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INSTITUTE OF ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Study of The Effect of Friction stir welding parameters for joining Nylon and Aluminum plate and Comparative study of Tig Welding Method"** Submitted by Ritesh Sapkota in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Systems Design and Engineering.

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Date:6th October, 2023

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Study of The Effect of Friction Stir Welding Parameters for Joining Nylon and Aluminum Plate and Comparative Study of TIG Welding Method

by

Ritesh Sapkota

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND

AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN

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LALITPUR, NEPAL

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ABSTRACT

Friction stir welding has shown positive outcome in joining thermoplastics, aluminum, surpassing traditional methods due to the heat generated by the friction than a direct flame. This experimental study explores the possibility of joining different materials through various criteria such as position alteration, tool rotation and offset. Tig welding of aluminum and friction stir welding (FSW) of nylon were used to create the butt joint of aluminum and nylon with a plate thickness of 6 mm. We conducted an experiment wherein we varied the tool's rotating speed from 180 to 360 rpm while maintaining a consistent traverse speed and a constant feed rate of 25 mm/min to 40 mm/min. It was observed that effective jointing significantly depends on process parameters. The aluminum joint is obtained by changing rotational speed of tool from 900 rpm to 1900 rpm and the microstructure analysis is carried out along with the mechanical properties study of material. The microstructure analysis of weld is done using optical microscope and mechanical properties of weld is obtained using UTM. The obtained tensile strength of the Aluminum weld using FSW is higher in comparison to the TIG welding. The welding strength regained is nearly 41.3% by the FSW and 15.6% by TIG welding. Coarse grain is obtained at the weld nugget in the FSW and finer grain is obtained in case of TIG Welding. Weld is less brittle in FSW than TIG Welding as the % elongation is 3.24 in FSW and 0.76 in TIG welding.

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LIST OF ACRONYMS

FSW	Friction Stir Welding
PP	Polypropylene
UTM	Universal Testing Machine
FW	Friction Welding
RFW	Rotary Friction Welding
GTAW	Gas Tungsten Arc Welding
TIG	Tungsten Arc Welding
UTS	Ultimate Tensile Strength

CHAPTER ONE: INTRODUCTION

1.1 Background

Without welding the modern fabrication process is not possible. It is a fabrication process that involves the joining of materials of similar and dissimilar mechanical and chemical properties.

In the 19th century, Sir Humphry Davy discovered the electric arc, paving the way for the development of carbon arc welding, fusion welding & bare metal electrode welding. The first intentional use of torches to melt metal was observed when the one tried one to break into a bank vault during robbery.

The 20th century witnessed the advent of thermite welding in 1903 and alternating current welding in 1919, invented by C.J. Holslag. The latter method became the most common type of welding in the US, replacing electric arc welding. The First and Second World Wars saw a sharp increase in the demand for welding. As a result, in order to increase the manufacture of various welding tools, President Woodrow Wilson founded the United States Wartime Welding Committee.

Currently, there are over 90 existing welding processes, which has been evolving more due to research in the industries such as nuclear, space, automobiles and shipbuilding. The development of different metals, polymers and plastic materials has played a significant factor in design and manufacturing while considering different factors like mass, strength and cost etc.

Although plastics have been significantly in use for many years, most parts were made using molding, so welding wasn't taken as crucial. However, the emergence of adhesive bonding, mechanical fastening in the aerospace industry's use of high-performance composites generated from thermoset-resin-based unidirectional laminates brought it into highlight. Consequently, plastic and plastic composite welding enhances importance for various reasons.

Nowadays, lightweight materials are mixed and welded to create the necessary structures and different parts for cars, ships, and other vehicles. Plastic welding can be done using several methods, including direct flame or heat generated through other mediums. The materials composition used in plastic and the type of weld determine the weld's strength. Generally, the weld strength obtained is about 90% of the strength of original material had.

There are three different techniques which has been used for the process of fabricating different metals & thermoplastic which are generally known as solid state welding, Mechanical Fastening &Adhesive Bonding. As the process advances, Friction welding was started on 1950s and used widely for joining the circular section of dissimilar and similar materials. Fig 1-1 represents the Rotary Friction welding process for joining dissimilar materials i.e., Aluminium and steel. Automotive rotary friction welding is typically employed in the process of lightening vehicles as carbon steels give way to high-strength steels and nonferrous substitutes.

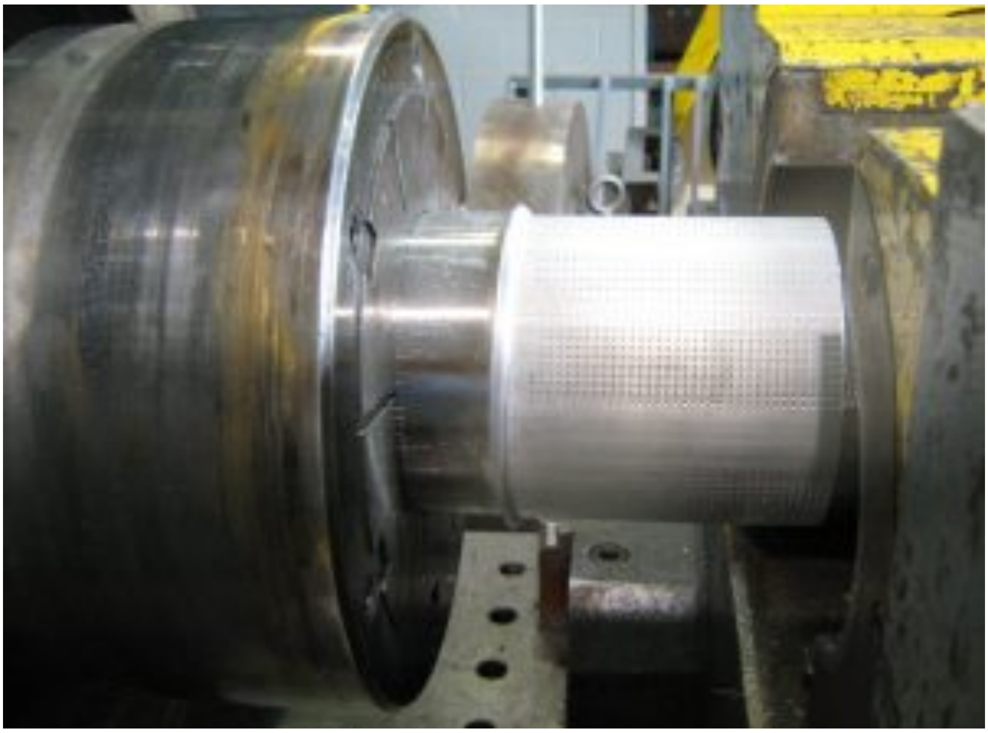


Figure 1-1: Friction Welding (Sato et al., 2015)

First, aluminum alloy is joined using the Friction Stir welding technique, which TWI patented in 1991. Metals that are at or below their melting point can be joined using the solid-state welding (FSW) procedure using a non-consumable tool (Sato et al., 2015). This technique is environmentally friendly as it doesn't produce fumes and uses a non-consumable tool.

These days, materials like polyethylene, polypropylene, and PMMA are also joined using this process (Oliveira et al., 2010). In FSW, a cylindrical tool is inserted into the workpiece at the point where the shoulder, which is movable at a different speed and has a bigger diameter than the pin, touches the surface. The tool moves during a short dwell time. The material movement in FSW occurs when the tool moves in a clockwise direction which is also known as advancing side.

Conventional welding processes like SMAW, GTAW, and GMAW are not suitable for plastic welding as the direct flame generated results in melting of plastic rather than welding. Despite the high cost of FSW tools for steel, Comparing FSW of steel to traditional fusion welding techniques reveals a number of benefits. Their primary factors are given as: (a) A large heat-affected zone (HAZ) from welding eventually reduces the quality and strength of the welding; (b) external filler metal is needed for joining the base material; External filler metals are not needed when using friction stir welding method. (c) In contrast to friction stir welding, which does not take any form of shielding gas, fusion welding requires shielding gas, which significantly pollutes the environment, in order to eliminate hydrogen embrittlement or other porosity flaws. (d) While fusion welding arcs release dangerous radiations including ultraviolet and infrared radiation, friction stir welding does not create any damaging rays or radiation to the welder and environment and is 100% eco-friendly joining process (Abedini et al., 2017; Avula et al., 2018; Mohan et al., 2021).

Because of the major advantages Aviation, automotive sectors and Ship Building are most likely to be garnished in the coming future. It is also noted that a great deal of work has been done on joining different metals instead of polymers and light metal. Hence there more exploration is required for information regarding Friction stir welding of light metals and polymers.

Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is an arc welding method that uses a non-consumable tungsten electrode to produce the weld.

This method of welding gained rapid popularity in the 1940s for joining materials like magnesium and aluminum. Instead of using slag, by the use of inert gas shield for protecting the weld pool made TIG welding an appealing alternative to other gas and conventional welding. Having high-quality of welding capabilities, TIG has generously contributed to the acceptance of joining of aluminum in different field.

1.2 Problem Statement

Conventional welding methods generally uses filler material for welding the joints of similar metals and High flames is used to join the specimen. Different factors influence the selection of Friction stir welding besides conventional welding's such as High cost, Health factor, Limited Application, Scrap. On Comparison to the conventional welding, Friction stir welding has higher tensile strength (Tribe and Nelson, 2015). The joining of Nylon and nylon is not comfortable as joining of metal by conventional method and studying the composite behaviors is difficult. This is due to great variation in the physical properties, mechanical properties, chemical composition of materials besides having very minimum joining method in current context and technology is still new, thus describing the lack to completely enhance its potential. This study helps to develop important and fundamental understanding of this technology by experimental work performed to obtain the joint of high strength and defect free specimen.

1.3 Objectives

1.3.1 General Objectives

Joining of Nylon and Nylon, aluminum and aluminum by the friction stir welding and Tig welding by varying the welding parameters and its effect on mechanical properties.

1.3.2 Specific Objectives

The specific objectives will be attained by the following auxiliary objectives:

- To analyze quality of welding of Nylon and Aluminum plates by varying the tool speed and feed.
- Comparative study of mechanical properties and microstructure analysis by Friction stir welding & Tig Welding.

CHAPTER TWO: LITERATURE REVIEW

2.1 Friction Welding

The process of joining two metallic surfaces by the frictional heat produced at their interface as a result of applied relative motion is known as friction welding. The first experimentation of rotary friction welding was carried out by Machinist A.J. chdikov in the Soviet Union in 1956.

