The Effects of Friction Stir Welding (FSW) of Polypropylene (PP) on Tensile Strength

by

Muhamad Bin Ishak

Dissertation submitted in partial fulfilment of

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

(Dr. Mohamad Zaki Abdullah)

UNIVERSITI TEKNOLOGI PETRONAS
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMAD BIN ISHAK

ABSTRACT

Friction Stir Welding (FSW) is a derivative of welding technique which applied the frictional energy conversion into thermal energy to melt the joint. The main objective of this report is to investigate and determine the effects of FSW technique of Polypropylene (PP) on their mechanical tensile strength. For that reason, the project needs to investigate the required parameters for PP friction stir welding. Currently, the FSW is applied for joining metals only. But the plastic joining method needs a new and reliable welding technique as well. Simultaneously with dynamic development of engineering plastics, the joining method for polymeric materials also increases. So, this paper will elaborate briefly on the applicability of FSW on PP plates and how to determine suitable parameters to do plastic joining using FSW technique and explain the effects of FSW procedure on plastics. The scope of study for this project includes the possibility of FSW of PP on the butt joining, the tool geometry as well as the welding parameters and the tensile strength of the welded PP. The proper project planning has been done started with fabrication of the tool for FSW, the familiarization of FSW procedure, test several parameters of FSW on PP and last but not least run the tensile test on the welded PP to get the strength and compared to the base PP. As a conclusion, this project found that the FSW of PP on the butt joint is practically successful given the tensile strength of welded PP compared to its based material is up to 20%. Apart from that, the joining structure of FSW on PP is similar to the FSW of metals.

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Finally many thanks to the author's family and fellow colleagues for their help and ideas throughout the completion of this study. I hope that the outcome of this report will bring beneficial output to others as well. Thank you very much everyone.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly and versatile. FSW was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique and it was initially applied to aluminum alloys.

In the meantime, FSW technique was introduced to join plastics in 1997 and the process continually being improved [1]. The technical concept of the FSW method is derived from the specially design tool that rotates at high speed on the surface of the weld line. The frictional heating from the rotating tool causes the plastic to soften without reaching the melting point and allows the tool transverse along the weld line [2]. Although FSW analytically proven to be relevant on polymeric materials, there has been very limited success due to thermal and viscoelastic properties of the material itself [3].

In UTP, the FSW research and experiment have been successfully done by several students. But they are focused on FSW metals. This project will concentrate on developing FSW parameters for PP and investigating their effects on tensile strength.

1.2 PROBLEM STATEMENT

Demand for rapid, reliable and high productivity welding methods (similar to those used for metals) increases simultaneously with the dynamic development of engineering plastics [4]. Application of welding technologies is useful not only during production but also during repairing or recycling. For that reason, new technologies with low cost and environmental-friendly are being investigated.

Methods of heat introduction in polymer welding can be divided into three groups: heat conduction, heat radiation and mechanical friction [5]. In case of heat conduction, such as heated wedge, socket and hot gas welding, surfaces to be welded are electrically heated. Then, they are pressed together to ensure proper joint strength [6, 7].

Welding method using radiation (e.g. high frequency of laser welding) utilizes electromagnetic radiations which are absorbed by the material to be welded and transform into heat, thus ensuring the proper rheological state for welding [8]. Mechanical friction method utilizes the heat through friction to soften the material and joins the pieces together. It involves the friction between a tool and the pieces to be weld. FSW is the derivation of the mechanical friction welding technique.

Among several methods studied in plastic welding, FSW technique stands out because of low cost, environmental friendly and minimum preparation and process time [1]. This project is proposed to apply FSW method for plastic specifically PP because there is very limited efforts have been made to improve FSW for plastics.

1.3 OBJECTIVE

The primary objective of this project is to investigate the effects of FSW technique of PP on their mechanical tensile strength. To achieve this goal, required parameters for PP friction stir welding need to be determined.

1.4 SCOPE OF STUDY

The scope of study will involve the PP properties, tool material properties, injection molding procedure to prepare sample and the parameters ranges of FSW. The tensile test of the non-welded and welded PP will be conducted according to ASTM D 638 standard.

The performance of the welding will be tested using several rotational speed and transverse speed ranging from 800 to 1500 rpm and 8 to 12.5 mm/min respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW OF FRICTION STIR WELDING

FSW was invented and patented by The Welding Institute (TWI), a British research and technology organization. Friction stir welding is a relatively new joining process. The process is solid-state in nature and relies on the localized forging of the weld zone to produce the joint. FSW of Aluminum (Al) alloy has been relatively well established these days since it was invented in 1991.

2.1.1 FSW Concept

The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets namely workpiece to be joined and transverse along the line of joint. The tool serves two primary functions: (a) heating of workpiece and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of the workpiece. The localized heating softens the material around the pin. Combination of tool rotation and translation lead to movement of material from the front of the pin to the back of the pin. Figure 2.1 below shows the technical concept of FSW process and the tool of FSW.

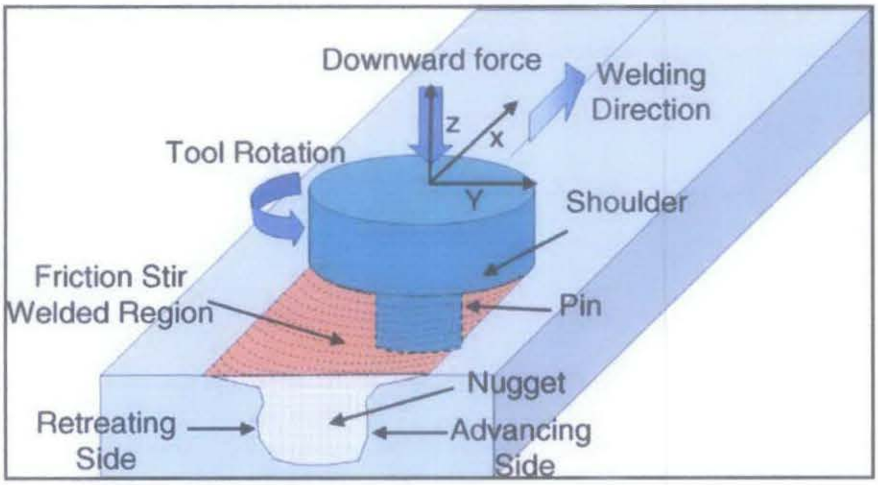


Figure 2.1: The concept of Friction Stir Welding process.

As a result of this process, a joint is produced in 'solid state'. Because of various geometrical features of the tool, the material movement around the pin can be quite complex. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The fine microstructure in friction stir welds produces good mechanical properties as it is forming lamellar profile [9].

2.1.2 The FSW Applications

The application of FSW Al alloy has been reported in many industrial sectors especially in transportation. Ship panel assembly, frame of high speed railway and the suspension arm of car are using the FSW technique. Although several trials of the materials joining using FSW such as titanium, magnesium alloy, mild steel and copper have been reported, the industrial application of FSW joints are limited to aluminum alloys [10].

The metal welding process is applicable to aerospace, ship building, aircraft and automotive industries. The advantage of this welding technique is elimination of the welding defects namely crack and porosity which often associated with fusion welding processes. On the other hand, FSW also reduced distortion, excluded joint edge preparation, applicable in all positions and improved mechanical properties of weldable alloys [11, 12]. Now, the FSW technique is potential to be applied on plastics.

2.1.3 FSW Development

As the FSW research develop, extensive study has been performed on tool designs, joint geometries, process parameters and weldable materials. Meanwhile, the process is still in its infancy among polymer processors. Relatively little is known about the process when applied to polymers, including the effects of FSW on the material microstructure. Very few groups have reported research on FSW of polymeric materials. Among thousands of polymers in existence, a mere half dozen have been investigated for compatibility with FSW technology. An entire manufacturing method is waiting to be developed.

