CHAPTER 3

DEVELOPMENT OF FRICTION STUD WELDING MACHINE

3.1 INTRODUCTION

Friction stud welding is a fast, reliable and accurate method of welding a metal fastener to another metal object. The resultant weld joint by means of friction stud welding, is stronger than the stud. In order to weld the stud, access is only required from one side which means that component handling is reduced. Welds are also leak proof and tamper proof, and since no holes are punched in the sheet, corrosion problems are reduced and the work piece is not weakened. Friction stud welding can also be used on single sided pre-coated polished or painted materials. This variant friction welding process can be employed for joining dissimilar materials and exotic materials (Stephan & Dave 1999).

This single-shot process is simple, energy efficient, environmentally sound, as there is no smoke, slag, flux, gas, or filler metal, and it could be fully automated. It is a solid-state process; the problems of a liquid weld pool are eliminated, including problems associated with positional welding. Welds produced are fine grained fully forged quality across the full contact area and have small heat affected zones (Akata et al 2006). There are no solidification defects, slag inclusions, or weld metal dilution. Joining of similar or dissimilar materials by friction stud welding method has saved a lot of energy and material in manufacturing sector.
Process automation using programmable logic controller and pneumatic drive would certainly enhance the precision of the process parameters and the quality of joints. It reduces the cycle time to a greater extent. Hence, the scope of the current work is developing an indigenous low cost friction stud welding machine for welding of studs in the range of 6mm to 12mm.

3.2 **FRICTION STUD WELDING PROCESS**

![Figure 3.1 Friction stud welding process](image)

In friction stud welding, one of the parts is rotated around its axis, while another is pushed toward the rotated part within a certain time. When sufficient temperature is reached at friction surfaces, the rotating process is stopped suddenly, the pressure is increased and the soft material is left to cool under this high pressure. Axial pressure is applied in two stages. The first stage is called "heating or friction pressure" and the second stage is called "upset or forging Pressure". Figure 3.1 shows the different stages involved in friction stud welding process.
In the first stage, the stud is fixed while the work piece is given a rotational velocity. The work piece is fitted to the chuck of the lathe machine which provides the required speed of rotation.

During the second stage, the work piece and stud are held in contact leading to an initial interfacial frictional heating. This removes surface irregularities, and it is a function of the process conditions, material and loading. This is referred as ‘friction stage’.

In the third stage, the temperature is generally just below the melting point and the resulting material behavior is viscoplastic. The plastic incompressibility leads to the formation of flash. Most of the friction pressure transmitted to the stud has been converted into heat and deformation. Therefore, the rotating work piece slows down progressively until a zero rotational velocity is reached.

The final stage is known as ‘forge stage’. The rotating work piece is made stationary by applying the brake. The temperature is decreasing at the interface, while the forging pressure is still being applied. The duration of this process depends on how long the temperature cools down on the required upset. At the end of this stage, the weld is completed.

3.3 DESCRIPTION OF FRICTION STUD WELDING MACHINE

In the present work, fabrication of Friction Stud Welding machine is envisaged by doing certain modifications in a lathe (Type A141, PSG, and Coimbatore). The critical parameters involved in friction stud welding are welding time, rigid clamping, axial pressure, forging pressure and instant stopping of rotating object. Hence, for instant stopping of the rotating object held in the chuck, an effective brake system is mandatory. To provide uniform axial & forging pressures to the stud against the rotating object in the chuck, a
pneumatic circuit is implemented. For rigid clamping of the stud, a stud holder is fabricated. The process parameters are controlled using a programmable logic controller. The layout of the friction stud welding machine is shown in the Figure 3.2.