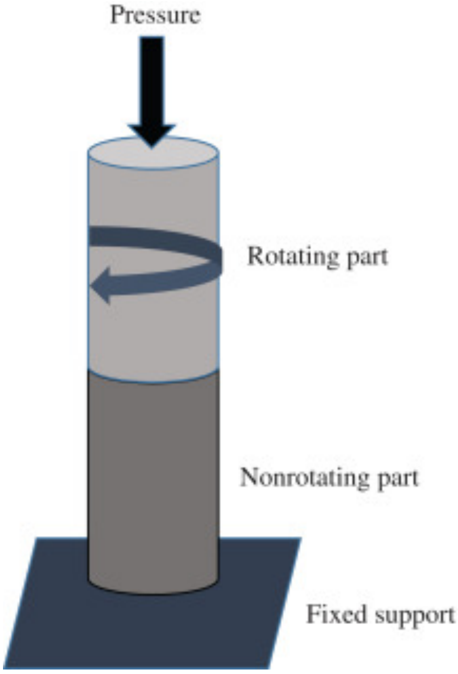


Figure 2-1: Rotary Friction Welding (Sato et al., 2015)

As seen in Figure 2-1, the equipment spindle motor continuously drives the rotating part. When the metal part rotates to the non-rotating metal, friction is generated on the joint such that the two metals is joined which is known as the Friction welding. Metals with circular cross section are joined by this process.

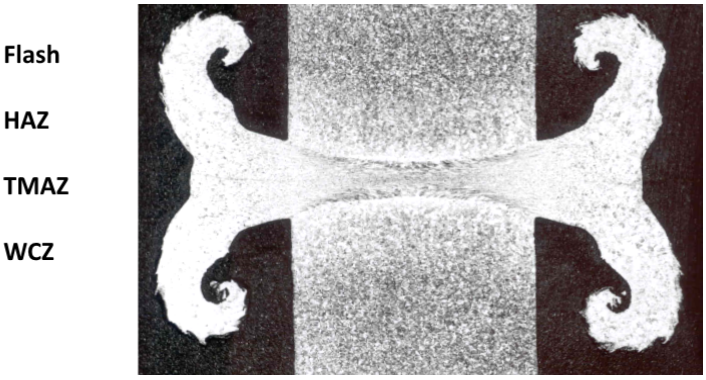


Figure 2-2: A Macroscopic image of weld joint by rotary friction (Sato et al., 2015)

The appearance of rotary friction welds is similar because they have multiple distinct zones: the heat affected zone (HAZ), the thermo-mechanically affected zone (TMAZ), and the weld center zone (WCZ). The material and processing conditions used determine the size and microstructural makeup of these zones. A flash collar surrounds the weld section. Figure 2-2 displays a typical example of a titanium alloy weld.

2.2 Development of Friction Stir Welding

The Friction Stir Welding (FSW) process, which was developed by The Welding Institute (TWI), was invented and patented in 1991, referring to novel terms for a manufacturing process at that time. Figure 2-3 displays a schematic representation of the friction stir welding process. FSW is an adaptation of the widely used friction welding technique, which joins metal by heating it frictionally. The joining method known as friction welding has been in use for more than a century. Mentioned method is generally known for joining material which

is in rod or iron form and mostly for the circular surface as the rotational motion produces frictional effect.

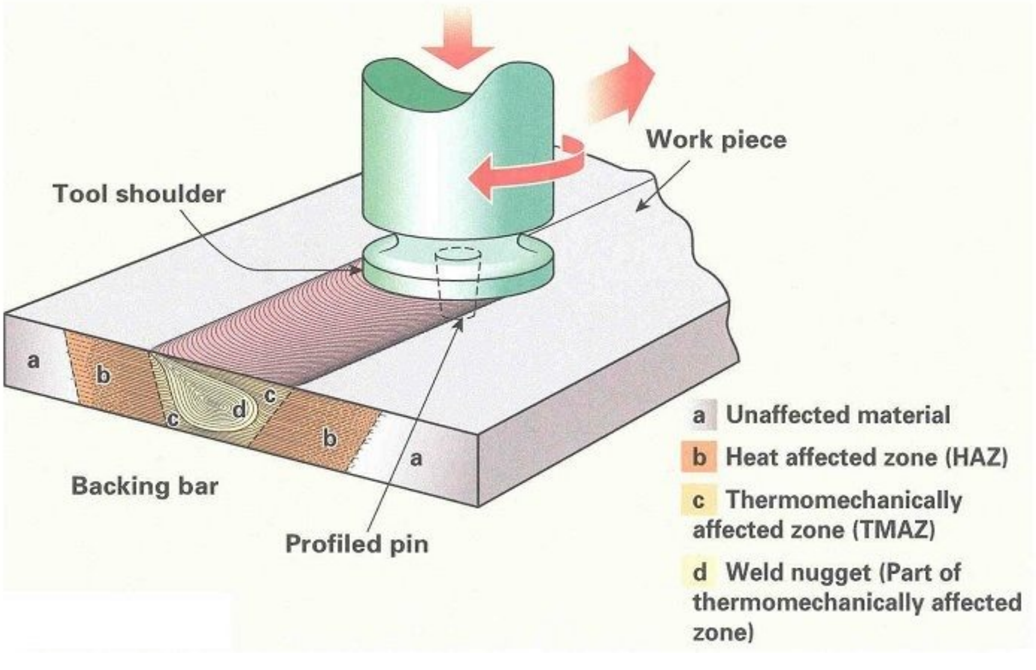


Figure 2-3: Welding zones

Different Zones formed around the weld surfaces which are shown in the above Figure 2-3. The development of different layers is denoted by A = unaffected material; B = Heat Affected Zone; C = Thermo-Mechanically Affected Zone.

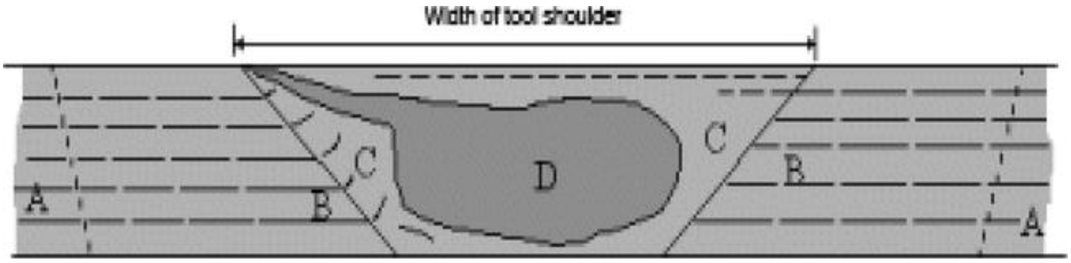


Figure 2-4: Different regions during welding

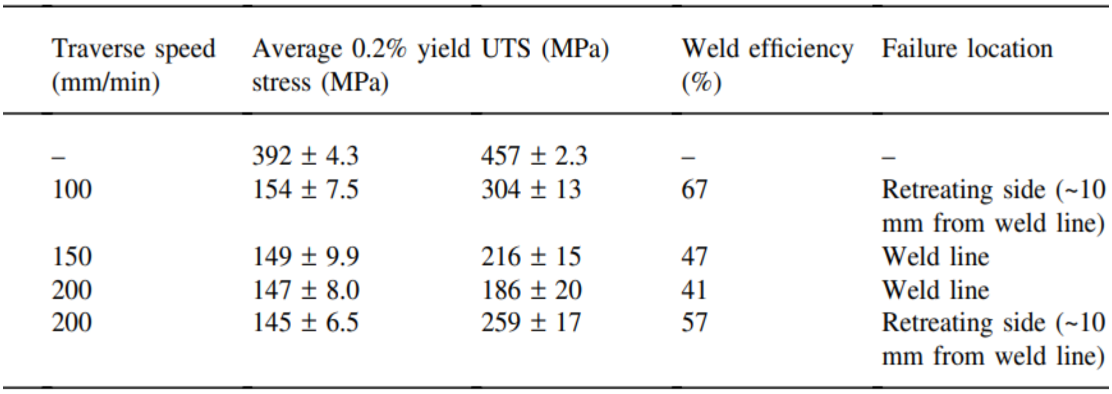
Figure 2-4 depicts the various areas that formed during the friction stir welding process. Weld denotes weld zone and C denotes different section of FSW weld joint which indicate the layer that forms during the process.

FSW is a solid-state joining method used for metallic and some polymeric materials. It is typically used in applications where the microstructure and properties of the original material must be preserved as much as possible after joining.

2.3 Effect of different welding parameters on Aluminum

According to Table 2-1, (Peel et al., 2003) used AA5083 aluminum alloy for FSW by altering the welding parameters, such as tool design, rotation speed, and translation speed. Investigations into the microstructural, mechanical, and residual stress of four aluminum AA5083 samples showed that the heat input, not the tool's mechanical deformation, determines the welding parameters.

Table 2-1: Welding efficiency and UTS at Different Transverse Speed



Traverse speed (mm/min)	Average 0.2% yield stress (MPa)	UTS (MPa)	Weld efficiency (%)	Failure location
–	392 ± 4.3	457 ± 2.3	–	–
100	154 ± 7.5	304 ± 13	67	Retreating side (~10 mm from weld line)
150	149 ± 9.9	216 ± 15	47	Weld line
200	147 ± 8.0	186 ± 20	41	Weld line
200	145 ± 6.5	259 ± 17	57	Retreating side (~10 mm from weld line)

The tensile, or mechanical and fatigue, behaviour of friction stir welding of 2024 and 7075 alloys was investigated by (Cavaliere et al., 2006). It was discovered that 7075 fails in the tensile test because of a reduced fatigue life, and 2024 fails because of a lower hardness.

Lap joint was conducted by W. Ratanathavorn between aluminium and nylon where he talk about the fracture occur in joint area. A specially-designed cylindrical, shouldered tool with a small diameter pin is rotated and plunged into the joint line between two butted plates to produce FSW.

2.4 Study of the Friction stir welding experimentation

Heat is produced by friction during the Friction Stir Welding (FSW) process, which softens the metal and permits the tool to move along the joint line. To keep the two plates from separating or lifting during the welding process, they are firmly clamped onto a strong backing support.

After that, the welding tool-which consists of a pin, shoulder, and shank—is rotated at the predetermined speed. The tool is inserted gradually at the butt line into the material until the pin is barely visible from the back plate and the tool's shoulder makes firm contact with the upper surface of the material.

This contact is maintained by applying a downward force, and a short dwell time is noted to permit the formation of thermal fields. In the joint line, this warm and softens the material. The tool is then forcefully moved along the butt line until it reaches the end of the weld by applying a lateral force in the direction of the welding (travel direction).

2.5 Determination of the different zones developed during the welding

In a study conducted by (Adamowski et al., 2006) the friction-stir welding of aluminum alloy was examined. It was discovered that there is a direct correlation between the travel/welding speed and the tensile strength of FSW welds. The weld region showed a reduction in hardness, with the heat-affected zone on the advancing side of the welds showing the most obvious softening. In tensile tests, this region matched the failure location.

For FSW-03, at the speed of 190 rpm, three distinct zones began to form at the intersection of the welding nuggets, the thermomechanical Therma, and the flow arm, which is a material flow from the welding nuggets to the joint edge on the advancing side. These zones separated, forming the origin of a tunnel defect, as illustrated in Figure. 2-5.