2.1.4 FSW Recent Studies

FSW utilizes the friction between a rotating tool and the workpiece to generate the necessary heat for fusion of the joint. The tool consists of a rotating pin, a large shoulder and a heater. The pin is primarily responsible for the frictional heating of the workpiece and stirring of material within the joint. The shoulder's main purpose is to trap the material displaced by the pin and to apply forging pressure to the joint as the weld cools. The heater supplies additional thermal energy when the frictional heating is not sufficient.

In some cases, the tool shoulder is larger than conventional tool. The larger part is called a "shoe." As the polymer cools, it is very important to promote a uniform cooling rate throughout the weld volume. If the outer material cools much quicker than the inner, a hard shell is formed. As the inner layers cool, the material contracts and pulls away from the shell. Large voids are formed which detract greatly from the mechanical performance of the welded joint.

As the tool rotates, there is very high friction occurs, evidenced by a release of thermal energy. The process is made more efficient when the majority of the energy goes into the workpiece rather than the tool. The tool then advances along the joint line, removing material from the front of the tool and depositing it behind the trailing edge of the tool. FSW of polymers is not strictly a solid state process. Because polymers consist of molecules of different lengths, and thus of different molecular weights, the materials do not have single melting points but ranges melting points.

During FSW processing, some shorter chains reach their melting point while longer chains do not. Thus some of solid material are suspended in molten material to render the mixture and it is easy to move and form [13].

A cylindrical-shouldered tool, with a threaded or unthreaded probe (nib or pin) rotated at a constant speed and moved at a constant transverse rate. The tool plunged into the joint line of two highly held PP sheet or plate. The length of the nib is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work surface. The nib usage is to produce frictional heating on work piece. The nib moved against workpiece or vice versa to stir the soften material [14]. Figure 2.2 below shows the process of FSW from tool penetration into welding line until the material has been joined together.

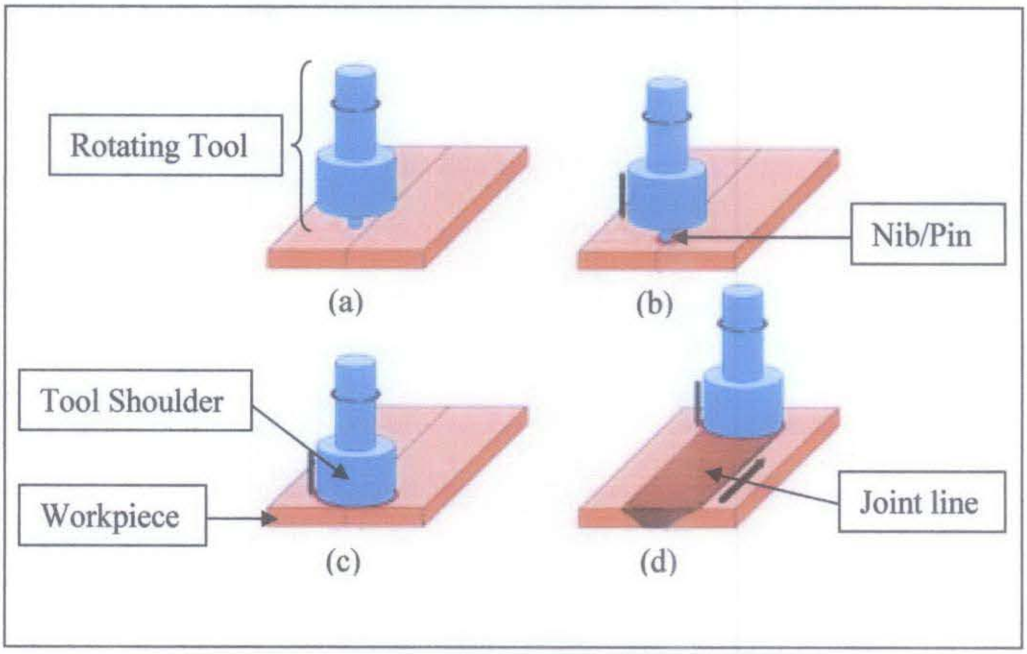


Figure 2.2: The process of Friction Stir Welding.

Principal technique for FSW:

a. Rotating tool is ready to penetrate the workpiece.
b. The pin is inserted into the joint line.
c. The shoulder touches the workpiece, resulting in frictional heat.
d. The pin stirs the material inside the workpiece and moves transversely along the joint line.

2.2 FRICTION STIR WELDING OF PLASTICS

In recent years, researchers have been trying to adapt FSW technology to the joining of thermoplastic materials. The technology has been developed rapidly since it was invented in aspect of welding techniques to improvise the mechanical strength of the joint. The dynamics of the tool geometry and design has also been evolving ever since.

For example, a new FSW technique was introduced by a research group of TWI in improving the efficiency of polymer welding. A vertical reciprocating blade was used instead of a rotating cylindrical tool to minimize the formation of void along the weld seam produced by the latter. They have successfully produced a weld in a 6 mm PVC plate [3]. Meanwhile, researchers from Brigham Young University in the United States have patented a new FSW method which involved the use of heated shoe at the tool which was claimed to be able to eliminate voids and improve mixing. Several polymeric materials have been successfully welded included PP, low density polyethylene (LDPE), high density polyethylene (HDPE), nylon, polycarbonate and acrylonitrile butadiene styrene (ABS) [15].

2.2.1 Joint configurations

The standard FSW process is a fairly flexible process, which can be used in a wide variety of joint configurations. A group of joint configurations that FSW is capable of performing is shown in Figure 2.3.

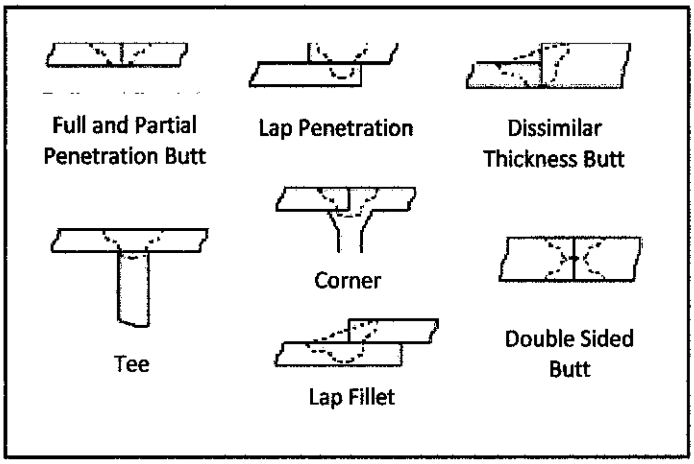


Figure 2.3: The FSW Joint Configurations.

The group includes the butt joint (similar thickness), dissimilar thickness butt joint, lap penetration joint, lap fillet joint, and corner joint. FSW process is not capable of performing welds in the T-fillet joint configuration, which is commonly used in many arc welding operations. However, one could come from the back-side on a T-fillet and join it to achieve this type of joint [16].

2.2.2 Experimental Methods

Arici *et al.* [15], reported a successful FSW on medium density polyethylene (MDPE). The MDPE plates of 3 mm and 5 mm thick were used. The plates were cut into rectangular welding samples of 200 mm by 80 mm. The samples were placed on a flat metal plate and clamped on a vice to avoid separation during the FSW process. Then, the samples were longitudinally butt welded by using rotating cylindrical shouldered tools. The shoulder and pin diameters were 16 mm and 5 mm respectively. The pin length was 2.8 mm.

In another work, Arici *et al.* [17], wrote that test on two PP strips of 5 mm X 60 mm X 120 mm were done in a lap configuration. The two specimens overlapped by 60 mm. The specimens were then welded with the rotating cylindrical shouldered tool in a milling machine. The strip specimens were firstly welded as a function of dwell times which ranged from 10 to 250 s. In this weld, the tool rotation speed and the tool penetration depth were held constant at 1250 rpm and 9.5 mm, respectively. The tool used for this set of welds had a shoulder diameter of 37 mm, a pin diameter of 12 mm, and a pin length of 7.5 mm.

