NOVEL METHOD TO JOIN ALUMINUM WITH NYLON

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Dissertation submitted in partial fulfilment of

Bachelor of Engineering (Hons)
Mechanical Engineering

JANUARY 2014

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

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January 2006

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.

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FAIQAH MOHD AZMIR

ABSTRACT

Today, frequently used joining methods for metal and polymer hybrid structures are adhesive bonding and mechanical fastening. These joining processes have several limitations. This project aims to utilized Friction Stir Welding (FSW) to join dissimilar material materials specifically nylon and aluminum. This kind of joining is often very difficult to achieve and the composite's behaviors are not completely understood. This study aims to develop fundamental understandings towards this technology by investigating the effects of joint configuration and length of tool tip to the welding quality. The scope of study revolves around the parameters of the friction stir welding process, the configuration of the samples and also the length of the tool tip used. This paper will discuss the literature that has been done by previous researcher relevant to this project. The literature aims to provide valuable information that may add to the progress of this project. The material used in this research is Aluminum 6061 and Polyethylene. At the end of the paper, the results of the research was discussed and conclusion were presented. The joint created were weak and some of them detached. The research shows that within the limited scope of time and resources, the FSW cannot be proved as the novel method to join Aluminum and Nylon since no good joint were achieved.

ACKNOWLEDMENT

First and foremost I would like to praise Allah the Almighty which have help and guided me in completing and finished my final report successfully for my Final Year Project. A special gratitude I give to my final year project supervisor, Dr Mokhtar Awang, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report. I would also like to thank the mechanical engineering department technician, Mr Shaiful, Mr. Jani, Mr. Daniel, Mr Irwan,Mr. Kamarul and Mr. Suria for their help in completing the experimental works and achieving the result for this project. Their contributions are very important in the progress of my project. A special thanks to my family. Words cannot express how grateful I am to my mother and father for all of the sacrifices that you've made on my behalf. Your prayer for me was what sustained me thus far. I would also like to thank all of my friends who supported me in writing, and help me to strive towards my goal. Last but not least, I hope that this report would be helpful to those who want to find more information on FSW in the future.

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1. INTRODUCTION

1.1. Project Background

Lightweight structures can be seen in many applications. They are used as body parts in modern automobile structures or as reinforced plastics wing or fuselage sections in modern aviation structures. On top of that, composite material such as glass fiber-reinforced polymer (GFRP) or carbon fiber- reinforced polymer (CFRP) can be integrated to lightweight metals such as aluminum or magnesium for a very strong and lightweight hybrid structures [1]. To compensate for this development, researches have been done to identify the best methods for joining different kind of polymers to metal [2]. Hybrid component aimed to increase strength-to-weight ratio and reduce fuel consumption in transportation components thereby reducing cost. Unfortunately, this type of dissimilar joints are often difficult to achieve and their behavior is not fully understood. Much of this is contributed by the vast differences in mechanical and physical properties of polymers and metal and also limited joining methods available for this type of hybrid structures.

Today, frequently used joining methods for metal and polymer hybrid structures are adhesive bonding and mechanical fastening [2]. These joining processes have several limitations, such as stress concentration, extensive surface preparation, extra weight alongside with environmental emissions.

Mechanical fastening and adhesive bonding are commonly applied in joining between polymer and metal. These approaches are usually associated with some drawbacks such as long processing time, accidental disassembly, and susceptibility to degradation by environmental factors. In order to solve these problems, several welding methods, such as laser joining, ultrasonic welding and friction joining have been investigated to exploit the possibility of obtaining high quality hybrid joints of plastics and metals [3, 4].

Among the mentioned welding techniques, Friction Stir Processing (FSP) based on Friction Stir Welding (FSW) is being researched extensively as an alternative technique to join metal with polymer effectively. This paper aims to develop an understanding to this technology's potential with regards to metal – polymer joining. Different configuration of work piece is one of the variables tested to see the effect it brings on the welding strength. The results of this research will revolve around strength testing and microscopic observations.