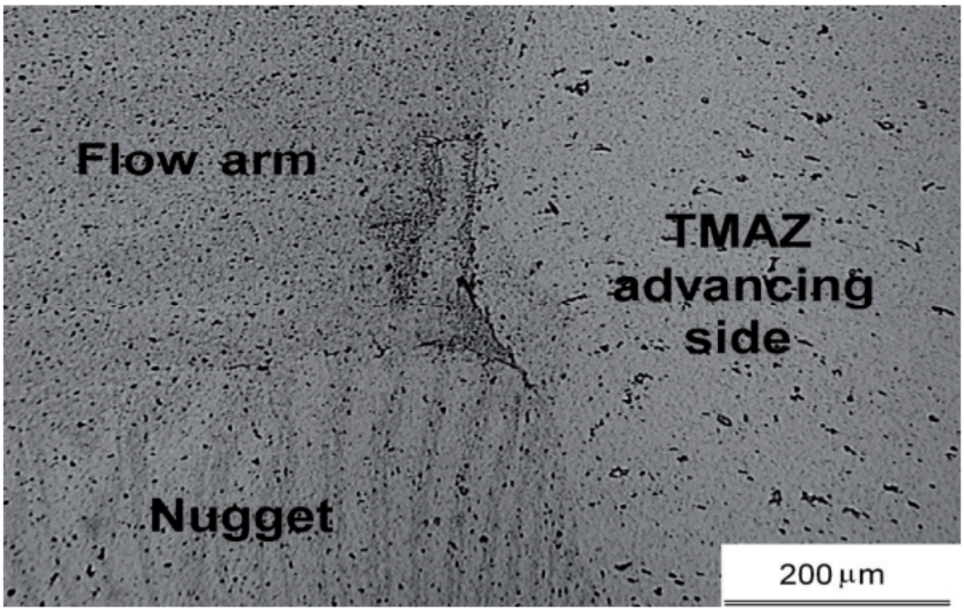


Figure 2-5: Microscopic image of Weld Zone (Adamowski et al., 2006)

2.6 Effect on Tensile strength with the variation of Tool speed

In order to analyze the impact on the alloy's mechanical and metallurgical properties, (Sakthivel et al., 2009) changed the traverse speed from 50 mm/min to 175 mm/min while conducting an investigation into the effects of various welding speeds during friction stir welding (FSW). As the traverse speed increases during tensile testing, it was found that the ultimate tensile strength decreases (Figure 2-6). This is explained by the inadequate heat input produced at faster velocities. Whereas at low weld speed, more heat is generated.

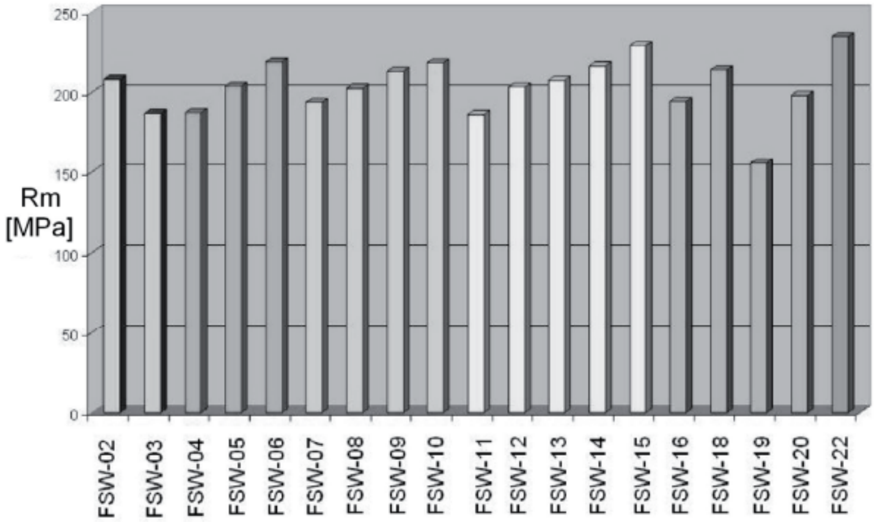


Figure 2-6: FSW at Diff Speed vs tensile Speed (Adamowski et al., 2006)

2.7 Mechanical properties obtained of Polycarbonate at varying speed

An Indian scholar named Santosh Kumar Sahu conducted an experiment on polycarbonate sheets and concluded that a rotational speed of 700 rpm was the optimal for achieving maximum efficiency. The tensile strength of the polycarbonate sheet weld at various tool speeds is shown in Figure 2-8. The tool's X-axis indicates its rotational speed, and the Y-axis shows its tensile strength.

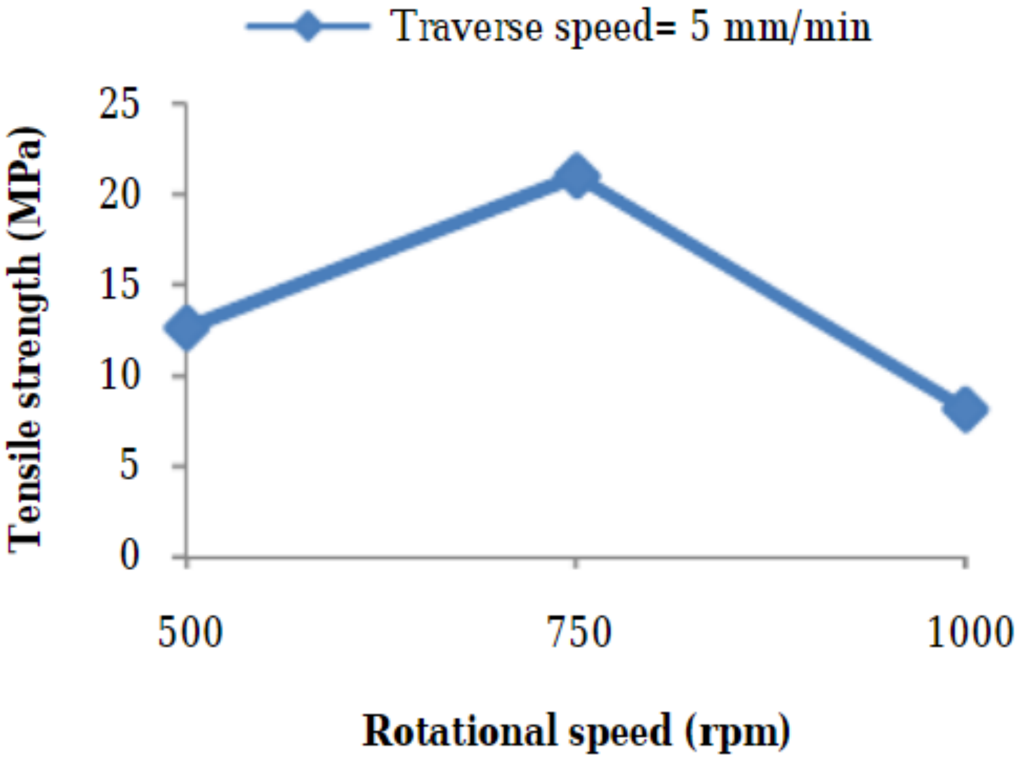


Figure 2-7: Tensile Strength vs Rotational Speed (Sahu, 2018)

2.8 Experimental Study of Tig Welding

The properties of Tig welding for 6061 and 7003 aluminum alloys were investigated (Zhu et al., 2021). The technology utilized in the aerospace industry is employed to conduct the experimental procedure. Weld porosity typically results from a flaw in the tig welding of aluminum alloy. According to the experimental investigation, the 6061-T6 alloy TIG welding sample with a 6 mm thickness groove has a tensile strength welding coefficient of 31.3%. The tensile strength of 6mm thick welding wire is 59.3%. The tensile strength increases as the procedure's wire thickness decreases.

The impact of pulsed tig welding on the weld is investigated (Arif and Kumar, 2021). The current study's welding speed is automatically controlled by a PUG machine that is linked to a TIG machine. Given the observation that the fusion zone's grain size decreases as welding speed increases, this could be the result of a change in heat input. Additionally, as figure 2-8 illustrates, it has been noted that as welding speed increases, the welded joint's ultimate tensile strength (UTS) decreases.

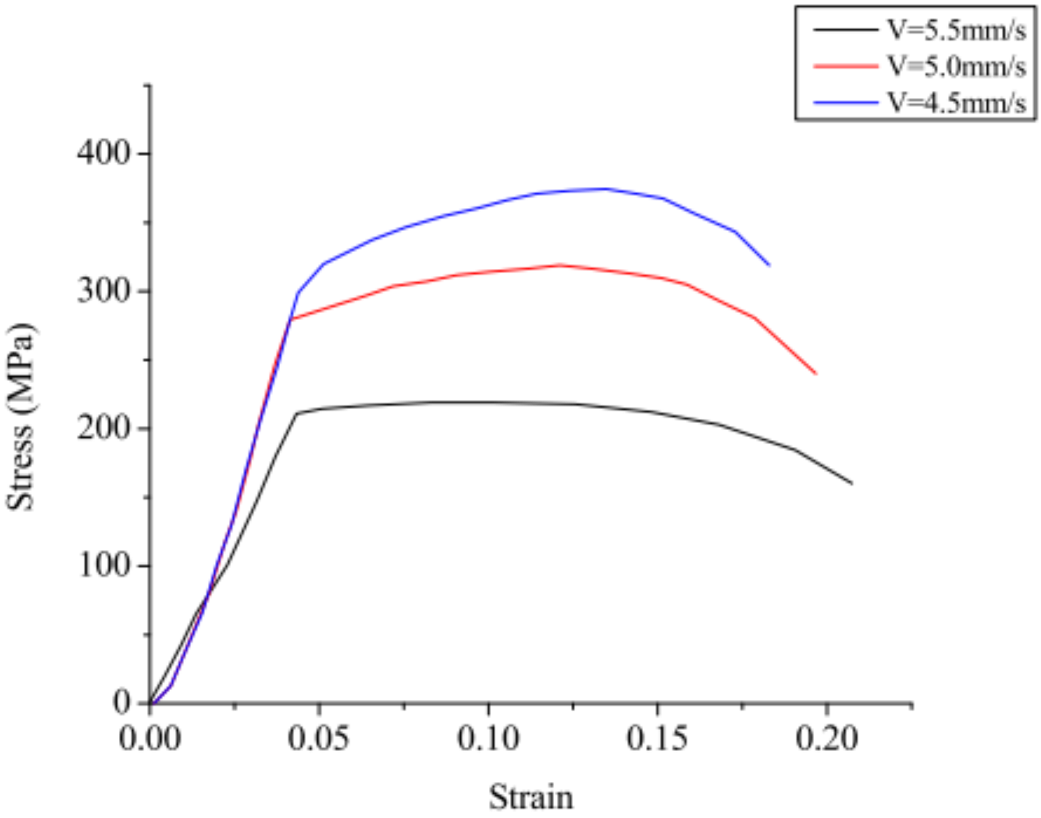


Figure 2-8: Stress & Strain curve at various speed (Kumar and Arif, 2021)

2.9 Comparison of Friction Stir welding with conventional welding

In order to support its application over more traditional techniques, Friction Stir Welding (FSW) is frequently compared to other welding processes. Understanding the features of the process in great detail is essential for using FSW successfully since it enables the creation of a strong technical and financial case.