The second experiment was done to investigate the influence of tool penetration depth. The tool penetration depth ranged from 7 to 9 mm. The tool used for the second set of welds had a shoulder diameter of 37 mm, a pin diameter of 12 mm, and a pin length of 6 mm. The tool rotation speed was 1250 rpm. The tensile shear tests were carried out using an Instron 4411 test machine at a crosshead speed of 5 mm/min. Shims of the same thickness as the strip specimens were used when gripping the samples to induce pure shear. The fracture locations were also observed [17].

2.2.3 Polypropylene (PP) Properties

The workpiece sample used is Polypropylene (PP). PP is a thermoplastic polymer, made by the chemical industry and used in a wide variety of applications, including packaging, textiles, stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. Polypropylene has good mechanical, electrical, and chemical properties and good resistance to tearing. Table 2.1 shows the PP mechanical and physical properties [18].

Table 2.1: Polypropylene properties.

Mechanical Properties	
Abrasive resistance – ASTM D1044 (mg/1000 cycles)	13-16
Coefficient of friction	0.1-0.3
Elongation at break (%)	150-300, for biax film >50
Hardness – Rockwell	R80-100
Izod impact strength ($J\ m^{-1}$)	20-100
Tensile modulus (Gpa)	0.9-1.5, for biax film 2.2-4.2
Tensile strength (Mpa)	25-40, for biax film 130-300
Physical Properties	
Density ($g\ cm^{-3}$)	0.9
Flammability	HB
Limiting oxygen index (%)	18
Radiation resistance	Fair
Refractive index	1.49
Resistance to Ultra-violet	Poor
Water absorption – equilibrium (%)	0.03

2.2.4 Mechanical Testing

Tensile test was chosen because it is probably the most fundamental type of mechanical test you can perform on material. By pulling on something, we will very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, we will find its strength along with how much it will elongate [19].

According to *Zoltán Kiss / Tibor Czigány* [16], the tensile tests of welded samples were performed on a ZWICK Z020 universal tensile tester, using 20 X 150 mm specimens at a tensile rate of 10 mm/min, at ambient temperature. Tensile strength was the average of five parallel tests.As refer to journal by *Armagan Arici/Tamer Sinmaz* [15], they stated that the tensile and bending tests were performed according to EN ISO 527 and ISO 178, respectively. The tensile and bending tests were carried out using an Instron 4411 test machine at a crosshead speed of 100 and 50 mm/min, respectively. The span of 80 mm was used in bending tests. The fracture locations were observed using an optical microscope and they founded that the welded samples were fractured without showing a yield necking.

CHAPTER 3
METHODOLOGY

3.1 PROJECT ACTIVITIES

Figure 3.1 below shows the project activities throughout the whole FYP timeframe.

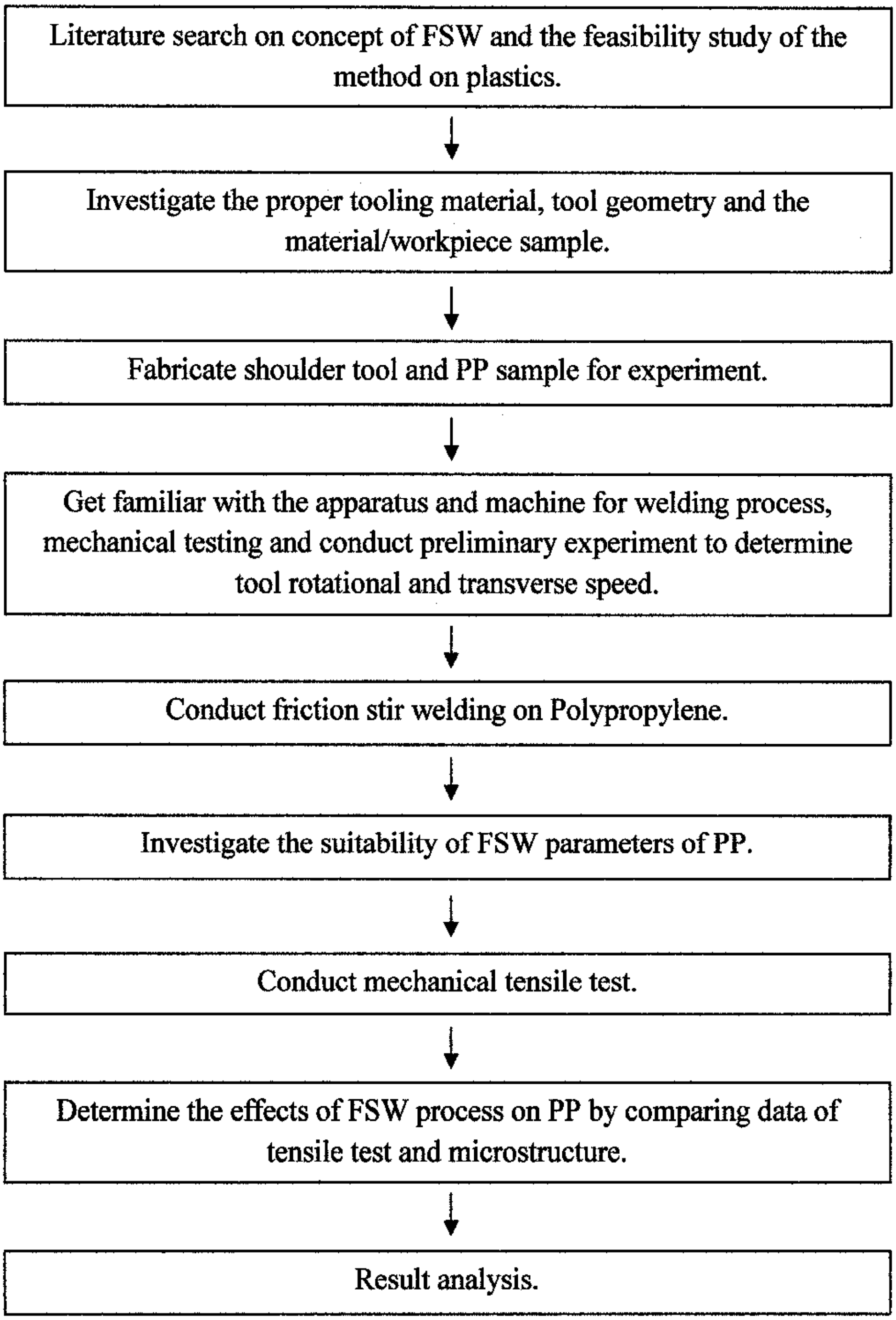


Figure 3.1: The Project Activities.

3.1.1 Literature Search

The project started with the literature search to comprehend as well as gathering information and basic knowledge on the topic from journals, books and technical papers. From the literature search, the project planning was planned. The basic concerns of the project planning were:

a) The dimensions of PP plate and shoulder tool required, i.e. thickness, width, tool diameter, pin length and pin diameter.
b) Parameters of FSW on the polymer workpiece: Using CNC milling machine with spindle speed ranging from 600 to 2000 rpm and feed rate of ranging from 8 to 12.5 mm/min.
c) The joint configuration: butt joint is the easiest and suitable for mechanical tensile test.
d) Tensile test according to ASTM D 638 standard was chosen.
e) The results of tensile test of the workpiece non-welded and welded using FSW process were analyzed.

3.1.2 Tooling material, tool geometry and material/workpiece sample.

Further analysis was done to determine the proper tooling material, tool geometry, tool transverse speed and rotational speed.