1.2. Problem Statement

Metal and polymer joining is often very difficult and the composite's behaviors are not completely understood. This is due to the fact that both materials varies greatly in their mechanical and physical properties besides the limited joining method available for this material type. This technology however is still new thus explaining the lack to fully understand its' potential. This study aims to develop fundamental understandings towards this technology by investigating the effects of joint configuration to the welding strength.

1.3. Objectives

- To investigate the effect of tool tip length on the quality of the joint.
- To investigate the effect of different joint configurations on the quality of the welding.
- To develop fundamental knowledge on the effectiveness of FSW in joining metal and polymer.

1.4. Scope of Study

This research will focus on the quality of joint created by using friction stir welding on aluminum and nylon. The materials that will be used are Aluminum (6061) and Polyethylene. Welding parameters and tools dimension will be based on relevant literatures. Other than that, this study will also investigate the effects of different joint configurations to the quality of the weld. Three joint configuration will be created, including one butt joint. The machining process is constraint by time therefore only available equipment in UTP will be used for this process primarily.

2. LITERATURE REVIEWS

After decades of research, many methods has been introduced to join polymers to metal effectively despite the differences in both material's properties [5]. However it is worth mentioning that it is still regarded as a new research topic. Studies have been carried out on reviewing available joining techniques for thermoplastics and thermoplastic matrix composites [2, 6, 7]. However, little information is available on the joining of polymer-metal multi-materials. As current studies shows, the common joining methods used today for dissimilar material joining are mechanical fastening, adhesive bonding, and welding.

Mechanical fastening is a widely used, cost-effective means of joining that can be used various dissimilar materials [8]. It involves a range of processes that utilize a variety of fasteners including nuts & bolts, screws & rivets, or mechanical interlocks to assemble materials without the need of heat. Among the types of materials are metal – metal, polymer – polymer and metal – polymer. Mechanical fastening has an advantage of giving joined material the ability to be disassembled for maintenance, repairing or recycling purposes. Several structures can be assembled independently of the properties of the joining partners when this technique is applied on polymer, polymeric composites and polymer-metal hybrid joints [2]. Unfortunately, stress concentration resulted from rivets hole of from the join can lead to crack formation and propagation inside the joint materials and it is the major concern in mechanical fastening [9]. Mechanically fastened polymeric joints frequently fail under loading by the same failure modes as those observed in metallic joints. These joints usually show higher susceptibility to hole-stress concentration due to the high polymer notch sensitivity fabric reinforced joints, even display lower joint efficiency (about 50% of the weaker joining partner) [10].

Some other disadvantages of joining polymer with metal using mechanical fastener is shown in some studies [9, 10]: (a) Augmented Stress Concentration. (b) Loosening of fasteners due to creep, moisture and stress relaxation. (c) Notch sensitivity and Crazing (beginning of cracking) of the polymeric partner. (d) Re-closure limitation (polymer does not withstand torque from inserted fasteners). (e) Differences between thermal expansion coefficient of plastics and metallic partners may increase residual stresses. (f) Loss of properties due to moisture. (g) Need to access both sides of the part.

The next joining technique used to join dissimilar materials is adhesive bonding. It is widely used for metal-polymer hybrid joining today and often seen used in industrial applications. It is a solid state joining technique that relies upon the formation of intermolecular forces between the work piece and the polymeric adhesive itself for joint formation [11]. It involves the use of polymeric adhesive which undergoes a chemical or physical reaction for eventual joint formation. The process begins with surface preparations for adherence. This is done by degreasing, grinding, etching or by applying a primer layer for increasing adhesion. The next step is to clamp the joining partners, and applying the adhesive. The joining surface is brought in contact and kept under constant pressure. When the adhesive cures, the two surface will join. This can be done at elevated or room temperature [2].

Adhesive bonding is widely used in the recent years due to the fact that tough adhesive with high strength is available. It is proven to be a very effective method for joining dissimilar materials [4, 12]. Although this method gives many advantages in material joining including uniform stress distribution, small distortion effect, ability to join almost any combination of materials, complex joint geometry and control physical properties of joints, a study shows that it post some potential problems due to its due to large surface free energy difference and very low surface free energy of polymers. This is mainly because this type pf joints depend majorly on surface free energy and wettability of materials [13].