During laser welding, the heat generation is at its maximum. However, this can lead to degradation of polymers before the metal, which is why the Friction Stir Welding (FSW) technique is preferred.

Use of aluminum & plastic provides a high degree of flexibility in both the design and manufacturing of products, making the fabrication or joining process extremely important.

According to Ghosh et al. (2011), advanced high strength steel (AHSS) has a dearth of friction stir welded joints. Nonetheless, they noted that the possibilities provided by Friction Stir Welding (FSW) and Friction Spot Stir Welding (FSSW) allow for the joining of sophisticated high-strength steels and the reduction of problems associated with Resistance Spot Welding (RSW).

Because of its distinct qualities, FSW is preferred over conventional arc welding techniques for a number of reasons. The primary point that justifies importance of FSW over other process include:

- Improved weldability
- Corrosion free, reduced residual, better fatigue stress at the joint
- Higher ductility and Strength

2.9.1 Improved Weldability

Some aluminum alloys and materials, such as castings, are difficult or impossible to fuse using traditional arc welding techniques because of flaws in the formation of brittle phases and cracks. When connecting various aluminum alloys, such as Al 2024/Al 7075, friction stir welding produces a junction with flawless welds.

2.9.2 Corrosion free, reduced residual, better fatigue stress at the joint

Friction stir welded joints only function better under fatigue conditions when they reach ideal microstructure configurations. The procedure generates the optimal temperature and strain rate conditions for butt joint microstructure production, which results in sound welds, when the revolutionary pitch is between 0.07 and 0.1 (Cavaliere et al., 2009).

2.9.3 Higher ductility and Strength

Unlike FSW, even with the right filler metals, the high temperature and sluggish material deposition rates of arc welding may damage the Heat-Affected Zone (HAZ). Both method joint strengths in thin-section aluminum alloys are frequently equivalent. Nonetheless, the ability of FSW to be completed in a single pass can result in noticeably better joint strength and ductility for thicker materials up to 75 mm.

2.10 Tool selection and its significance

The choice of tool material is essential throughout the welding process since it directly affects the wear and endurance of the tool as well as the quality of the weld. The quality of the weld can be impacted by the characteristics of the tool material, which can also affect heat generation and dissipation. Interaction with degraded tool material can potentially change the weld's microstructure.

It negatively impacts the microstructure of the weld, and tool wear and durability can raise the cost. During Process, the tool may be subjected to high temperatures, if the tool material has a low yield strength, could result in considerable wear. The tool's ability to withstand stresses depends on the workpiece's strength at elevated temperatures, which are typical during friction stir welding (Tiwari et al., 2018).

2.10.1 Effect of the Tool Geometry

The purpose of this work is to examine how tool geometry factors affect the thermo-mechanical behavior of FSW plates. In this study, welding experiments and a finite-element model were used. The next section goes into detail about the welding tool specifications.

- Mechanical Properties obtained by the conical tool is higher as compared to other. The yield strength obtained was 12% higher to the base metal.
- Based on the simulation results, it was obtained that the conical threaded pin has generated 44% extra heat from plastic and dissipated 6% higher friction the cylindrical pin with a same shoulder diameter friction.

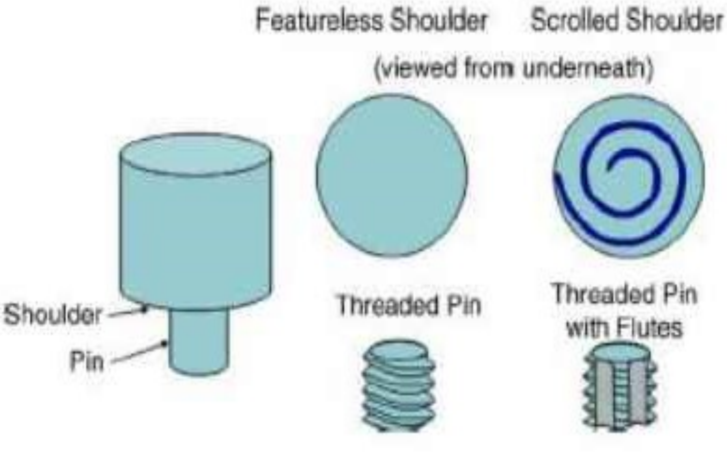


Figure 2-9: Schematic Diagram of Tool

CHAPTER THREE: RESEARCH METHODOLOGY

The experimentation involves the following methodologies shown in the chart. The task Carried out to complete the study is mentioned in this methodology.

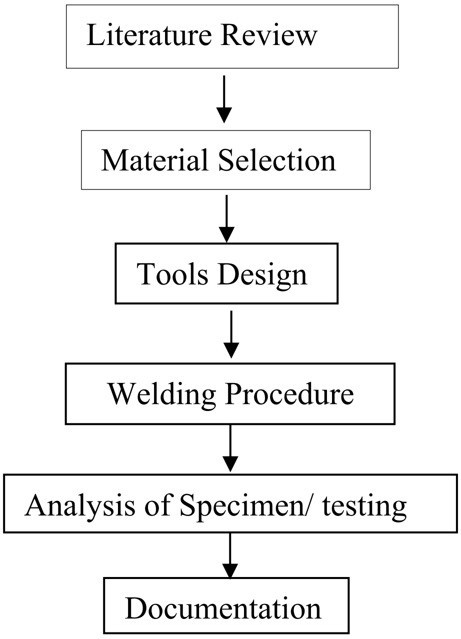


Figure 3-1: Methodology

3.1 Literature Review

The available research papers and experimental results are analyzed. Numerous scholars have examined the impact of a single parameter at a time. However, there hasn't been much research done on the combined impact of the process factors. This work aims to develop important and fundamental understanding for this technology by experimental work performed to obtain the joint of high strength and defect free. The material properties have to be studied properly.

3.2 Selection of Work Piece Material

Nylon 6 is it is the first manmade fiber. It is a synthetic fiber called as polymer.

Caprolactam is polymerized to generate a polymer by opening its rings. Heating caprolactam to 250 degrees C and adding around 4% water is the main process used to make nylon 6. 130mm × 45 mm × 6mm of the nylon piece is break down into half piece for the procedure. Chemical formula for Nylon is $(C_6H_{11}NO)_n$ and Tensile strength of Nylon 50-60 KPA.

The Friction stir welding and Tig welding is processed out on Aluminum (6061) Alloy. 120mm × 45 mm × 6mm of Aluminum piece is divided and held in the jig or support clamp for the welding procedure.

3.3 Tool Selection

The design of FSW tool shoulders is typically simpler than that of probes. In basic linear welds, the tool is frequently slanted so that the trailing edge of the shoulder penetrates the work piece and applies additional forging pressure. This means that the tool shoulder does not always run parallel to the surface of the work piece. Frictional heat generation during FSW is greatly influenced by the tool shoulder profile. The maximum heat input comes from tool shoulder shapes with restricted material flow, such the scroll, because of their larger surface area. Therefore, smaller scroll shoulder diameters are employed. Machining of the tool is carried out in the lathe machine.

The high carbon steel tool, as depicted in Figure 3-2, has a shoulder diameter of 19 mm, a pin length of 4.5 mm, and a pin diameter of 5.5 mm at the root and 4 mm at the tip.

Figure 3-2: High Carbon Steel Tool used for friction stir welding

3.3.1 Heat Treatment of the tool

The need of the Heat treatment for the High Carbon Steel Tool is surface hardening. On Heat treatment the previous researcher has attained the tough and hard wearing on welding temperature. After machining the tool, the Heat Treatment of the tool is carried out at around 700 Degree Celsius for the better result of the tool.

3.3.2 Chemical Composition of Nylon6

Nylon6 is composed of different chemical elements such as Carbon, Manganese, Silicon, Chromium. The chemical formula of Nylon is $(C_6H_{11}NO)_n$. It can resist most chemicals, including acids, alkalis, and organic solvents. This property makes nylon-6 suitable for applications that involve exposure to harsh environments.

3.3.3 Mechanical Properties of Nylon 6

The yield strength, ultimate tensile strength of Nylon 6 is 50-90 MPA, 40-100 MPA. At normal condition the maximum percentage elongation of nylon is 5%. The melting temperature of Nylon 6 is 190-280 degree Celsius.

3.3.4 Chemical Composition of Aluminum

The aluminum alloy's constituent elements are as follows: aluminum (Al: 97.9%), magnesium (Mg: 1%), silicon (Si: 0.60%), copper (Cu: 0.28%), and chromium (Cr: 0.20%).

3.3.5 Mechanical Properties of the Aluminum 6061 Alloy:

The Aluminium 6061 alloy has an ultimate tensile strength of 276 MPa. The material has an elastic modulus of 68,9 MPa, a shear strength of 207 MPA, a Poisson's ratio of 0.33, and an elongation percentage of 12–17%.

3.4 Experimental Procedure

For the Nylon welding, the specimen was first cut into 130 mm × 45 mm × 6 mm pieces. A tapered steel tool with the dimensions depicted in fig. has a shoulder diameter of 19 mm, a pin length of 4.5 mm, and a pin diameter of 5.5 mm at the root and 3 mm at the tip. To read the parametric range, the nylon-to-nylon process is first performed. Once the plates are properly positioned using mechanical clamps, they will be fastened throughout their length on a vertical milling machine. The tool rotates together with the chemical formula $(C_{12}H_{22}N_2O_2)_n$ and in a similar manner with the tool diameter, producing heat as a result of friction between the tool and the work piece, which softens the material surrounding the joint area and in the same way, with the tool diameter 22 mm ,pin length of 4.5 mm and pin diameter of 5.5 mm at the root and tip of 3mm. The joint of another specimen of 120mm × 45 mm × 6mm Aluminum 6061 is considered which is composed of different elements mixture.

The new specimen of same dimension of aluminum is again welded by the help of tig welding. The amount of time taken increases on starting the feed from one end to the other. The specimen obtained by the Tig welding is cut into small pieces for the mechanical properties test and Micro structure observation.