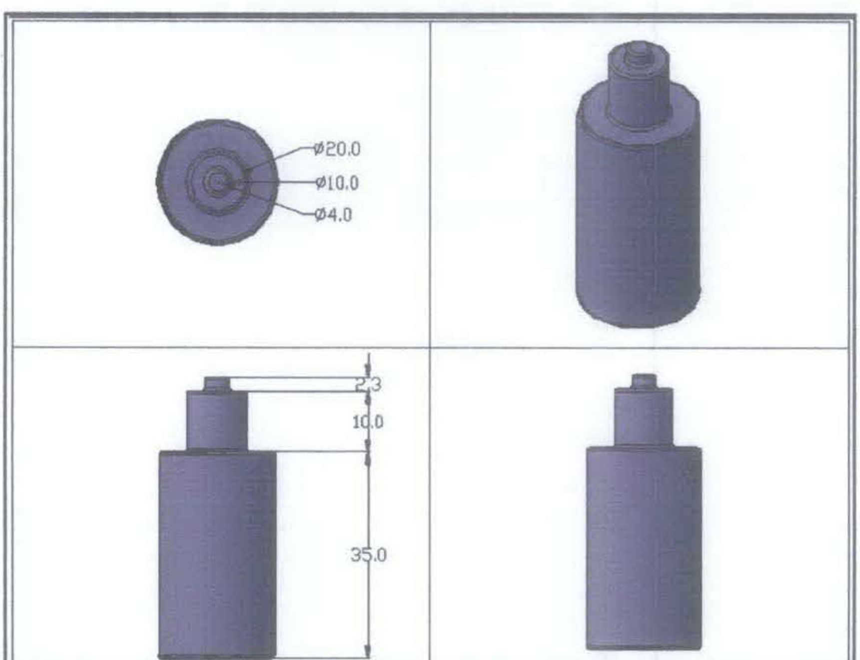
Initially, the tooling material listed for FSW on PP was Aluminum and Tool Steel H13. Both materials were tested. Tool Steel H13 demonstrates more advantage features than the aluminum tool. The Tool Steel H13 properties such as melting point, machinability features and heat treatment procedure showed in the Table 3.1. This alloy is one of the Hot Work, Chromium type tool steels. It also contains molybdenum and vanadium as strengthening agents. The chromium content assist this alloy to resist softening if used at higher temperatures [18].

The H13 is machinability so that it can go through the profiling procedure using CNC lathe machine accordingly to the dimension required. It can undergo heat treatment according to the descriptions to make sure that the tool is hardened and can provide enough friction to give heat to the workpiece to make sure workpiece soften without reaching its melting point.

Table 3.1: Tool Steel H13 Properties.

Properties	Descriptions
Melting Point	1426°C
Machinability	Machinability of H13 is rated as medium to good. It rates as 75% that of the W group water hardening tool steels which are low alloy and generally good machinability.
Forming	H13 has good ductility and may be formed by conventional means.
Heat Treatment	Preheat to 815°C and then heat to 1010°C. Hold at 1010°C for 15 to 40 minutes and then exposed air cool (air quench).

Figure 3.2 shows the FSW tool geometry. The tool geometry consists of the shoulder part and the nib part. The shoulder diameter was 10 mm while the nib diameter was 4 mm. The nib length was 2.3 mm that is slightly less than the weld depth required.



Unit: mm Note: All fillet is 0.5 mm

Figure 3.2: The Tool Steel Geometry.

The suggested geometry of the cylindrical shouldered tool should be at 20 mm of shoulder diameter, 4 mm nib diameter and 2.3 mm nib length which is slightly more than half of the plate thickness. In addition, the welding tool will have a shaft length of around 35 mm in order to attach the welding tool onto the tool holder in Computer Numerically Controlled (CNC), MAZAK milling machine.

At first, the welding sample was PP plate with dimension of 200 mm long by 80 mm wide. This PP slab was used to test the procedure and get the suitable parameters for FSW on PP. However, since the welded plate will be tested using mechanical tensile test later, the dimension of the PP plate is fabricated according to the dog bone tensile bar of ASTM D 638 Type 1 specification [19].

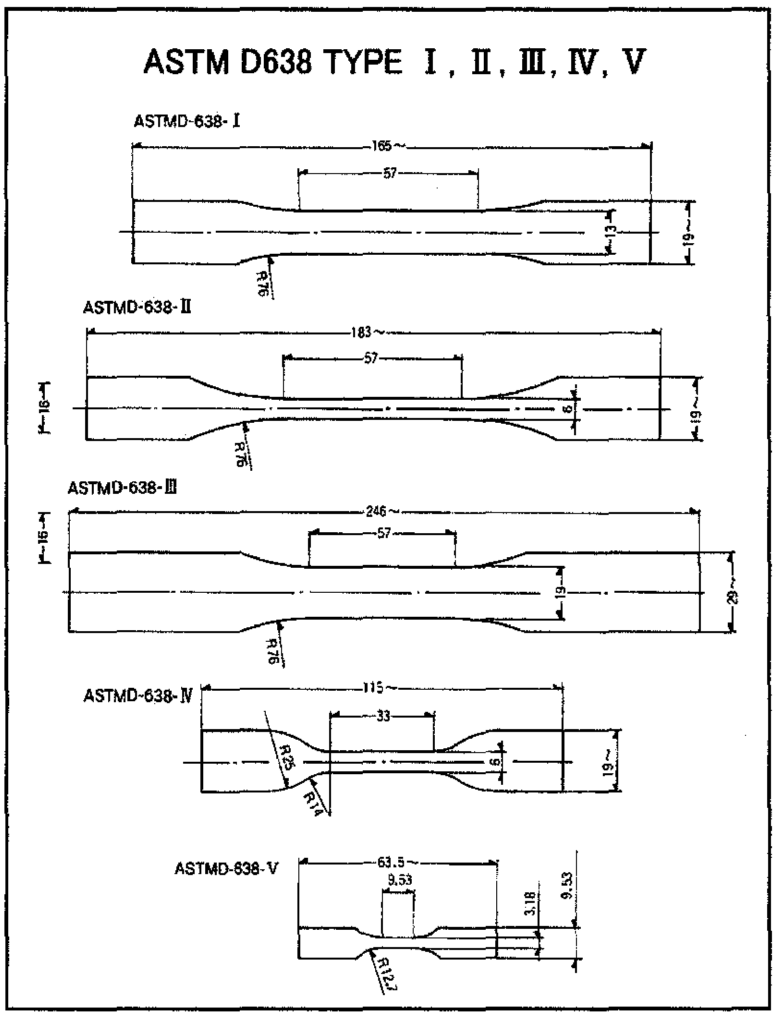


Figure 3.3: ASTM D 638 standard dimension.

3.1.3 Fabrication of shoulder tool for experiment

Once the drawing of the shoulder tool was completed, it was fabricated using the CNC lathes. The shoulder tool was successfully fabricated using MAZAK CNC lathe machine. Figure 3.4 shows the MAZAK CNC lathe machine.

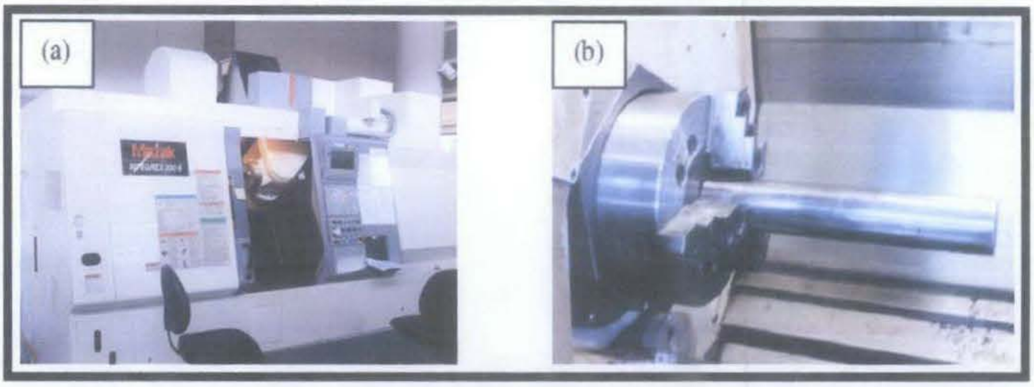


Figure 3.4: (a) MAZAK CNC Lathe Machine. (b) Tool steel H13 being lathe.

Then, it underwent the heat treatment, a method used to alter the physical and sometimes chemical, properties of a material. For this project, the procedures of the heat treatment to harden the tool are as follow:

a) The welding tool was inserted in the Tube Furnace and preheated initially for two (2) hours from 0°C – 732°C.
b) Next, the welding tool was heated slowly from 732 - 760°C for another two (2) hours.
c) Then, the temperature was raised to 1000° C for one (1) hour.
d) Finally, cooling down process took placed at room temperature for two (2) hours.