![Schematic representation of the developed friction stud welding machine](image)

**Figure 3.2**  Schematic representation of the developed friction stud welding machine

### 3.3.1  Pneumatic Drive Unit

The simulation of the pneumatic circuit is carried out using Fluid SIM software. The circuit is made as shown in the Figure 3.3 and 3.4. The stud holder is connected to a double acting cylinder and double solenoid operated 5/2 Directional Control Valve. The breaking unit is connected to single solenoid operated spring return Directional Control Valve and a double acting cylinder. The compressed air enters into the pneumatic drive unit through the input of the FRL unit. During the initial stage, the stud holder cylinder would be in its normal position A1 whereas breaking cylinder would be in its advanced position B2 as shown in the Figure 3.3.
Figure 3.3 Simulation of pneumatic circuit in FLUID SIM

When the motor runs, the chuck rotates. After a time delay, the solenoid coil S1 is energized and the stud holder cylinder moves to its advanced position from A1 to A2. This is known as friction stage since the stud rubs with the rotating components and heat is generated. After a time delay, at the end of upsetting, solenoid coil S3 is energized and piston in the braking cylinder retracts from its advanced position B1. A dynamic braking is applied to the rotating chuck and it comes to a halt. When the cycle time is over, the piston in the braking cylinder comes back to its advance position. Meanwhile, solenoid coil S2 is energized and the piston connected to the stud holder retracts to its original position A1, along with the welded component.
3.3.2 Programmable Logic Controller Unit

Figure 3.4 Arrangement of components in pneumatic drive unit

Figure 3.5 Installed PLC unit
For controlling the process parameters during the friction stud welding process, PLC model number: HIO10-08080102 (Make: Renu Electronics, Pune, India) is selected. Human machine interface is provided to add much more versatility than traditional mechanical control panels. Through the serial communications port, the human machine interface is connected to the programmable logic controller (Figure 3.5). The human machine interface can be programmed to monitor and/or change current values stored in the data memory of the PLC.

### 3.3.3 Ladder Programming

The PLC unit possesses both operator interface known as Prizm as well as programmable logic features. User can implement logic, specific to application using standard Ladder programming. The HIO unit has four High speed counters (5 K Hz.), hundreds of timers and counters, thousands of internal coils, retentive and non-retentive memory. A programming logic task can be programmed for continuous scanning, or only when a specific screen is showing.

The ladder programming for the execution of friction stud welding process is shown in Figure 3.6. X0001 represents the cycle start, green push button and X0000 represents the mushroom shaped emergency stop, red push button. When the cycle start green push button is pressed, the output coil B0000 is energized as seen in rung 1 of the ladder. Non-retentive TOFF timer T0001 in the fourth rung is triggered and the motor runs for a preset value.

When the input B0000 to the non-retentive TOFF timer T0001 in rung five is active, the output B0020 is turned on and the time register starts decrementing from the preset value. During this time the motor starts running and the chuck rotates with the component B0020 input to the non-retentive
ON timer T0004 in sixth rung active and the output coil B0100 will turn on after preset dwell time.

Once the input B0100 to non-retentive TOFF timer T0002 in the seventh rung is turned ON, the corresponding time register starts decrementing from the pre-set value of friction time. Meanwhile the input B0100 in the tenth rung is active and solenoid coil S1 is energized. The output coil Y0006 is active and the piston connected to stud holder comes to its advanced position. The component attached to the stud holder rubs with the rotating component and frictional heating takes place. This is referred as friction stage.

![Ladder diagram](image)

Figure 3.6 Ladder programming using Prism operator interface
As soon as the preset time for friction stage is reached, the output coil B0200 in the eighth rung is active and upsetting takes place for a preset value of non-retentive TOFF timer T0003. Simultaneously, the input B0200 in twelfth and thirteenth rung is active. When the output coil Y0007 is energized, the piston connected braking cylinder retracts applying dynamic braking to the rotating chuck and the component held at the chuck comes to an immediate halt. At the same time, the output coil Y0000 is energized and the power supply to the motor is cutoff as shown in the thirteenth rung of the ladder. When the cycle time is over, the solenoid coil S2 is energized and the output coil Y0005 is active. Thus piston connected to the stud holder retracts to its initial position. This sequence of operations is repeated for each cycle.

At the time of emergency, when the mushroom shaped red push button is pressed, the bit specified by the operand B0000 is turned off. When the emergency button is released, output coil B0500 is active and the piston connected to the stud holder retracts. After pressing the reset button, the machine gets ready for the cycle start.