3.5 Test for determination of Mechanical Properties and Microstructure Analysis

The Specimen is tested using universal testing machine by applying the load such that the different mechanical properties are observed through the graph. The cut piece of different specimen is applied for the load and the analysis of result is carried out. Microstructure analysis is examined optically which is taken perfectly flat and same level. It is challenging to focus on the entire field of vision on the uneven surface when the viewing area is changed across it. The view obtained and analysis is carried out on 200x and 100 micrometer.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Joining of Nylon and Nylon Plate

4.1.1 Nylon-Nylon Butt joint welding by varying Spindle Speed

Table 4-1 shows the welding of two nylon pieces at the Speed of 180, 250, 360 rpm. At first the Experimentation is carried out by keeping the Feed Constant for each specimen considering the tilt angle as 1 degree and offset 0. Butt Joint is obtained at the welding section of the specimen.

Table 4-1: Experiment with variation of spindle speed and other parameters constant

S. No.	Spindle Speed (rpm)	Feed (mm/min)	Tilt Angle	Material Used	Material Used	Types of Joint
1	180	30	1	Nylon	Nylon	Butt
2	250	30	1	Nylon	Nylon	Butt
3	360	30	1	Nylon	Nylon	Butt

Two Piece of Nylon is Welded by Friction Stir welding. The spindle speed is kept as 180 rpm and feed of 30mm/min is provided. At the start as the tool pin inserted into joint hole is created at the starting point as the tool moves on the transverse direction the growth of flash is observed gradually on the Retracting side. The flash gradually increases as the tool approaches near to the end point. The Front and Backside of the welded specimen can be seen in Fig 4-1 and Fig 4-2.

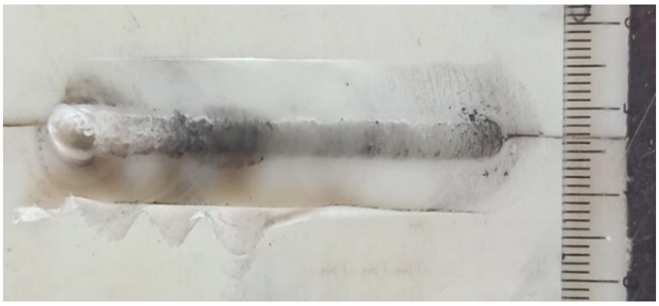


Figure 4-1: Spindle Speed at 180 rpm (Front View)

Figure 4-2: Spindle Speed at 180 rpm (Back View)

Fig 4-3 and 4-4 Represent the Nylon joint at speed of 250 rpm and 25mm/min of feed. As the tool travels on the transverse direction excess flash is generated on advancing and retracting side of the joint piece. The heat generation was more as excess flash was observed at the weld surface and formation of cavity was observed. The weld surface was declined with respect to the speed at 180 rpm.

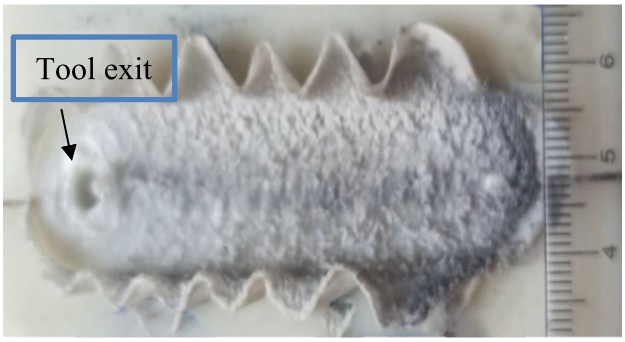


Figure 4-3: Spindle Speed at 250 rpm (Front View)

Figure 4-4: Spindle Speed at 250 rpm (Back View)

The 3rd specimen is welded with the speed of 360 rpm. On observing the flash obtained on the weld joint at the speed of 250 rpm is higher than 180 rpm thus we gave less plunge at the speed of 360 rpm. At the start the weld quality surface seems stupendous and further the flash was seen along with cavity in the weld surface. On visual observation it is seen that at the flash generated area, melting of nylon is observed due to the high speed and heat, which is observed in Fig 4-5.

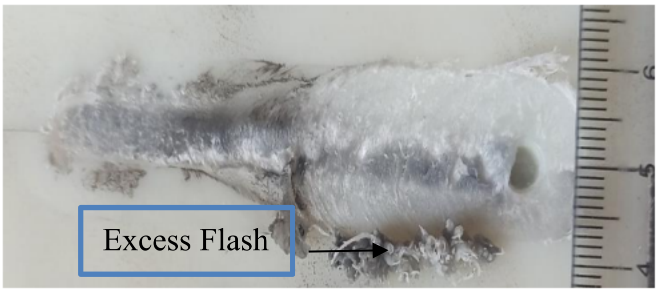


Figure 4-5: Spindle Speed at 360 rpm (Front View)

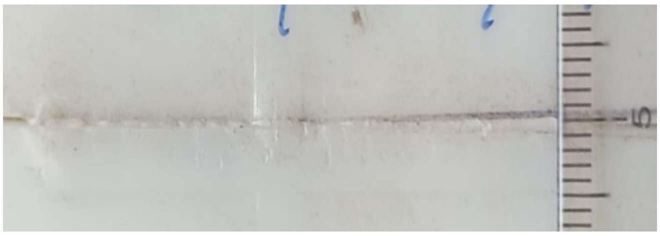


Figure 4 -6: Spindle Speed at 360 rpm (Back View)

4.1.2 Experimentation of Nylon-Nylon Butt joint welding by varying Feed

Table 4-2 shows the welding of two Nylon pieces at the Speed of 250 rpm with varying feed. Experimentation is carried out by keeping the Spindle Speed Constant for each specimen considering the tilt angle as 1 degree and offset 0. Butt Joint is obtained at the welding section of the specimen.

Table 4-2: Experiment by Varying Feed and keeping other parameters constant.

S. No.	Feed (mm/min)	Spindle Speed (rpm)	Tilt Angle	Material Used	Material Used	Types of Joint
1	25	250	1	Nylon	Nylon	Butt
2	30	250	1	Nylon	Nylon	Butt
3	40	250	1	Nylon	Nylon	Butt

The experimental study at 250 rpm with 30mm/min shows better result. Thus at 250 rpm speed with feed of 25mm/ min, the sample obtained is shown in fig 4.7. Some portion at the intersection of the nylon melted obtaining thin weld with excess flash.

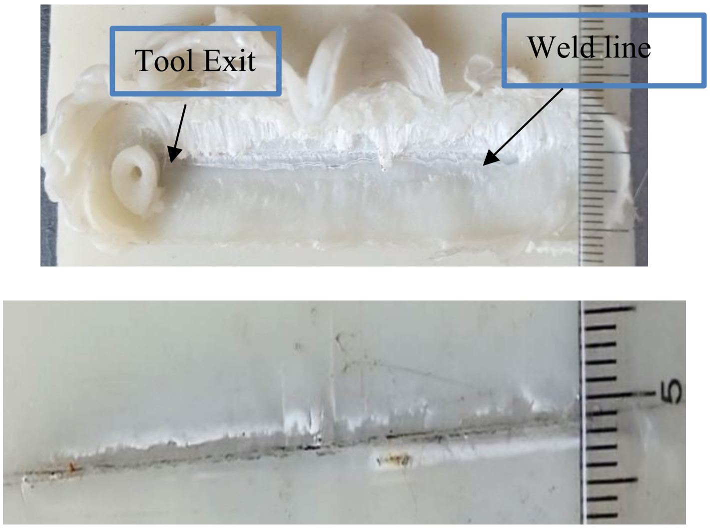


Figure 4-7: Feed at 25 mm/min. (Front & Back View)

The Fig 4-8 represents the weld joint at 30 mm/min at speed of 250 rpm. As the tool travels the flash is observed on the retracting side as well as advancing side. The specimen obtained is somehow similar with the feed at 25 mm/min.

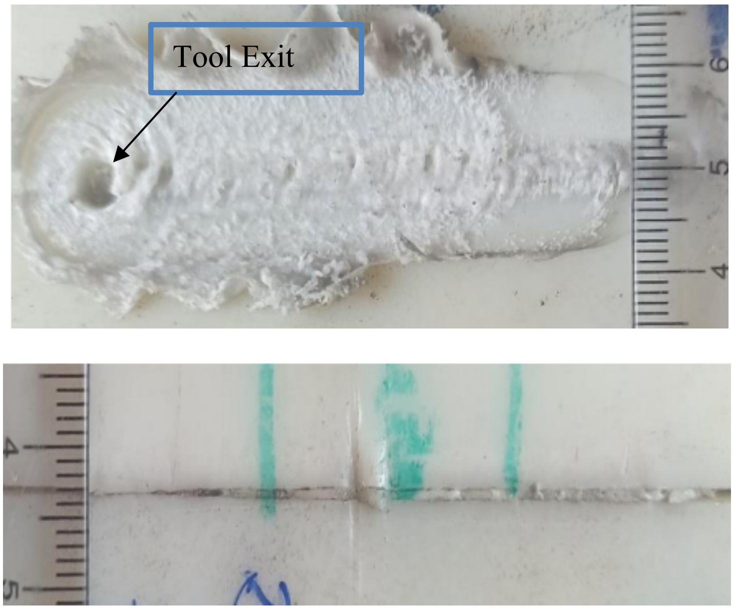


Figure 4-8: Feed at 30 mm/min. (Front & Back View)

Fig 4-9 represents the weld joint at feed of 40mm/min. As the time increases flash production increases making cavity on the weld surface. The flash generated on the surface is more. The joint obtained is not good as compared to the previous sample.