Figure 3.5: Tool heat treatment process in Tube Furnace.

3.1.4 Familiarization to the experimental setup

A preliminary experiment had been conducted to familiarize with the operational procedure of the machine and to determine the proper rotational speed and transverse speed to produce sufficient heat for the weld to occur. The test was conducted using the different rotational speeds (800 rpm and 1000 rpm) and different welding speeds (10 mm/min and 12.5 mm/min).

The slab dimension of 100 mm X 50 mm X 4 mm was placed onto the simple jig that can hold the pieces together at the butt joint. The tool for the trial experiment is both Aluminum tool and Tool Steel H13. The jig usage is to provide intermediate slot between workpiece and the clam vice at the milling machine.

The first experiment was to find out the suitable tool for FSW on PP. The tool used is aluminum tool and the workpiece used is PP slab. The output of the FSW is observed and the joining seems failed. Figure 3.6 shows the output of friction stir welded slab. The aluminum tool then has been discarded from the project.

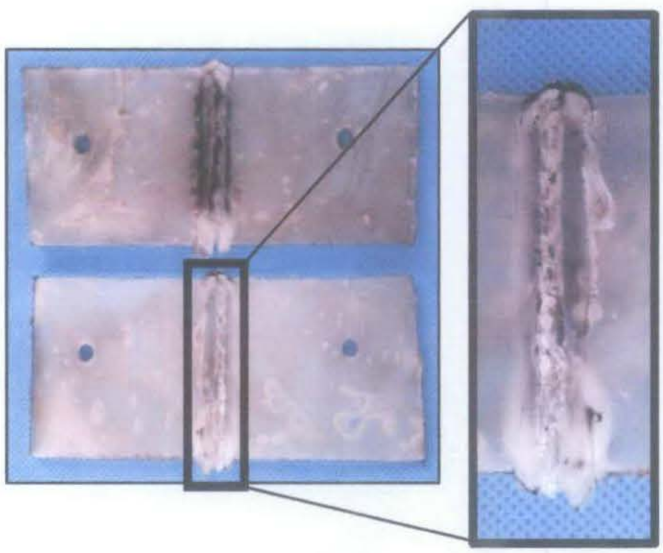


Figure 3.6: Output of FSW process trial run on PP slab.

Using the H13 tool steel for the further experiment is the best choice because the hardened tool steel has the rough surface that can give more heat through friction and can stir the material well. The next experiment is setup using the tool steel H13 only.

The result and conclusion of the preliminary experiment on conventional milling machine are:

a) The suitable spindle speed can be used is between 600 – 1500 rpm.
b) The jig orientation must at least hold the workpiece so that workpiece do not move to the side when the tool stirs through the welding line.

c) The tool steel H13 is suitable and works better than aluminum tool because tool steel H13 provides better heat through rough surfaces friction between the shoulder tool and the workpiece.

Familiarization of FSW continues to the conventional machine once the suitable parameters have been achieved and the FSW on PP successfully joined. The author used the CNC milling machine to run the FSW experiment on PP with the parameters stated the Table 3.4. The parameters of this preliminary experiment being changes several times until the author satisfied with the output of the PP samples butt joint.

Table 3.2: Parameters of PP FSW using CNC milling machine.

No	Spindle Speed (rpm)	Transverse Speed Feed Rate (mm/min)	Plunge Depth Feed Rate (mm/min)	Plunge Depth (mm)	Dwell time (s)
1	600	6	6	2.4	30
2	800	10	8	2.4	30
3	1000	10	8	2.4	30
4	1000	8	8	2.4	30

a) The first run of the experiment was done with the lowest rpm and transverse speed from parameters that FSW with conventional milling machine achieved. The results did not portray very well.

b) The second run the spindle speed increased to 800 rpm with transverse speed of 10 mm/min. the results seems better with these parameters.

c) The third and fourth run increased again to 1000 rpm and transverse speed of 10 mm/min and 8 mm/min. Both of the welding parameters are evenly suitable by the author observation of the welded PP joint line.

d) The next experiments were done by using the 1500 rpm spindle speed and 10-12.5 mm/min transverse speed. These parameters turned out to be the better version of FSW on PP.

3.1.5 FSW on PP using CNC milling machine

A few additional features of workpiece handling and process of FSW on PP firstly need to be set. They are:

a) Jig orientation - The jig orientation is important during the FSW process to hold the workpiece together because when the nib tool penetrates the welding line and start stirring, the process could shift the workpiece to the side. So the jig must be able to hold the workpiece so the stirring happened exactly on the welding line. Apart from that, arrangement of PP samples on the jig must be tightly assemble to avoid dissimilar surface thickness while welding. The jig configuration is set to fitted two dogbone shape PP samples in each experiment. Figure 3.7 in the next page shows the jig orientation with workpiece arrangement.

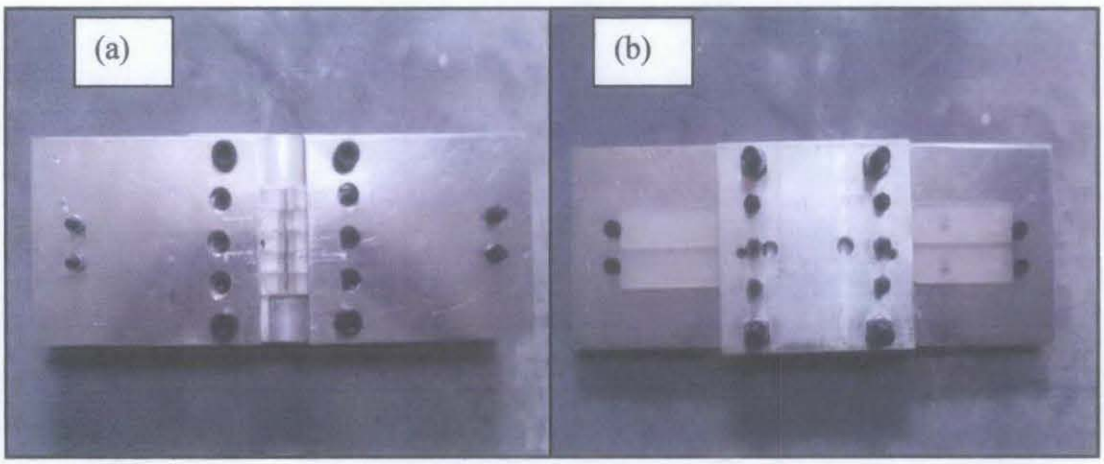


Figure 3.7: Jig with workpiece. (a) Top view. (b) Bottom view.

b) Sample preparation - The half cut dog bone shape PP samples were arranged accordingly to be fitted into jig. Figure 3.8 shows the process of PP samples preparation before FSW process.

Figure 3.8: Sample preparation before FSW process.

c) CNC milling machine clamp table – The workpiece then placed onto jig and been hold tightly on the CNC milling clamp vice as shown in Figure 3.9 below.

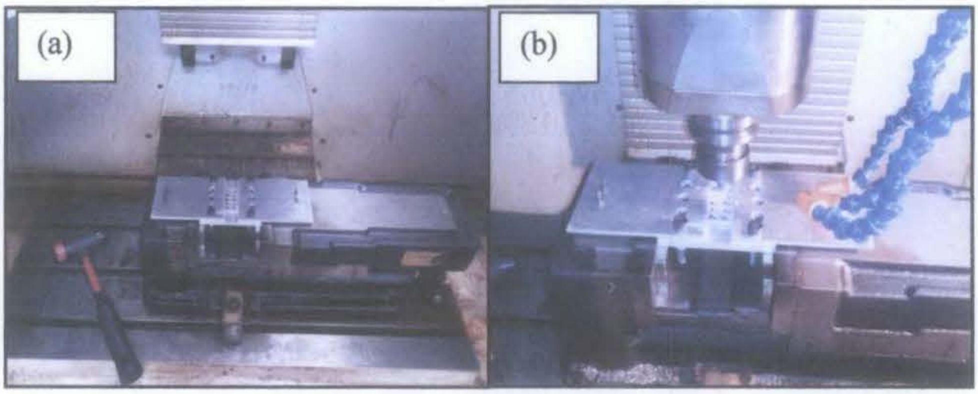


Figure 3.9: (a) Workpiece on clamp vice. (b) FSW of PP in progress.