A study show that the SLB test of a mirror-polished metal substrate joined with polymer by adhesive bonding resulted in almost pure interfacial failure while the micro-patterned metal substrates resulted in a partial cohesive failure [14]. In a magnified view of the interfacial failure region on a patterned substrate many scraps of epoxy resin could be found on the fracture surface, which indicates frictional resistance during pull out of the interlocked epoxy resins. Therefore, although adhesion strength can be enhanced under crack opening-mode loading, a mechanically interlocked steel/epoxy interface under loading does not provide sufficiently reliable bond strength to be used for load-bearing joints.

Mechanical fastening and adhesive bonding are commonly applied in joining between polymer and metal. These approaches are usually associated with some drawbacks such as long processing time, accidental disassembly, and susceptibility to degradation by environmental factors. In order to solve these problems, several welding methods, such as laser joining, ultrasonic welding and friction spot joining have been investigated to exploit the possibility of obtaining high quality hybrid joints of plastics and metals.

Ultrasonic welding utilizes localized high frequency vibration technique usually at 20 to 40 kHz that initiates coalescence coupled with moderate clamping force. The vibration will create surface and intermolecular friction that will melt the polymer. After cooling under the same clamping force, the joints are formed It is a solid state welding joining technique characterized by low energy input in welding zone with short welding time [15]. It can achieve high quality joints of dissimilar material. For this type of welding, the shear strength of the joints welded depends mostly on the level of contact between both material involved. A study shows that by using ultrasonic welding with two vibration systems, the plastic specimens were joined successfully with uniform weld strength of about 50 to 60 kgf along the specimen width [16]. Excessive welding time over however causes damages to the specimens and the weld strength decreases. Uniform weld strength along the specimen width could not be obtain with only one vibration system.

Laser welding has been long since introduced but it is only being exploited and gaining popularity not until recently. It utilizes a laser beam application on the joint region which produces heat thus melting the joint area.[4] Molecular vibration during the laser radiation will vibrates the molecules inside the material which in turn create resonance. This resonance will create heat for the welding purposes. Applications of this welding technique includes food and medical packages as well as electronic and micro-components. Other than that, its application can be seen in the automotive industry where it is use for joining instrument panel clusters, head lights and many others. Joining of polymer to metal is often being done by laser welding. [2] Laser welding pose may advantages in the joining of dissimilar materials. It has fast weld cycles, absence of generated particulate, smooth flash, relatively low amount of residual stress, and a well-defined heat affected zone. A study by Kayatama and Kawahito of Osaka University shows that a 30 mm wide metal-plastic joints possess high tensile shear loads of more than 1.2 kN [17]. Therefore, this newly developed laser joining process should contribute to the development of bonding of dissimilar materials from both the theoretical and practical viewpoints. However, laser welding needs high-cost equipment, limitation in availability of weld able materials and geometries characterizes the negative points of laser welding.

The next joining technique use for polymer-metal joining is Friction Spot Welding. It is also known as re-fill spot welding. It is a solid state welding technique for lightweight metals developed by GKSS research center, Geesthacht. It uses a three-piece, non-consumable tool system comprising a clamping ring, a shoulder, and a pin (Fig. 1A). The tool components are mounted coaxially and can be rotated and moved in and out independently of each another.

A study shows that FSW on magnesium and reinforced composite results in a joint with shear strength between 22 – 26 Mpa depending on the variation of composite [2]. It has demonstrated that friction spot joining can be successfully used to join magnesium to thermoplastic composites. Although the bonding mechanisms of FSpJ are not yet well understood, there are strong indications that joining is accomplished by a mixed regime of surface mechanical interlocking (through micro and macro constraints related to the metallic nub) and adhesion between the metallic and consolidated polymeric layers, as well as direct partial fiber attachment on the metallic plate. The main advantages are as follows: short joining cycles, absence of emissions, operation simplicity, availability of commercial equipment, and good mechanical performance. The limitations include the following: only overlap configurations and spot geometries can be produced; the technique is not directly applicable to thermoset matrix composites (the use of an adhesive layer is required); and it is not adequate for very thick metallic partners (currently tested thicknesses are within 1–2 mm). The positive preliminary results of this work make FSW an alternative joining technology for polymer–metals hybrid structures.