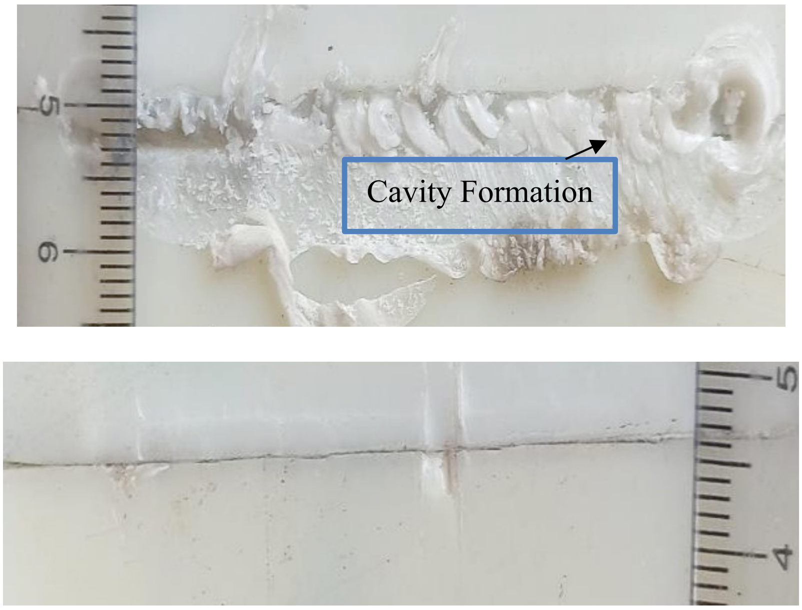


Figure 4-9: Feed at 40 mm/min. (Front & Back View)

4.2 Analysis of Mechanical Properties

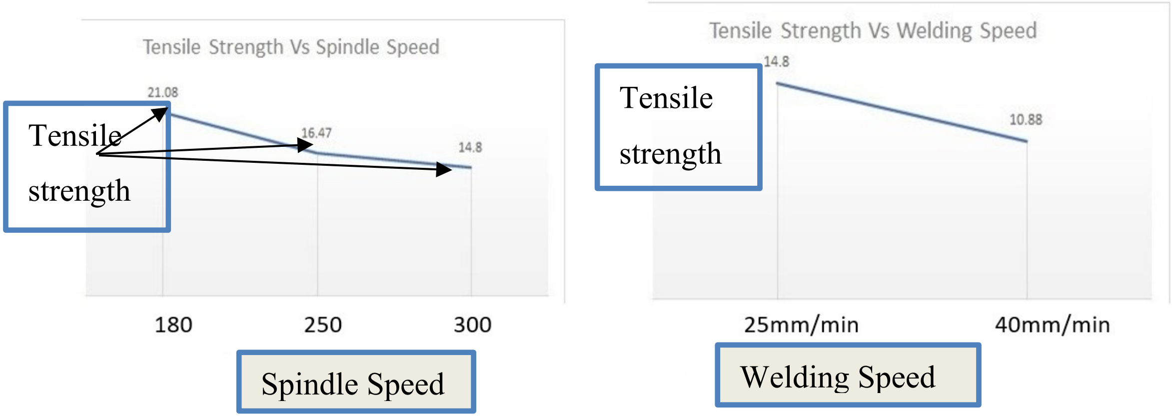


Figure 4-10: Tensile strength vs Welding Speed

The tensile test of various specimen was considered and taken into account for the testing. The cut piece of the specimen was tested in the UTM machine considering strain as 50mm/min during the testing. The graph of the test specifies the variation of spindle speed and welding speed with the tensile strength as shown in Fig 4-10 and 4-11. X-axis denotes the Spindle Speed and Y Axis denotes the Tensile Strength of Nylon.

The specimen with the feed at 30mm/min different specimen obtained by varying spindle speed at 180 rpm, 250 rpm, 360 rpm was tested. At 180 rpm the maximum tensile strength obtained as 21 MPA followed by 16 and 14 MPA. As spindle speed increases, the tensile strength falls as seen in Fig. 4-10.

The specimen obtained on keeping the spindle speed constant and varying feed is analyzed for tensile test. At lower feed the tensile strength obtained is higher. As the feed goes on increasing the tensile strength decreases.

4.3 Joining of Aluminium and Aluminium (6061)

Experimentation is carried out with varying different spindle speed on keeping Feed constant. Table 4-3 represents the Joining of aluminum pieces by changing the spindle speed. At the feed of 25mm/min for the different spindle speed butt joint of aluminum weld is obtained.

Table 4-3: Varying Spindle Speed

S.N	Spindle Speed (rpm)	Feed (mm/min)	Tilt Angle	Material Used	Material Used	Types of Joint
1	900	25	1	Aluminium	Aluminium	Butt
2	1100	25	1	Aluminium	Aluminium	Butt
3	1900	35	1	Aluminium	Aluminium	Butt

4.3.1 Spindle speed at a feed rate of 25 mm/min and 900 rpm.

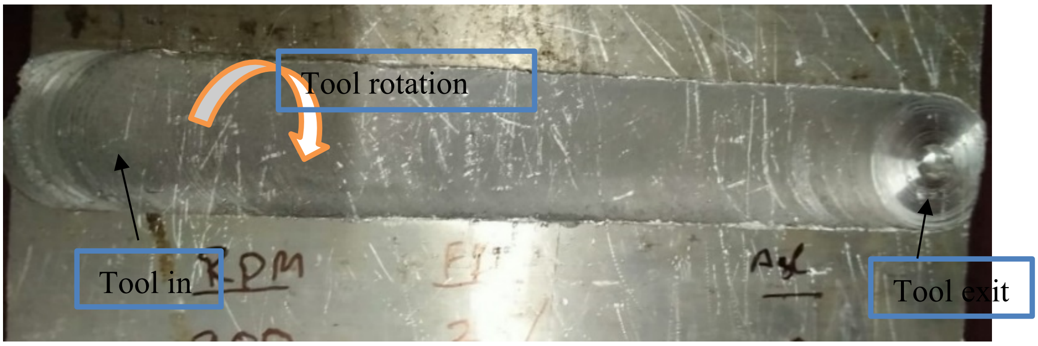


Figure 4-11: Welding at Speed 900 rpm

The specimen of 6mm thick Aluminum 6061 alloy undergo friction stir welding for the joining of two plates. The pin of the tool has been plunged more into the advancing side keeping offset as 1mm and feed of 25mm/min with the spindle speed of 900 rpm is provided. Little bit of external flush has been observed on the ending side of the specimen resulting the outflow of material through shoulder. The Mechanical properties of the sample testing is carried out on UTM machine and the graph obtained is shown in Figure 4-13:

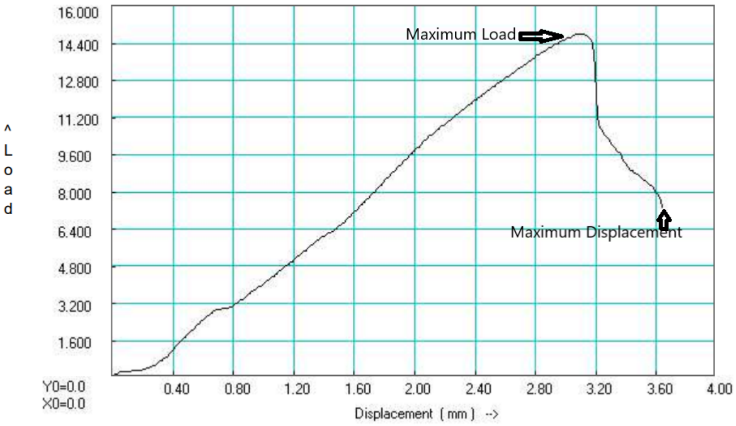


Figure 4-12: Load vs Displacement for Specimen at 900 rpm

The Load vs Displacement Graph as shown in Figure 4-13 is obtained by testing the rectangular piece of aluminum weld on UTM. X-axis represent the Displacement at mm and Y-Axis represent the load at KN. As the load goes on increasing the displacement also increases. At the displacement of 3.10 mm the maximum of load is attained. The tensile strength obtained from the graph is 112.50 MPa i.e., 3 times higher than the strength of joining of the Aluminum 6061 by conventional Welding. The Welded joint has regained nearly 40 Percent of the original Alloy. The sample with original gauge Length of 50mm is provided with the load such that the Final gauge Length obtained on breaking is 51.4 mm. The % Elongation of the specimen is 2.88 The Maximum Force obtained is 14.8 KN, Displacement at Maximum Load is 3.10mm, Maximum Displacement is 3.64 and Yield Load: 13.62 KN. The maximum yield Stress obtained is 103.530 MPa.

4.3.1 Spindle speed at 1100 rpm and feed of 25mm/min

The specimen made of 6 mm thick aluminum 6061 alloy is joined together via friction stir welding. The pin of the tool has been plunged more into the advancing side keeping offset as 1mm and feed of 25mm/min with the spindle speed of 1100 rpm is provided. Little bit of external flush has been observed on the ending side of the specimen resulting the outflow of material through shoulder. The Mechanical properties of the sample testing is carried out on UTM machine which can be observed in Figure 4-15:

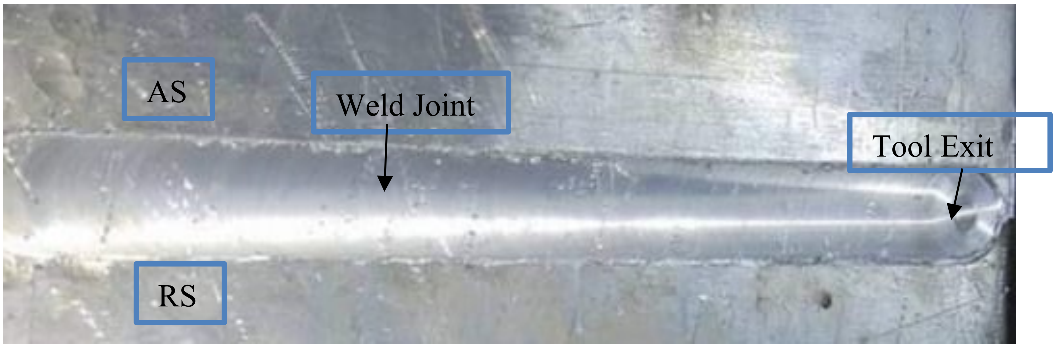


Figure 4-13: Welding at Speed 1100 rpm

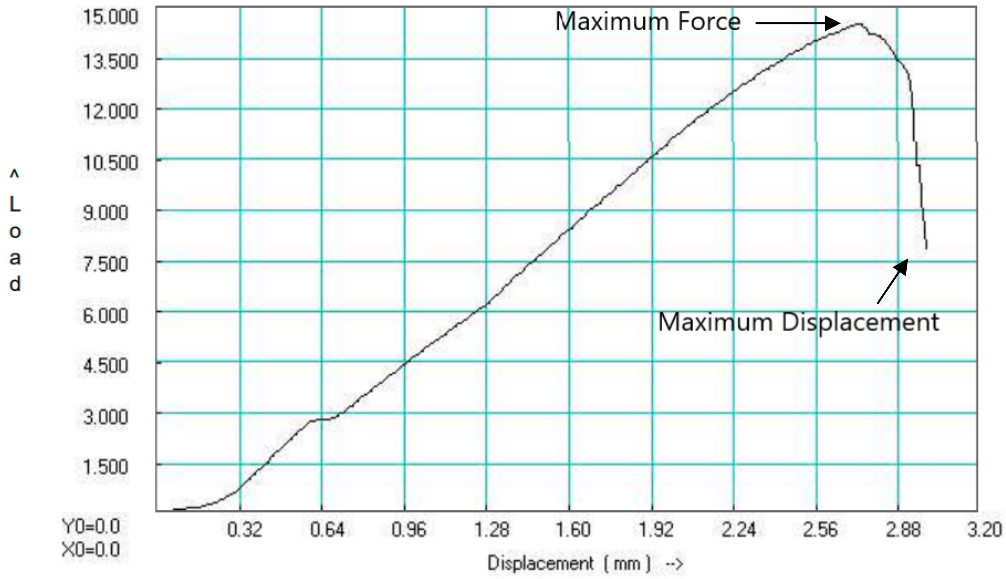


Figure 4-14: Load vs Displacement for Specimen at 1100 rpm

After the placement of the tool on the universal testing machine, load is applied. As the load goes on increasing the displacement also increases. The curve obtained is shown in figure 4-15. As the curve goes on increasing deformation occurs. At the displacement of 2.73 mm the maximum of load is attained. The tensile strength obtained is 3 times higher than that of the strength obtained by joining through Tig Welding. The results obtained through the testing of the specimen is given below. The specimen with original Gauge Length of 50mm is applied such that final Gauge Length obtained is 51.6 mm. % Elongation of 3.24 is calculated from the gauge length. Maximum Displacement of 2.99mm is obtained with tensile strength of 114.297 MPA. At 13.3 KN of Load Maximum yield stress of 104.693 is gained.