3.3.4 Installation of Dynamic Brake System

![Dynamic braking arrangement](image)

Figure 3.7 Dynamic braking arrangement
A brake system is indispensable for the welding of studs. Figure 3.7 shows the braking arrangement made by means of a simple band brake. A simple band brake has a brake drum. A belt is wound around the brake drum whose one side is attached to a fixed end and the other side is attached to a movable end. The fixed end is the slacking side and the movable end is the tight side. A lever arrangement is provided to apply less effort while actuating the brake. Using a limit switch, the motor power gets cut-off simultaneously while the brake lever is actuated.

For cylinder bore 40 cm, Stroke length 50mm and with 1118.54 W motor, the torque can be calculated by using the following formula.

\[
\text{Torque, } T = \frac{P \times 60}{2 \pi \times N} 
\]  
(3.1)

When the rotational speed is 1600 rpm,

\[
\text{Torque} = \frac{P \times 60}{2 \pi \times 1600} 
\]  
(3.2)

\[
\text{Torque, } T_{1600} = 6.67 \text{N/m}^2 
\]  
(3.3)

When the rotational speed is 1150 rpm,

\[
\text{Torque} = \frac{P \times 60}{2 \pi \times 1150} 
\]  
(3.4)

\[
\text{Torque, } T_{1150} = 9.29 \text{N/m}^2 
\]  
(3.5)

When the rotational speed of the spindle is 1150 rpm,

\[
\text{Torque} = \frac{P \times 60}{2 \pi \times 800} 
\]  
(3.6)

\[
\text{Torque, } T_{800} = 13.35 \text{N/m}^2 
\]  
(3.7)

\[
\text{Area} = \frac{\pi}{4} \times R^2 
\]  
(3.8)

\[
= \frac{\pi}{4} \times (20 \times 10^{-2})^2 = 0.0314 \text{ m}^2 
\]  
(3.9)

\[
\text{Thrust} = \text{pressure} \times \text{area} 
\]  
(3.10)

\[
= 7 \times 10^5 \times 0.0314 = 21991.15 \text{ N} 
\]  
(3.11)
3.3.5 Fabrication of Stud Holder

Figure 3.8 Stud holder assembly

The purpose of stud holder is to hold the stud. The stud is screwed into a morse taper which is fitted in the front end of the stud holder. The front end of the stud holder is machined to suit the morse taper. The rear end of the stud holder is machined to suit the rod end of the pneumatic cylinder. At the bottom of the stud holder, two holes are drilled and tapped so that it is fastened to the sliding plate with bolts. The sliding plate slides in the guide ways as shown in the Figure 3.8. The guide ways are fastened to a base plate by means of four allen screws. The base plate which contains the stud holder assembly and the pneumatic cylinder, replaces the compound rest of the lathe.

3.4 PREPARATION OF WELD SPECIMENS

Before friction stud welding process, the samples should be prepared well to ensure sound joint. While joining the components made of aluminum surface impurities, oxide layer, grease or oil get trapped in the interface and decrease the joint strength. Usually, newly machined components are used to evade problems due to contamination.
3.4.1 Faying Surfaces

Foreign matter such as scale, rolling or casting skin, thick oxide films, drawing or forging powder residue, lubricants, bonding agents must be removed from the faying surfaces. They impair the development of frictional heat. Carbonizing layers in the joint area should be avoided; alternatively, the depth of the respective layers ought to be so thin that they will readily be removed by the welding process. When joining dissimilar materials, the welding geometry must be adapted to the specific nature and condition of the materials employed.

3.4.2 Clamping of Components

Both torque and axial forces needed for friction welding must be able to be transmitted by the clamping system. To contain these forces, adequate contact lengths for gripping, fully or partially fitted clamps or perhaps the use of an end stop, is needed. Fully fitted clamping is advisable where the gripping lengths are limited and for finished machined parts. The gripping surfaces must be kept clean at all times. Component overhang, i.e. the part sticking out from the clamping jaws, should be kept as short as possible to avoid vibration and lateral deflection. It must, however be long enough for the ensuing gap to allow the upset flash to extrude unhindered.

\[
\text{Component overhang} = \leq 1.5 \times \text{diameter} \quad \quad (3.12)
\]

3.4.3 Additional Length for Axial Shortening

The additional component length depends essentially upon the material used, on the preparation of the faying surfaces and on the welding parameters. For each individual weld joint it may vary within 1 – 15 mm.
With tubular components, it is greater than with solid materials of identical cross-section.