Besides the mentioned techniques, there are many other methods of joining polymer with metal currently being studied all over the world. Many aspects of these methods are not grossly understood, providing the vast opportunity to develop a novel joining technique for joining polymer with metal. The table below summarizes some other results of current studies with regard to this topic.

Table 2.1: A summary of fracture type with different polymer - metal joining process [2]

Joining process	Materials	Surface treatment	Process conditions	Testing method	Fracture type
FSpW	Mg AZ31/PPS-CF	Grinding SiC grid paper P1200 + acetone rinsing	1950 rpm, 0.25 mm plunge depth, 8 s, 2.5 bar	DIN EN 10002	Mixed cohesive/adhesive regime (composite)
FSpW	Mg AZ31/PPS-CF	Grinding SiC grid paper P1200 + acetone rinsing	3000 rpm, 0.25 mm plunge depth, 8 s, 2 bar	DIN EN 10002	Mixed cohesive/adhesive regime (polymer)
Ultrasonic welding	$AlMg_3$ (1 mm)/PA 66-CF (2 mm)	As-received	Vibration amplitude: 40 µm; axial force: 140 MPa; energy: 2160 J	Single lap joints (single specimens of 25 mm × 70 mm)	Cohesive (composite)
Ultrasonic welding	$AlMg_3$ (1 mm)/PA 66-CF (2 mm)	Corundum blasting + HNO^{3-} pickling	Vibration amplitude: 37–43 µm; axial force: 100–200 MPa; energy: 1700–2500 Ws	Single lap joints (single specimens of 25 mm × 70 mm. Overlap: 25 mm × 25 mm)	Cohesive (composite)
Induction welding	$AlMg_3$ (1 mm)/PA 66-CF (2 mm)	Acetone wiping and corundum blasting + additional 100 µm PA 66 film	Welding force: 0.5 MPa and 800 Hz	DIN EN 1465	Mixed cohesive/adhesive regime (composite)
Resistance welding	Al 7075-T6 (3 mm)/PEI-CF (3.14 mm)	Abrasion + degreasing + alkaline cleaning + phosphoric acid anodization (PAA)	Power: 90 kW/m^2; welding time: 10 min	ASTM D-1002	Cohesive (composite)
Friction stir spot welding	Al 5754 (2 mm)/PA 66 (1.6 mm)	Aluminum: as-received/nylon heat treated in air at 125 °C/24 h.	Tool: steel, shoulder Φ10 mm/pin Φ2.5 mm	Single lap joints (specimens: 25.4 mm × 100 mm. Overlap: 25.4 mm × 25.4 mm)	Cohesive (polymer)
Adhesive bonding	Ti 15–3 (1.6 mm)/PPS-GF (2.5 mm). Adhesive: AF-3109-2K	Ti: sodium hydroxide anodization (SHA). Composite: corundum blasting	Curing: 150 °C/60 min/350 KPa	ASTM D-5868-95	Cohesive (composite)

*Joint's strength consecutively (Mpa): 23 [2], 28 [2], 32 [18], 50 [18], 8 [19], 14 [20], 25 [21], 24 [22], 16 [22]

Friction stir welding is a thermo mechanical process that involves the complex interactions between different phenomena and varies throughout the weld regions [23]. Generally, friction stir welded material can be divided into four regions as shown in the figure below. In the heat affected zone (HAZ), there is no plastic deformation; however, metallurgical microstructure and mechanical properties of parent material are modified by the heat generated from the weld-center. In the thermo-mechanically affected zone (TMAZ) and the stirred zone, the combination of plastic deformation, dynamic recrystallization and recovery occur simultaneously during the process [23]. Whilst the deformed grains are still retained in TMAZ, fully recrystallization significantly occurs in the stirred zone only.