4.3.2 Spindle Speed at 1900 rpm and feed of 35 mm/min

The specimen of Aluminum is welded by keeping spindle speed at 1900 rpm and feed at 35mm/min. The Weld obtained at that speed is shown in Figure 4-16. The sample obtained on completion of process is defective. We can see tunnel defect at the retracting side due to high downward pressure.as shown in figure 4-16. On plunging, the excess flash has been observed outside the shoulder.

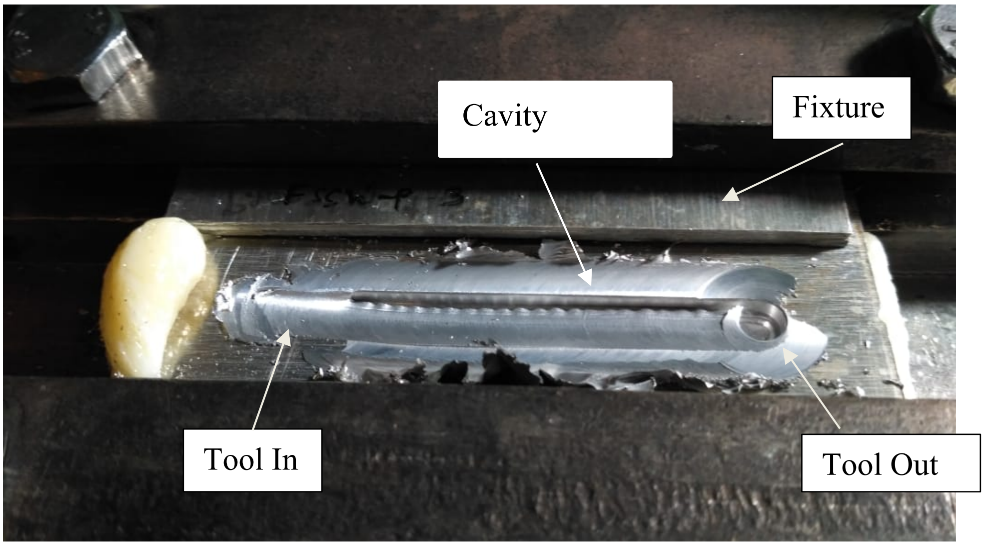


Figure 4-15: Friction Stir welding at higher speed of 1900 rpm

4.4 Microstructure Analysis

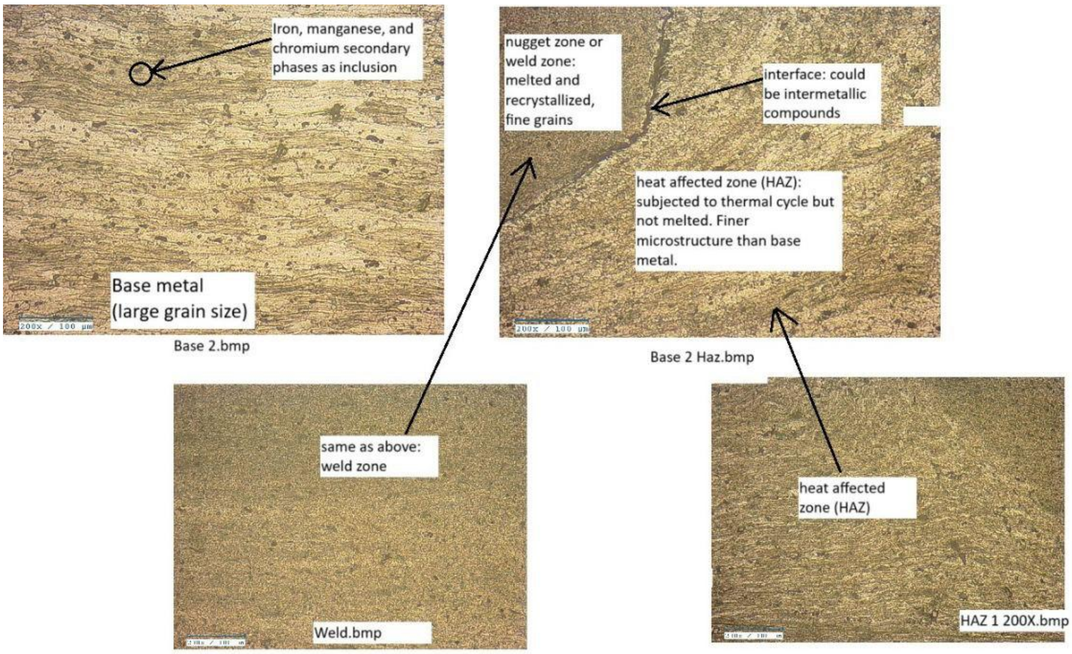


Figure 4-16: Microstructure Photographs of Friction Stir Welding Specimen

The sample piece obtained went through the microstructure test. The different zones obtained on the periphery of the joint were established and analyzed. At the Base metal the grain structure is larger is size compared to the heat affected and weld zone at the intersection i.e., weld zone underwent through crystallization temperature during the process which is shown in figure 4-17.

The chemical composition of Aluminum i.e., Iron Manganese, Chromium is seen on the base as inclusion. The black dot spotted on the fig represent the chemical mixture of the alloy.

Figure 4-17 represents the Heat affected and weld zone intersection. The generation of high temperature held recrystallization and formation of finer grain at the weld zone. The image at 200x zoom could locate the intersection of the metallic compounds. On the advancing side the Equiaxed grain structure is found.

Even though the metal content of the particles is low for the section, the grain seen in the heat-affected zone is finer than that of the base metal. Finer microstructure is observed on Heat affected zone.

4.5 Tig Welding (Tungsten Inert Gas Welding) Aluminum

Basically, for the Tig welding of thin layer Tig welding is preferred. We have experimented the joining of Aluminum 6061 Plates by tig welding process. The non-heated specimen is welded during the process in the open room. As it uses non consuming electrode, the filler metal is used during the process which can be seen on the intersection. The 2 -3 mm of external layer is formed on the top of the intersection as the plates get welded.

Figure 4-17: Tig Welding of Aluminum Alloy

4.5.1 Mechanical Properties Analysis

Rectangular piece of specimen is obtained by cutting and Analysis of mechanical properties is carried out on testing through UTM machine.

As the load goes on increasing the displacement also increases. At the displacement of 1.49 mm the maximum of load is attained. The tensile strength obtained from the graph is 15-20 % of the original strength of the Aluminum 6061. 1.49 mm of displacement is observed at maximum load which is shown in 4-19.

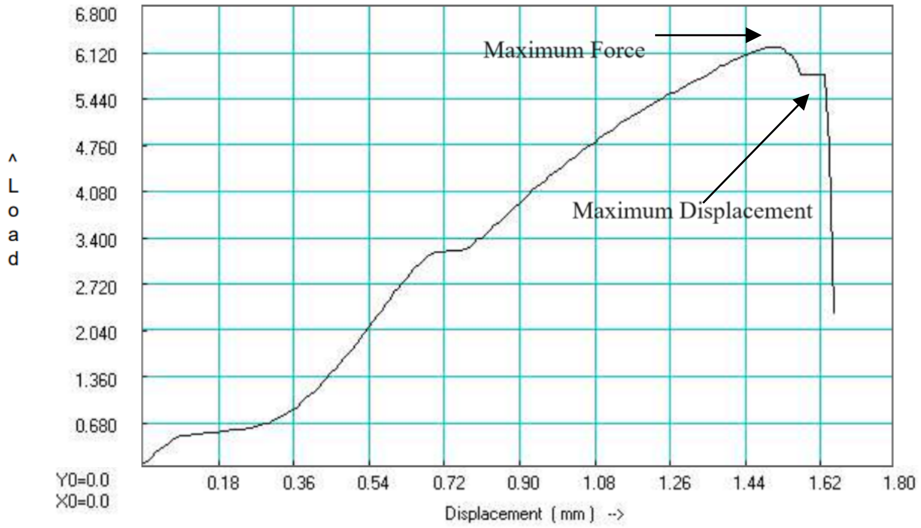


Figure 4-18: Load vs Displacement Curve

The change in mechanical properties had been observed on the weld sample. The original gauge length of 50mm is tested on Universal testing machine such that final Gauge Length of 50.4mm is attained. % Elongation of the specimen obtained is 0.76. Maximum Displacement of 1.65 mm is obtained such that the yield load is 5.58 KN which is shown in Figure 4-19.

The material obtained has a yield stress of 39.391 MPA and a tensile strength of 43.767 MPa.

For Lower Rate of feed of fillet cut piece of rectangular shape is taken for Analysis of mechanical properties is carried out on testing through UTM machine.

As the load goes on increasing the displacement also increases. At the displacement of 1.8 mm the maximum of load is attained. The tensile strength obtained from the graph is better at lower speed than the previous sample which attained around 18% of the original strength of the Aluminum 6061. The weld joint's tensile strength as determined by tig welding on following the parameters of aerospace industry is high as compared to the conventional method.