Figure 3.10 shows the output of welded PP using FSW process. From the author observation, the PP samples were successfully joined together. The finished products are ready to be tested on Universal Testing Machine (UTM) 5kN accordingly to ASTM D 638 tensile test standard.

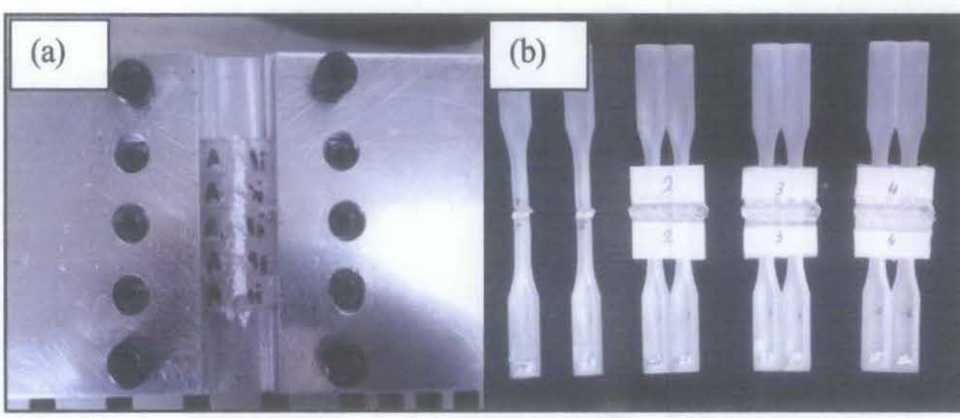


Figure 3.10: (a) The output of FSW process on PP workpiece. (b) The dogbone shape PP finished product after FSW process; ready to be test.

3.1.6 Tensile Test and Microstructure Study

After the FSW of PP on CNC milling machine, the project continued to the tensile test and samples were captured by the Optical Microscopy (OM). The tension test is the most common test for determining such mechanical properties of materials such as strength, ductility, toughness, elastic modulus, and strain hardening capability. For the study in this project, the tensile strength property is the only properties that will be consider.

Basically the tensile strength can be determine from the stress-strain curve that been produce during the test [20]. The test result collected has been analyzed and discussed for future studies to improve the weld properties and to get a joint with the desired tensile strength that sufficiently portray the based PP tensile strength value.

The test was conducted using the LLOYD Instruments LR5K 5 kN Universal Testing Machine (UTM) that available in UTP. The machine was operated the tensile test at crosshead speed of 5 mm/min in ambient temperature. Figure 3.11 shows the LLOYD Instruments LR5K 5 kN UTM.

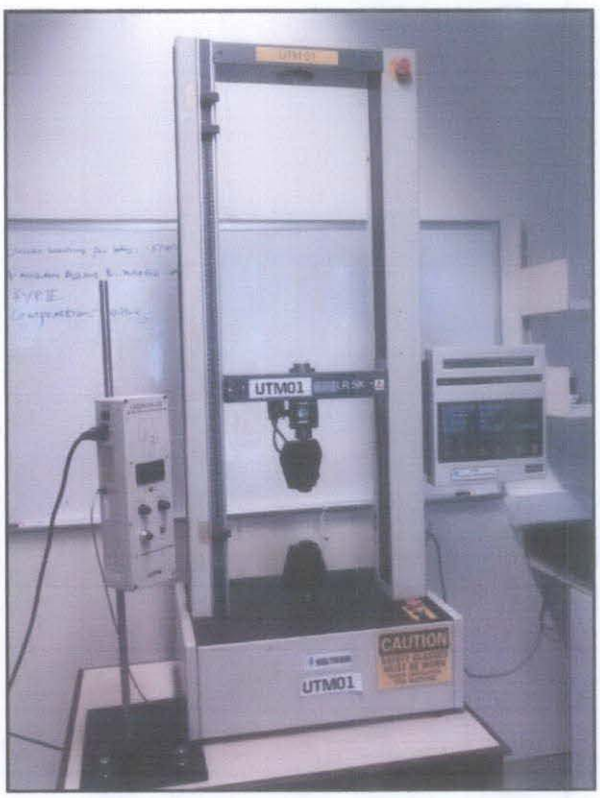


Figure 3.11: Universal Testing Machine (UTM) 5 kN.

The LLOYD Instruments LR5K 5 kN (UTM) features:

1. Simple to set up, operate and maintain.
2. High accuracy load measurement.
3. Crosshead travel 975 mm (38.5 in).
4. Speed range 0.01 – 1016 mm/min (0.0004 to 40 in/min).
5. Saves up to 600 test results.

6. 10 programmable test set-ups.
7. High resolution backlit LCD display with intuitive operator interface.
8. Flash memory upgradeable.
9. Can be mounted above floor standing compression cage for large sample/complete assembly testing.
10. Pre-loading of samples and cycling to load or extension limits.
11. Multi-stage testing with NEXYGEN*Plus* software.
12. Wide selection of load cells, grips, jigs, extensometers, temperature chambers and other accessories.
13. Constant load loading.

The two features in microstructures are grain size and shape of the materials. These are called microstructural characteristics. The microstructure of the PP samples is taken using Optical Microscopy (OM). With the optical microscopy, the light microscope is used to study the microstructure; optical and illumination systems are its basic elements.

For materials that are opaque to visible light (all metals, many ceramics and polymers), only the surface is subject to observation, and the light microscope must be used in a reflecting mode. Contrasts in the image produced resulting from differences in reflectivity of the various regions of the microstructure. Investigations of this type are often termed metallographic, since metals were first examined using this technique. Figure 3.12 shows the author examines the microstructure of welded PP samples.

Figure 3.12: Optical Microscopy (OM).

3.1.8 FYP II Key Milestone

List below is the FYP I key milestone, done in the final year first semester:

i. Preliminary research work/ literature search.
ii. Investigation of proper geometry and tooling material.
iii. Design and fabricate the shoulder tool.
iv. Fabricate the PP material sample (injection molding).

3.1.9 FYP II Key Milestone

The FYP II is continued with what has FYP I left of, so the research work and most of the methodology has been set. As the project continues, literature review has been study from time to time to make sure project is based on the approved and known journals. List below is the key milestone for FYP II:

i. Start: Reviewing the FYP I key milestone/Gantt chart.
ii. Sample preparation using compression molding:-
   (a) Fabricate mold for compression molding
   (b) Fabrication of PP slab using compression molding
iii. Fabricate tool:-
   (a) Tool fabrication according to dimension in Figure 3.2 using H13 Tool Steel
   (b) Tool fabrication according to dimension in Figure 3.2 using Aluminum (for trial run purpose)
iv. FSW trial run on conventional milling machine.
v. Fabricate the jig for workpiece.
vi. FSW on CNC milling: Parameters testing.
vii. FSW with several parameters.
viii. Mechanical testing: Tensile test.
ix. Conduct study using Optical Microscopy (OM).
x. Poster Presentation.
xi. Draft Report/Dissertation.
xii. Final Presentation.