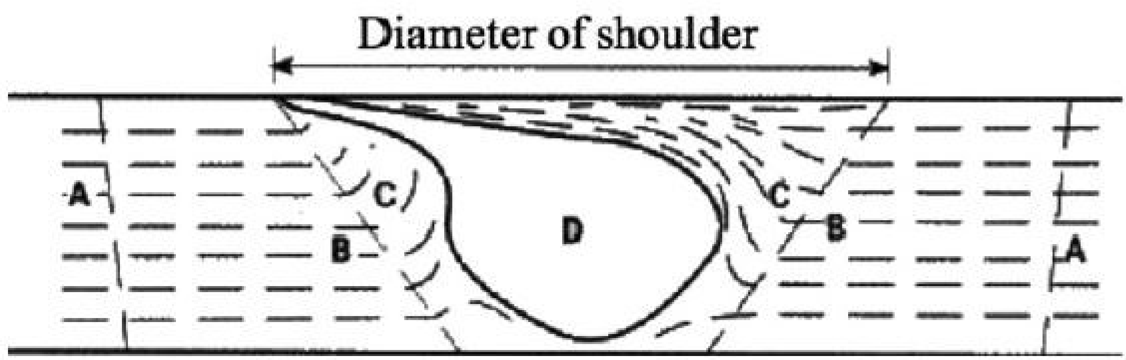


Figure 1: The schematic shows different regions of the cross section of friction stir welded material. A) Parent material B) Heat affected zone (HAZ) C) Thermomechanically affected zone (TMAZ) D) Stirred zone [1]

A study by Zoltan of Budapest University of Technology and Economics shows that using a full factorial experimental design, covering the most important technical parameters of friction stir welding; from feeding rate, rotation speed, tool diameter and cutting depth rotation speed and cutting depth have the largest effect on the flexural strength of the welded seam in polypropylene. Provided the welding is 10 mm thick polypropylene plates at a cutting depth of 9.6 mm and using 1 mm grooved root support, the difference between the flexural strength values measured from the crown side and from the root side disappears, and a quality factor of 90% can be achieved at 3000 rpm rotation speedand 50 mm/min feed rate [24].

3. METHODOLOGY

3.1. Flow chart of methods

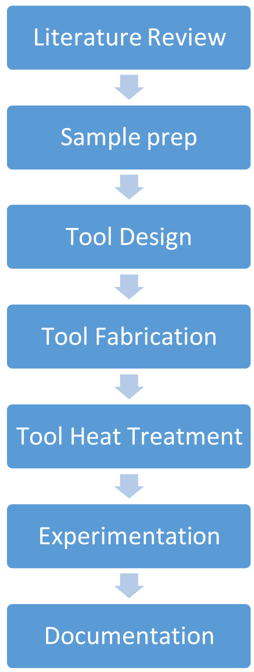


Figure 2: Project's process flow

Friction stir welding of aluminum and nylon sheets of 10 mm thickness have been carried out at laboratory in block 16, Universiti Teknologi Petronas. The first trial have been done with the CNC Bridgeport machine. The details of material specifications, experimental equipments and experimental setup are reported in this chapter. This chapter begins with the specification of material properties including mechanical and thermophysical properties. The second part of this chapter illustrate the equipments used in the experiments including welding machine, FSW tools and specimen fabrication machine. The details of welding variables are reported in the experimental procedures section in this chapter.

3.2. Materials

The materials involved in this research are;

1. H13 Tool steel
2. Polyethelene
3. Aluminum 6061

The properties for this material can be found in appendix 1, 2 and 3.

3.3. Experiment Apparatus

The experiment will be done with a CNC Bridgeport milling machine in block 16 with a customized tool as seen in figure 3.1. A customized jig will also be used to clamp the workpiece in place while the welding process takes place as seen in figure 3.2. For workpiece preparation, a conventional milling machine and band saw will be used. CNC Lathe Bridgeport model Power Path-15 is used to fabricate the raw materials into welding tools. Residuals on the fabricated welding tool will be removed using a conventional lathe machine. Hardening process for the welding tool will be done on CARBOLITE Heat Treatment Furnace.