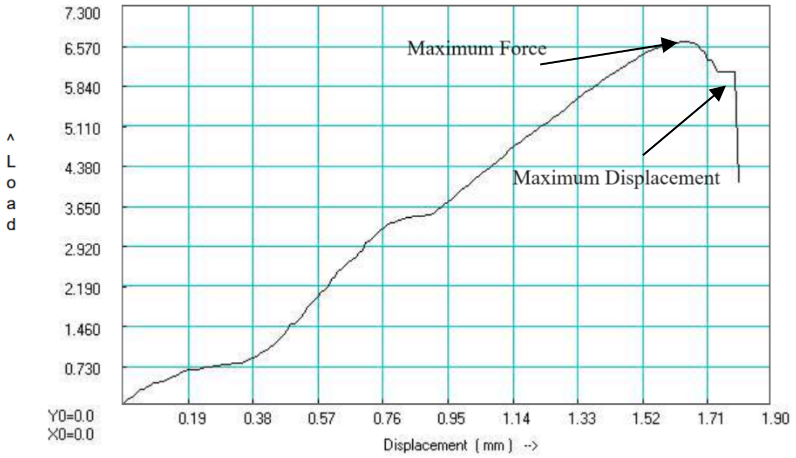
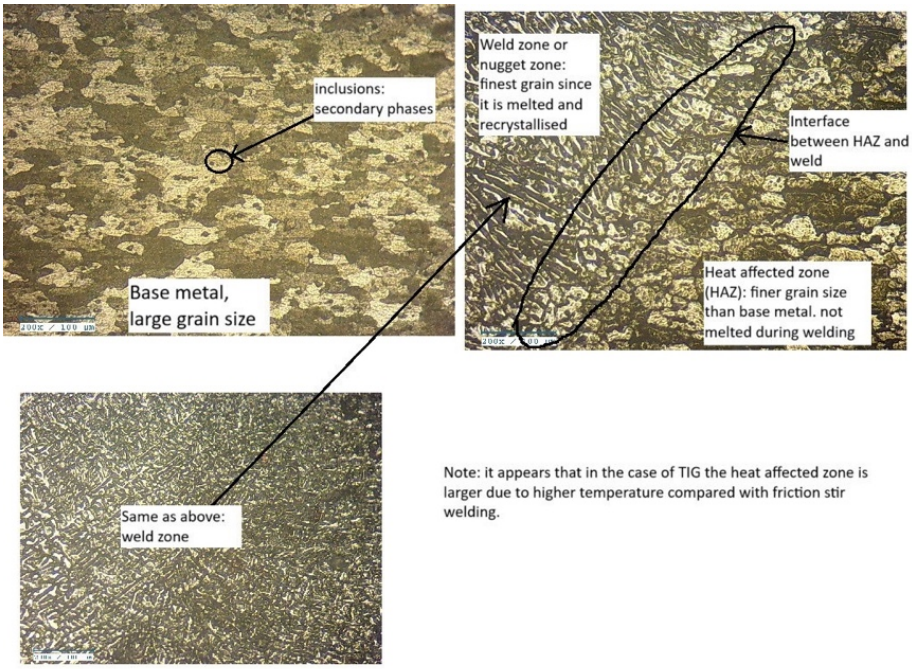


Figure 4-19: Load vs Displacement Curve at Low Feed

The Specimen with gauge length of 50mm is tested on the Universal testing machine. The final gauge length obtained on maximum displacement of 1.63 mm is 50.3mm. %elongation obtained on maximum load is 0.64 %. The tensile strength obtained on maximum load is 46.6 MPA. Yield load of 5.8 KN is obtained with the Yield Stress of 40.64 MPA.

4.6 Microstructure Analysis of Tig Welding



Note: it appears that in the case of TIG the heat affected zone is larger due to higher temperature compared with friction stir welding.

Figure 4-20: Microstructure Photographs of Tig Welding

The sample piece obtained went through the microstructure test. The different zones obtained on the periphery of the joint were established and analyzed. At the Base metal the grain structure is larger in size than compared to the base metal obtained by friction-stir welding the process which is observed in figure 4-21

The chemical composition of Aluminum i.e., Iron Magness, Chromium is seen on the base as inclusion. The black dot spotted on the fig represent the chemical mixture of the alloy.

Fig 4-21 presents the Heat affected, weld nuggets at the intersection. The generation of high temperature held recrystallization and formation of larger finer grain at the weld zone. Dendrite like structure is found at the Weld zone. The image at 200x zoom could locate the intersection of the metallic compounds.

The measured grain size in the heat-affected zone is less than that of the base metal, despite the fact that the melting metal content of the particles is lower in the close section. On the heat-affected zone, finer grain is seen. There is a combination of larger and finer grain sizes at the HAZ and Weld zone contact.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As was covered in the earlier chapters, joining nylon-nylon and aluminum-aluminum is possible using solid state friction stir welding. During the joining of Nylon and Nylon, the excess flash is produced as the length of shoulder enters more into the specimen at the period of rotation. The increase of rotational speed more the flash generation and the strength decrease on increase in the spindle speed. Plasticizing of material is more at the advancing side on giving offset of 1 mm as the heat generation is higher at advancing side. Aluminum Joints obtained by the Friction-stir welding at welding speed of 900 rpm and 1100 rpm is analyzed and compared with the specimen obtained of tig welding joint.

The FSW joint has a higher tensile strength than the TIG welding joint. Additionally, the weld surface obtained during Friction welding exhibits finer grain compared to the TIG weld. In terms of tensile strength, Aluminum welds are stronger when created with FSW as opposed to TIG welding. The strength regained is approximately 41.3% with FSW, compared to around 15.6% with TIG welding. FSW results in a coarse grain at the weld nugget, while TIG Welding produces a finer grain. Furthermore, FSW welds are less brittle than TIG Welds, as indicated by the % elongation of 3.24 in FSW compared to 0.76 in TIG welding.

5.2 Recommendations

Though we have used tool of High Carbon steel tool changing of composition of tool and the tilt angle during the procedure can be studied. The change of the tool and the conical of Pin has shown various result as per the literature review which can be analyzed. Some of the points that can be taken during the process are:

- Heat Treatment of tools for multiple times. Cutting of Specimen for the testing such that the original weld is affected minimum.
- Tig Welding inside the closed booth with low speed.
- Only the observation of microstructure size can be used for result analysis. Based on quantitative measurements, more accurate results may be analyzed.
- For instance, the Hall-Petch equation can be used to determine the precise grain size.

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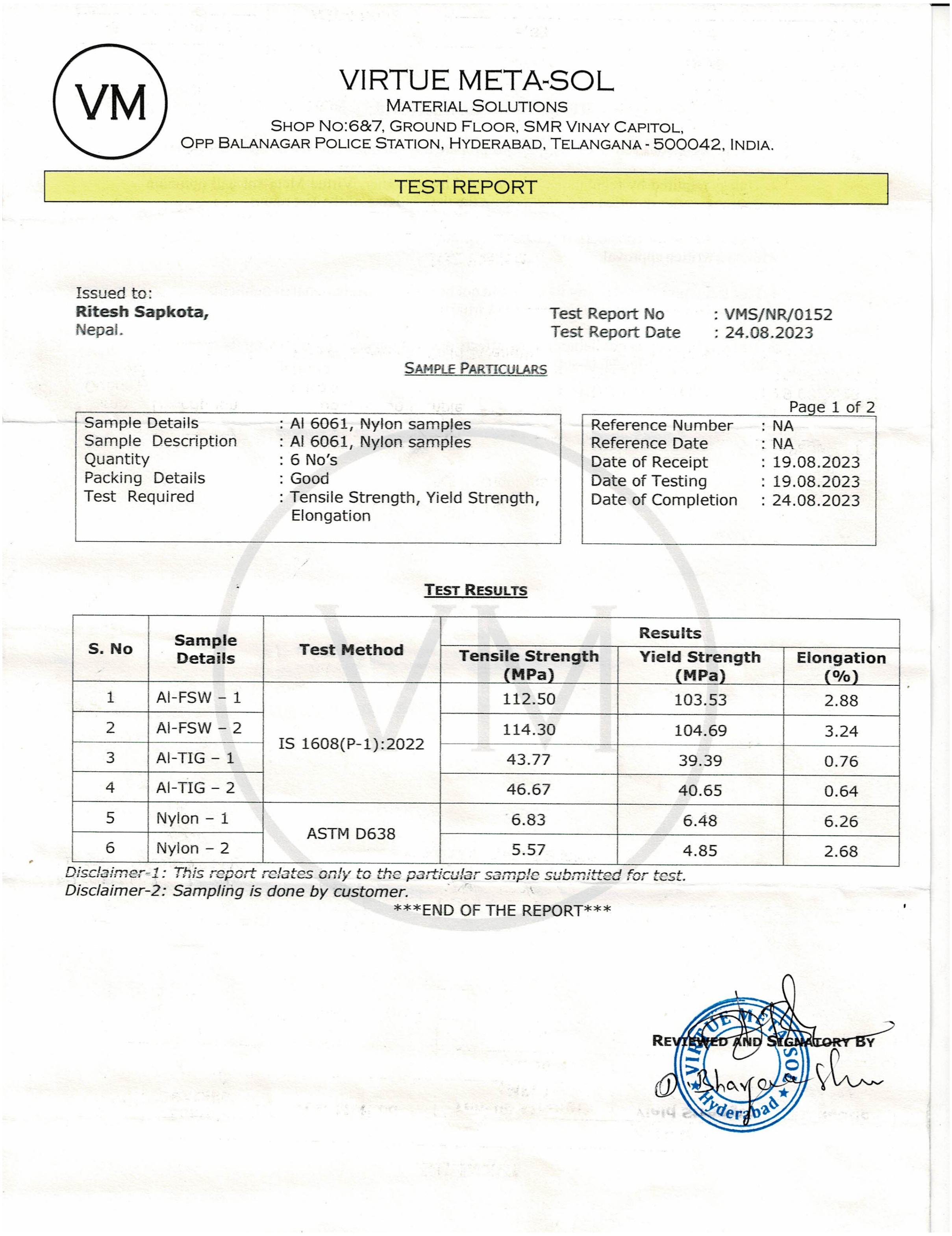
APENDIX: Friction Stir Welding Procedure

Joining of Two Materials

Sample Obtained after Cutting the Welded Joint

Sample Obtained after Testing on UTM Machine

Test Report



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SHOP NO:6&7, GROUND FLOOR, SMR VINAY CAPITOL,
OPP BALANAGAR POLICE STATION, HYDERABAD, TELANGANA - 500042, INDIA.

TEST REPORT

Issued to:
Ritesh Sapkota,
Nepal.

Test Report No : VMS/NR/0152
Test Report Date : 24.08.2023

SAMPLE PARTICULARS

Page 1 of 2

Sample Details	: Al 6061, Nylon samples
Sample Description	: Al 6061, Nylon samples
Quantity	: 6 No's
Packing Details	: Good
Test Required	: Tensile Strength, Yield Strength, Elongation

Reference Number	: NA
Reference Date	: NA
Date of Receipt	: 19.08.2023
Date of Testing	: 19.08.2023
Date of Completion	: 24.08.2023

TEST RESULTS

S. No	**Sample Details**	**Test Method**	**Results**		
			Tensile Strength (MPa)	**Yield Strength (MPa)**	**Elongation (%)**
1	Al-FSW – 1	IS 1608(P-1):2022	112.50	103.53	2.88
2	Al-FSW – 2		114.30	104.69	3.24
3	Al-TIG – 1		43.77	39.39	0.76
4	Al-TIG – 2		46.67	40.65	0.64
5	Nylon – 1	ASTM D638	6.83	6.48	6.26
6	Nylon – 2		5.57	4.85	2.68

Disclaimer-1: This report relates only to the particular sample submitted for test.
Disclaimer-2: Sampling is done by customer.

END OF THE REPORT

REVIEWED AND SIGNATORY BY

D. Bhargava

Study of The Effect of Friction stir welding parameters for joining Nylon and Aluminum plate and Comparative studyof TIG Welding Method

ORIGINALITY REPORT

12%

SIMILARITY INDEX

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