GANTT CHART FOR FINAL YEAR PROJECT (FYP)

Table 3.3: Gantt Chart for Final Year Project (FYP)

No	Details	FYP 1														FYP 2													
		Week														Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**LITERATURE SEARCH**															**30% complete**													
	Select FYP title and preliminary search																												
	Literature review on background, technical concept & scope of study for the FSW																												
	Investigation of proper geometry and tooling material for FSW																												
	Drawing FSW tool design																												
2	**FABRICATION**																						**60% complete**						
	Fabricate the dog bone shape PP samples																												
	Fabricate the mold for PP slab																												
	Fabricate the slab PP samples using																												
	Fabricate the shoulder tool for FSW																												
	Fabricate Jig for FSW																												
3	**EXPERIMENT**																											**90% complete**	
	Preliminary experiment on conventional																												
	FSW of PP experiment using CNC milling																												
4	**TEST & ANALYSIS**																												
	Mechanical Testing: Tensile Test																												
	Optical Microscope																												

Project Finished

CHAPTER 4

RESULT AND DISCUSSION

4.1 DATA GATHERING AND ANALYSIS

4.1.1 Joint Visual Inspection

Table 4.1 shows the experimental output with several FSW parameters. The plunge depth, plunge feed rate and dwell time were kept constant 2.4 mm, 8 mm/min and 30 s, respectively.

Table 4.1: FSW on PP with various parameters.

No	Rotating tool speed (rpm)	Transverse speed feed rate (mm/min)	Rating (based on visual)
1	1200	10	Good
2	1500	12.5	Very Good
3	1500	10	Very Good
4	1500	8	Good
5	2000	10	Good
6	1500	10	Very Good
7	1500	10	Very Good
8	1500	12.5	Very Good
9	1500	12.5	Very Good

From naked eyes observation, the experiments with 1500 rpm spindle speed and 10-12.5 mm/min feed rate had smoother surface finish than other parameters. Figure 4.1 shows the output of the FSW on PP using CNC milling machine with the parameters stated in the Table 4.1. By visual inspection of surface finish of the output, the samples with good joint and smooth surface finish were ranked as very good welded PP. The samples were using experiment setup number 2, 3, 6, 7, 8 and 9. Other than that, the welded PP of experiments 1, 4 and 5 only showed quite fair butt joint quality with too much splash suggesting that the material inside the joint was reduced.

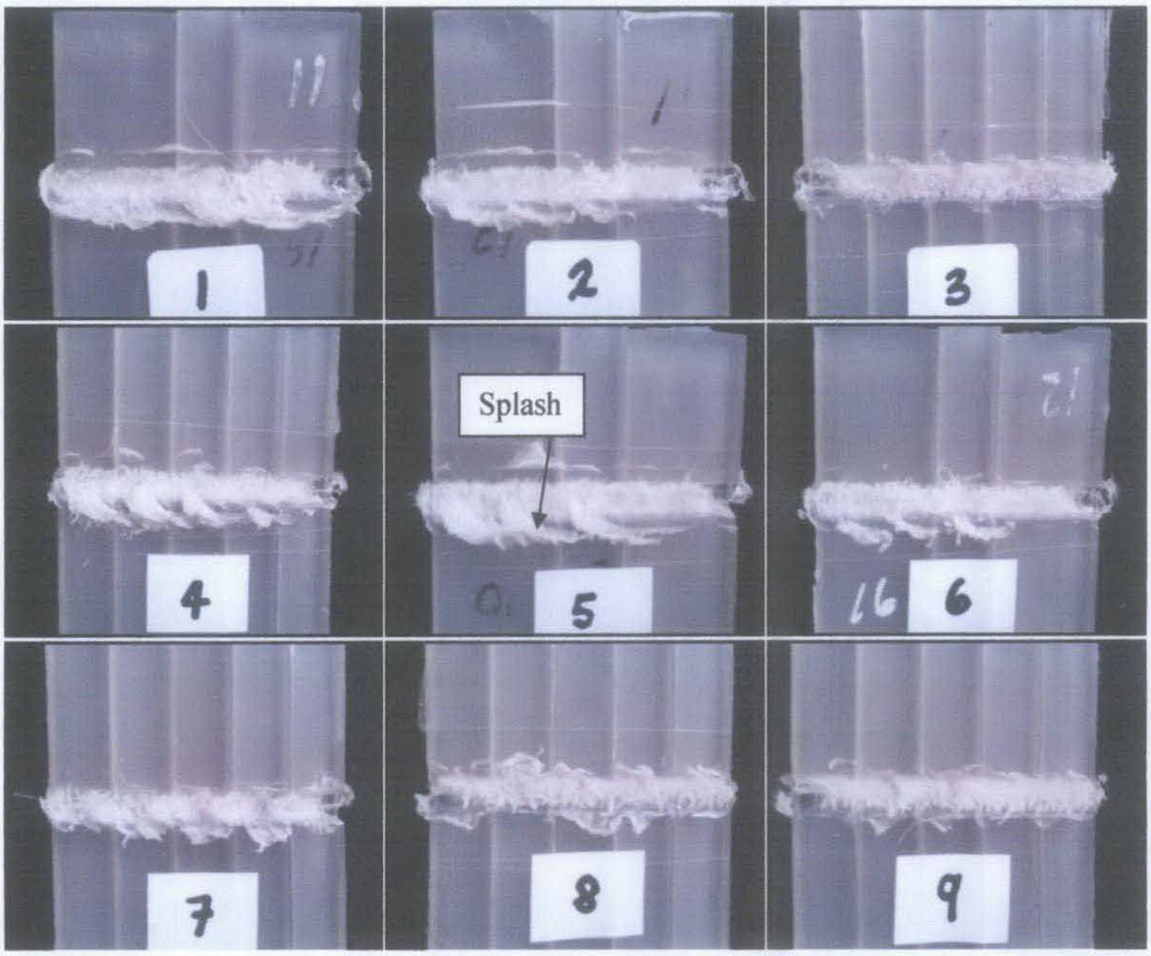


Figure 4.1: The surface finish of the FSW of PP output

4.1.2 Tensile Test

The tensile test was run using 5 kN UTM available in Block 17, UTP. The crosshead speed was 5 mm/min; accordingly to ASTM D 638 standard. Table 4.2 shows the comparison of the tensile strengths of non-welded and welded PP samples.

Table 4.2: Tensile Strength of non-welded and welded PP.

Samples	Tensile Strength (MPa)		
	Base PP	FSW 1	FSW 2
1	34.34	8.64	8.94
2	33.97	4.43	5.65
3	33.61	7.01	7.25
4	34.05	5.78	8.60
5	33.99	7.25	7.33
Average	33.99	6.62	7.55
Standard Deviation	0.26	1.59	1.30

For this result the author differentiate the parameters namely FSW 1 for 1500 rpm tool spindle speed with 10 mm/min transverse feed rate and FSW 2 for 1500 rpm tool spindle speed with 12.5 mm/min transverse feed rate. By calculation, the tensile strength of welded PP using FSW 1 parameters is averagely 19.48% of the tensile strength of base PP material However, the tensile strength of welded PP using FSW 2 parameters is 22.21% of the strength of base PP material which is slightly higher than the FSW 1.

The bar graph in Figure 4.2 shows the comparison of the tensile strength of base PP and welded PP using the FSW technique. The author tested 5 sample of the base PP and welded PP (FSW 1 and FSW 2) respectively and the error bars shown tell us that the data taken were merely accurate. It is observed that joint samples using experiment FSW 2 parameters resulted to be stronger than the samples from experiment FSW 1 parameters.

The tensile strength of the welded PP using FSW process mostly depends on the stirred procedure of FSW which is the rotating tool spindle speed and its transverse speed. Both of these features affect the heat friction introduced in the FSW process and stirring process of the material. In the future, the author would suggest that the tool can provided external heat through its shaft that connected to the tool handler or through the jig that holds the workpiece. Apparently the heat needs to come from the outer source, not only from friction solely.