3.4. Welding Tool

The welding tool was fabricated first in order begin the welding process. The steps of the fabrication of the welding are tool is design, fabricate and heat treatment. Firstly, the welding tool have been designed with suitable dimensions and geometry based on the researches in literature review and discussions with supervisor. Based Nakata, a tool with no tip were used for their set of experiments involving the same material with thickness of 2mm for both aluminum a nylon plate. However, it has been established that this particular experiments involved a much thicker plate therefore a tip is a must [3]. Then there's the question of whether the tool tip should penetrate the second layer of overlapping material or not. Therefore the author ended up with designing 2 tool tip.

The detail of the design was given to lab technician for fabrication process. Details of the tool will be as specified in the next figure. The tool will be made out of H13 tool steel. Properties of this material can be find in appendix 1.

Materials	Dimension	Unit
Tool Steel	Diameter: 25mm Length: 100 mm	2

Table 3.1 Dimensions of Tool Steel

The diameter of the sample purchased was slightly larger than the designed diameter. This is to give room for polishing for surface of the tool steel. Quotation was sent and upon the agreement of the supervisor purchasing was made. The fabrication process was done with the aid from the lab technicians. Figure 3.7 shows the design of the tool. The design was based on the thickness of the nylon and aluminum plate that is going to be welded together with different configurations.

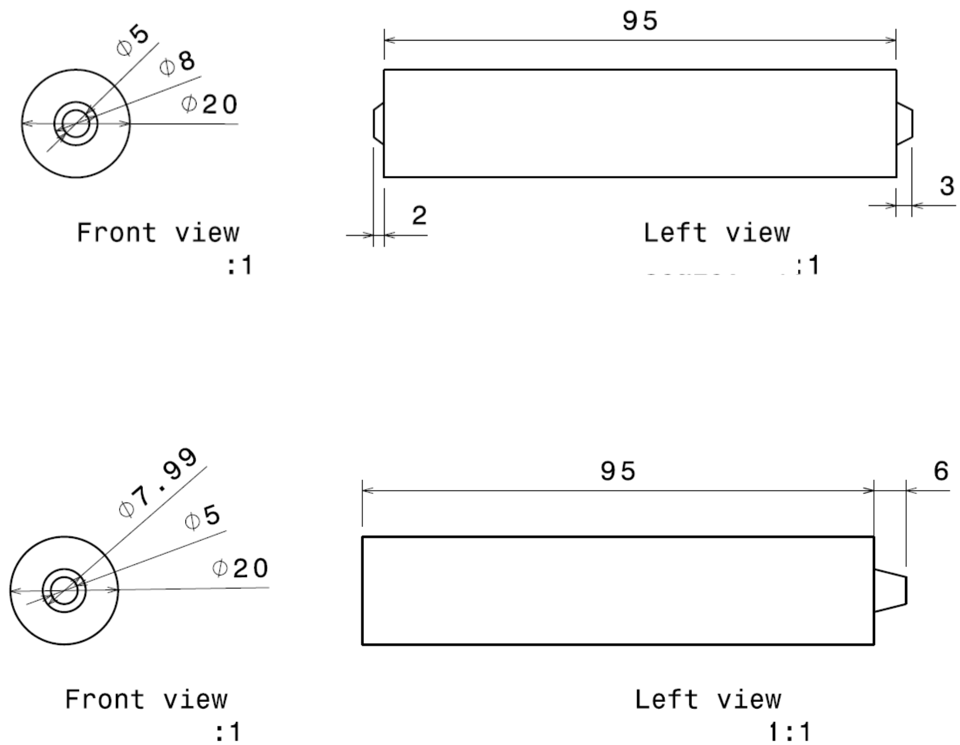


Figure 3.1 The design of the tool

3.5. Experimental Procedures

Aluminum alloy (A6061) and Polyethylene sheets with dimensions of 100 x 50 x 10 mm were prepared. The chemical composition of the AA6061 and PE are listed in the appendix. Both the Aluminum and the Nylon were used as received and no preparation or alteration was done on it. Both the plates were chosen because of its availability and the direct correlation with the research's objective. The welding processes were conducted using a FSW machine with the specially designed cylindrical tool.

