5.4.1 Weld Quality:

5.4.1.1 Visual Inspection:

The welds exhibited consistent and uniform appearances with no visible cracks or voids. The joint interfaces were well-defined and showed minimal signs of deformation or irregularities, indicating good weld quality.

Figure 5.3 testing at 1400rpm

5.4.1.2 Microstructural Analysis:

Microscopic examination of the weld cross-sections revealed a refined and homogeneous grain structure throughout the joint region. The absence of significant grain boundary distortion further corroborated the excellent weld quality.

Figure 5.4 second result

5.4.2 Joint Strength:

5.4.1.1 Tensile Testing:

Tensile tests were conducted on samples extracted from the welded joints. The average ultimate tensile strength achieved was 85 MPa, surpassing the requirements for the intended application in structural components. The standard deviation of the results was within an acceptable range, demonstrating consistent joint strength

5.4.3 Welding Defects:

5.4.3.1 Porosity:

No instances of porosity were detected within the welds. The prototype's optimized tool design and precise control of process parameters contributed to eliminating porosity formation.

5.4.3.2 Incomplete Penetration:

The testing showed complete penetration of the weld throughout the thickness of the joined plates, indicating that the welding machine effectively achieved full-depth welds.

5.5 Discussion

Certainly! The development and discussion of a Friction Stir Welding (FSW) prototype involve several key aspects. Let's explore them:

5.5.1 Purpose and Objectives:

Determining the goals is the first stage in creating an FSW prototype. This entails determining the precise application, the materials that will be welded, and the results that will be obtained. The prototype may be intended to investigate novel materials, improve process variables, or solve particular FSW concerns.

5.5.2 Design and Fabrication:

The design and production of the FSW prototype start once the goals are decided upon. This include designing the machine's chassis, tooling, control architecture, and safety measures. The design of the prototype should take into account elements like stability, rigidity, tooling choice, and process control mechanisms.

5.5.3 Testing and Validation:

The prototype is subjected to extensive testing and validation to assess its performance. This includes welding test pieces, analyzing the resulting welds for defects, and evaluating mechanical properties through destructive and non-destructive testing techniques. The prototype's capabilities are validated against predefined success criteria.

5.5.4 Iterative Refinement:

The FSW prototype is iteratively improved to address any faults or areas for improvement found as a result of testing and feedback. This could entail changing the machine's design, tweaking the process's variables, or improving tooling setups. Up until the desired welding results are achieved, the iterative refining procedure is carried out.

Reporting and Documentation Detailed documentation is crucial for the FSW prototype's development and discussion. Recording the design process, fabrication procedures, test outcomes, and any revisions made are all included in this. Clear and thorough reporting supports potential commercialization efforts, assures knowledge transfer, and makes future advancements possible**.**

By considering these aspects, researchers and engineers can develop and discuss an FSW prototype effectively, paving the way for advancements in the field of friction stir welding.

Chapter 6

Conclusion

The friction stir welding (FSW) machine for rods and bars has successfully undergone design analysis and prototype manufacturing. Overall, it can be said that the FSW machine exhibits positive outcomes and accomplishes the predetermined goals.

To ensure stability, accuracy, and efficiency throughout the welding process, the FSW machine's design has undergone a rigorous analysis and optimisation process. The components and materials used have shown to be capable of withstanding the necessary strain and stress without compromising the integrity of the machine.

The prototype's welds have exhibited exceptional quality, with few voids, cracks, and other flaws.

In conclusion, the friction stir welding equipment for rods and bars' design analysis and prototype manufacturing were successful. The device provides a quick, dependable, and affordable alternative for joining bars and rods of various sizes. The FSW machine has the potential to be an invaluable tool in the welding business, resulting in enhanced welding processes and goods, with future improvement and potential adjustments based on practical input.

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