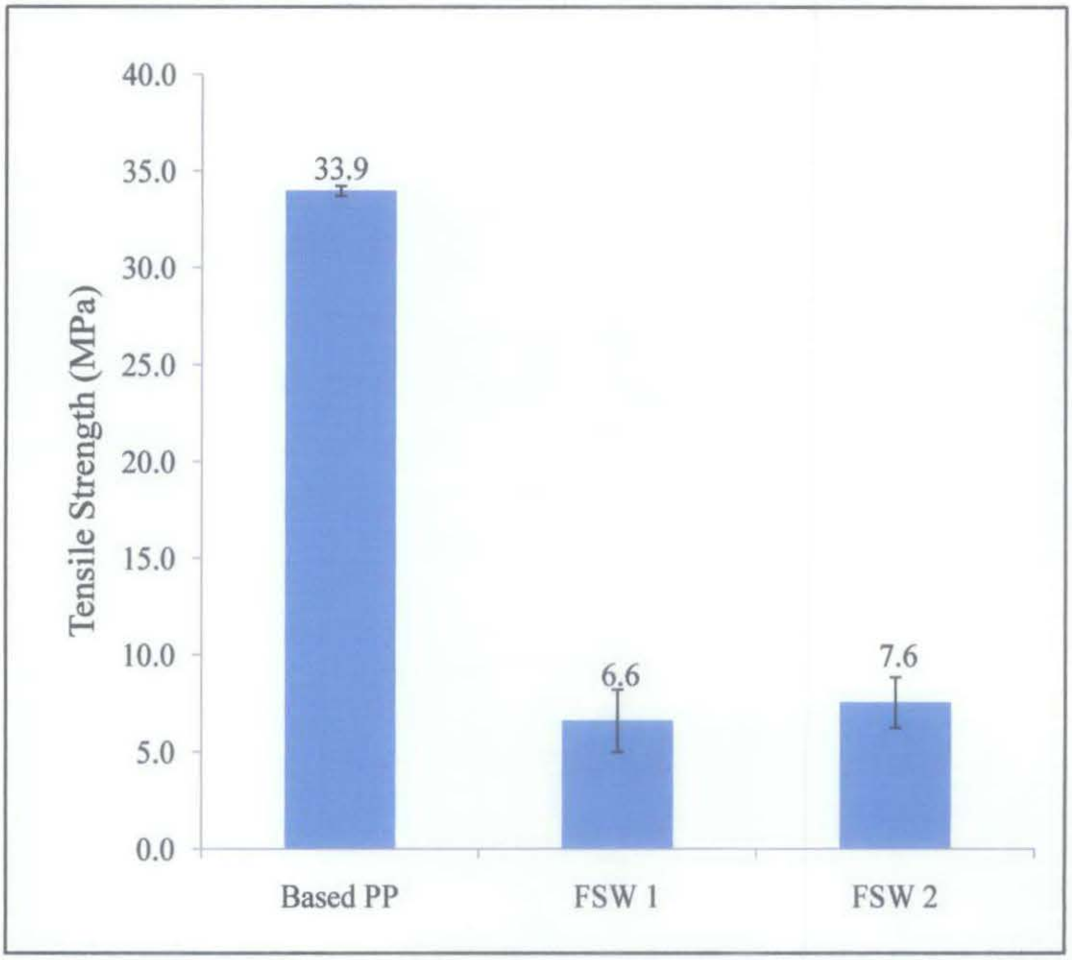


Figure 4.2: Tensile strength comparison between base PP and welded PP.

The parameters that the author tested on the experiment can be variously changed and improved in the future, using the higher rotational spindle speed and higher feed rate value. The other parameters such as tool dimensioning can be study more and the tool nib perhaps should be threaded to make sure stirring of polymer happens thoroughly.

The FSW process for this project merely uses one side of the butt joint to be welded. The strength of the joint would be higher if the FSW process is done not only by single pass but double passes; at the upper side and backside of the joint line. Since the scope of study for this FYP II is limited to only testing FSW parameters and the tensile strength, the effects of double passes FSW process on PP butt joint should be done in the future.

4.1.3 Microstructure study using Optical Microscopy

The purpose of microstructure study was to show the comparison between base PP and its joining zones. Figure 4.3 shows the photograph of PP welded zone.

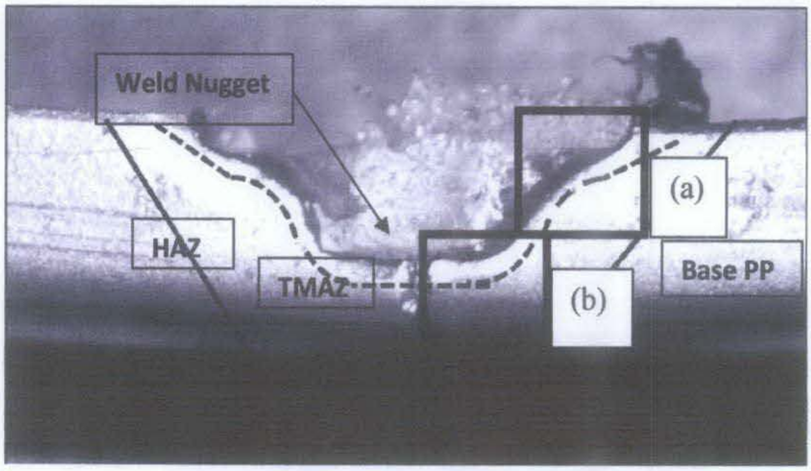


Figure 4.3: Photograph of surface finish of welded PP using FSW process.

Figure 4.4 shows the microstructure of interface between welded zone and the base PP using Optical Microscopy with 5X magnification. The lighter color showed the based PP macrostructure which is observed to have the stacked grain arrangement. On the other side, the darker zone with laminar or vertical arrangement showed the welded or joining area.

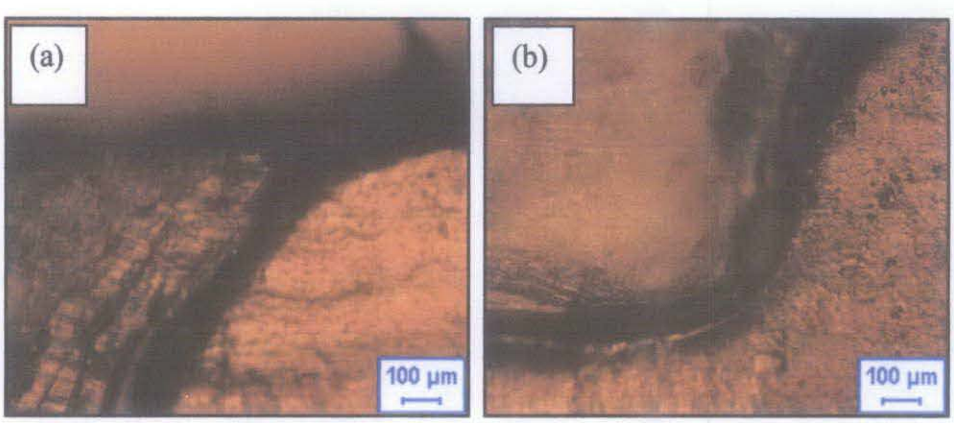


Figure 4.4: (a) The microstructure of base PP zone and the welded zone.
(b) The interface of the base PP zone and stirred/joining zone.

In this project, the author only differentiates the zones of based PP and the welded zone. The author shows that the interface of the welding zone and the based PP are not so tightly joined; meaning it shows the crack initiation happened in the interface. But from observation, it can be said that the intermeshing between particles at the welded zone has accomplished the stirring concept in the FSW.

According to several papers that report on the FSW on Aluminum Al, the welded zone shape of FSW on the butt joint has similar shape compared to this FSW on PP [21, 22]. This supports that the process of joining two PP samples on the butt joint has been achieved in this project.

In the future, improvement on the project could include the study of Heat Affected Zone (HAZ) and Thermo-Mechanically Affected Zone (TMAZ) of FSW on polymer to make sure that the welding line is thoroughly joined together and that should portray better results in term of tensile strength and its elasticity.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions can be drawn from this study:

a) FSW technique was successfully applied on PP.
b) Visually, the welded quality of PP was quite fair.
c) Tensile strength of the welded specimen was only about 20% compared to that of neat PP.

5.2 RECOMMENDATIONS

Several recommendations are suggested for future work including:

a) Use double passes of welding line; upper and below part of butt joining using the FSW process. For that purpose, the study the tool dimension and penetration as well as HAZ and TMAZ should be included into the research to make sure there is no overlapping or void occurred inside the joining zone [15].
b) Add heater into the FSW tool. The purpose of heater is to provide external heat so the workpiece is soften and easy to stir [1].

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