The parameters under investigation in the first set of trials are tool tip length, tool rotation speed, dwell time, feed rate and configurations. The range of parameters for the first trial is summarized in Table 3.4.

No	Configuration	Tool rotation speed (rpm)	Feed rate (mm/min)	Plunging depth (mm)	Dwell time (s^{-1})	Tool tip (mm)
1	A & C	1400 – 800	25 – 50	+1/2mm from tool tip length	15 - 20	6 & 3

Table 3.2. Summarized welding parameter's range

During the FSW process, the specimen is placed with tested configuration, with the top plate being the aluminum, on the advancing side. The specimen were welded with a controlled length of 60 – 80 mm. Figure below illustrate the welding process.

The process of FSW using the CNC milling machine is described as follows:

1. One aluminum plate and one nylon plate are placed together and clamped on the jig with bolts and nuts.
2. The jig is clamped to the Bridgeport Milling Machine
3. Tool is then attached to the machine
4. Proceed with the welding process by coding and adjustment on the milling machine.

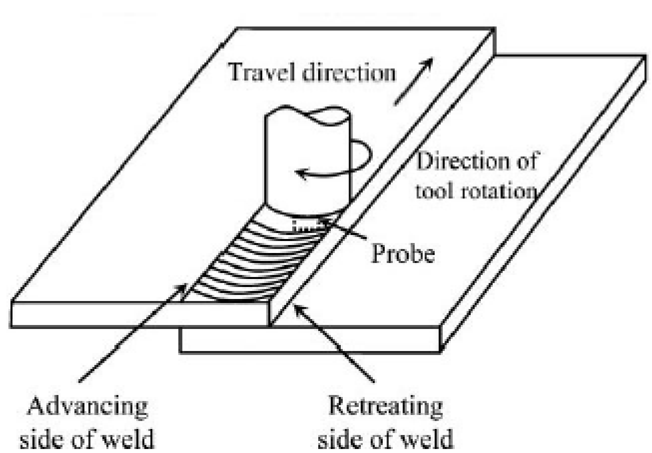


Figure 3.2. Schematic showing the lap joint configuration for tensile test

3.6. Visual inspection

The next step is to observe the joint created. The observation will be done on the actual physical workpiece upon completion of the test without any alteration on its surface. Analysis will be made with regard to the quality of the joint. Another observation will then be done to inspect the cross section of the joint. This will be done by first cutting the workpiece perpendicular to the welding line. A regular band saw will be used for this process.

3.7. Universal tensile test

Generally, upon the completion of the experiment, testing should be done to determine the strength of the joint created. The proposed test to analyse the strength of the joint is the tensile (pull-to-break) test, using UTP's 100kN Universal Testing Machine with reference with the ASM guideline. The results of each experiment with different parameters will then be compared with each other in order to determine the relationship between the spindle speed and travelling speed with the maximum load of the end result. The planned procedure is to cut the workpiece with the EDM machine for the aluminium part, and using a regular saw to cut the remaining nylon part of the joint.

Electric discharge machining (EDM), is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage [25]. This method however will only work on metal surfaces therefore only half of the joint will be cut using this technique.