3.4 EXPERIMENTATION

Figure 3.9 Developed friction stud welding machine

In the developed friction stud welding machine (Figure 3.9) experiments were carried by varying the process parameters such as rotational speed, friction time, friction pressure, forging pressure and forging time. The range of process parameters of the developed friction stud welding machine is given in Table 3.1.

Figure 3.9 shows the full view of the developed friction stud welding machine. A compressor is connected to the pneumatic control unit. For compactness, the pneumatic components are kept in an exclusive compartment and PLC unit with human machine interface, in another compartment.
Initially air is supplied to the FRL unit with the help of a compressor. The stud holder cylinder would be in its normal position whereas braking cylinder would be in its advanced position (Figure 3.10a). Now the solenoid valve on the left side of the 5/3 Direction Control Valve is energized. The air passes through the pressure regulator which is set at lower pressure. This axial force pushes the cylinder to a predefined distance. The pressure applied during this stage is called friction pressure (Figure 3.10b). After a set friction time, the solenoid valve on the right side of the 5/3 Direction Control Valve is energized. So air passes through the pressure regulator which is set at higher pressure. This pressure applied during this stage is called forging pressure (Figure 3.10c). Again after a set forging time, the solenoid valve on the left side of the 5/3 Direction Control Valve is energized. This actuates the
piston in the braking cylinder and the brake is applied. Simultaneously, the motor is turned off and the welding is completed (Figure 3.10 d).

### Table 3.1 Range of process parameters

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Friction pressure</td>
<td>200 to 600 kPa</td>
</tr>
<tr>
<td>2</td>
<td>Friction time</td>
<td>2 to 10 seconds</td>
</tr>
<tr>
<td>3</td>
<td>Forging time</td>
<td>2 to 10 seconds</td>
</tr>
<tr>
<td>4</td>
<td>Forging pressure</td>
<td>200 to 800 kPa</td>
</tr>
<tr>
<td>5</td>
<td>Rotational speed</td>
<td>800 to 1600 rpm</td>
</tr>
</tbody>
</table>

### 3.5 JOINING OF SIMILAR AND DISSIMILAR METALS

![Image](image.png)

**Figure 3.11** Joining of similar and dissimilar metals of different diameter

In the newly developed friction stud welding machine, joining of dissimilar metals in different combinations were tried out. Combinations such as aluminum alloy/stainless steel, aluminum/mild steel, aluminum/copper and aluminum/brass were successfully welded. Welded components of similar and dissimilar metals of different diameter are shown in Figure 3.11. Welded
components of similar and dissimilar metals of same diameter are shown in Figure 3.12.

Figure 3.12 Joining of similar and dissimilar metals of same diameter

Figure 3.13 shows friction stud welded joints of different combination such as AA 6063/AISiC, AA 6063/brass, AA 6063/copper,
AA 6063/AISI 304 steel and AA 6063/AISI 1030 steel. A detailed investigation on mechanical properties and micro structural aspects has been explained in the subsequent chapters.

3.7 SUMMARY

The newly developed welding machine is made by modifying a conventional lathe by installing brake system and replacing compound rest by stud holder assembly. The in-house made friction stud welding machine is ecofriendly and cost effective. It offers the following benefits:

- Similar and dissimilar studs can be welded with ease.
- No defects due to solidification, since there is no melting.
- No filler, flux, consumables or shielding gases required.
- Eco-friendly, no smoke, fumes, or gases
- No weld spatter

Mechanical evaluation shows that the strength of the joint is comparable to the strength of the base metal. Hence, this product would be useful to small scale industries and machine shops. The present work offers an affordable add-on unit to convert lathe into welding machine without disturbing the functionality of lathe.