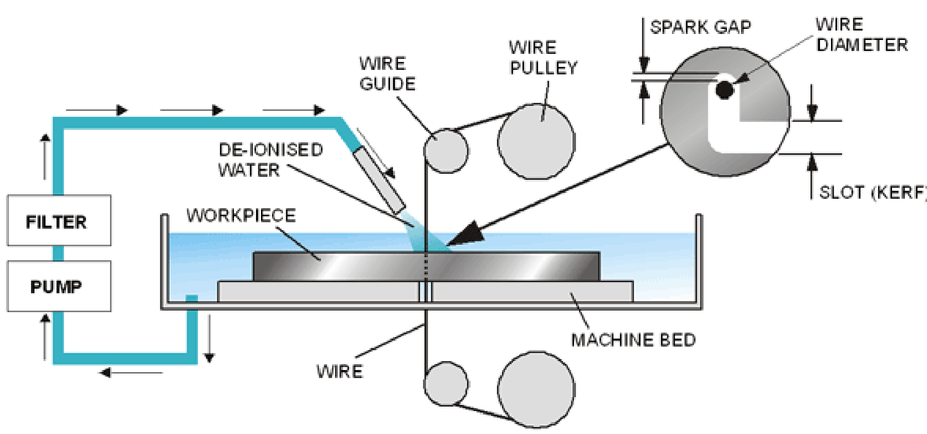
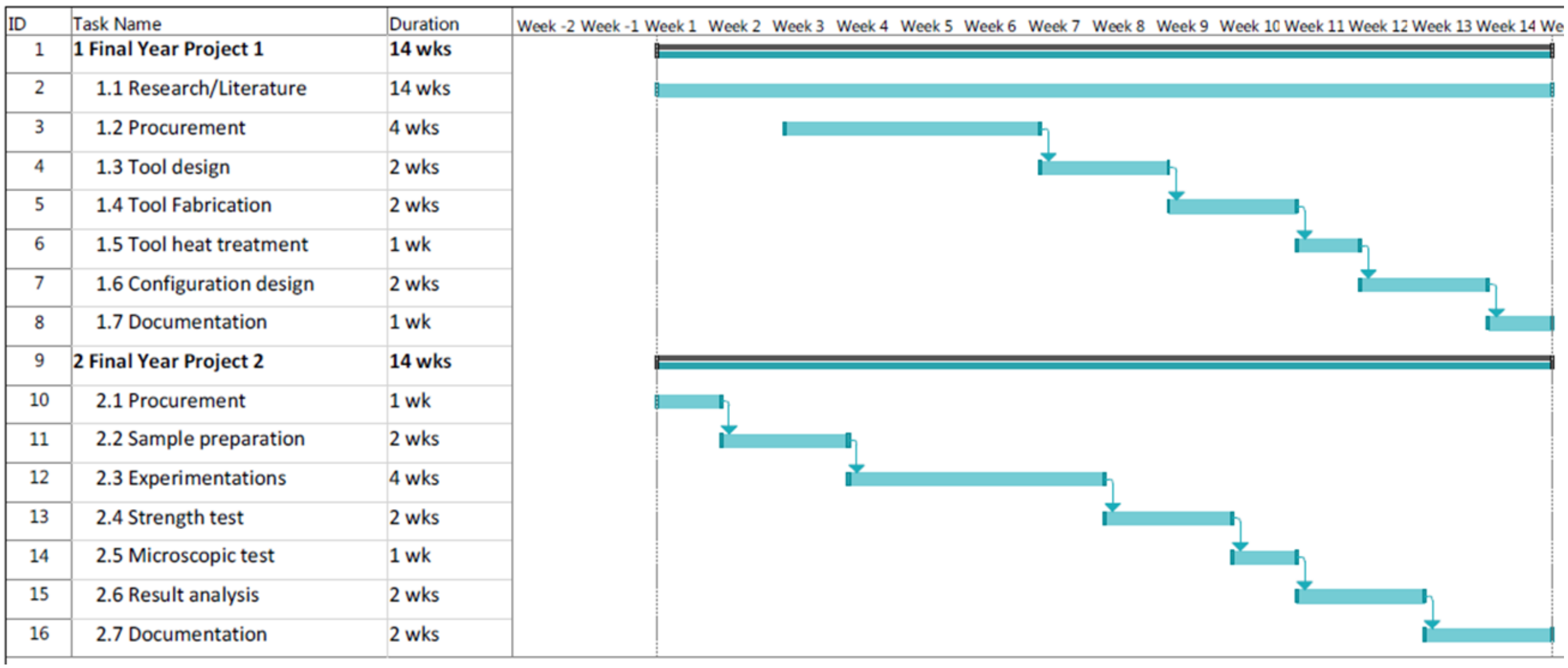


Figure 3.3 Schematic diagram of the process of cutting using the EDM machine

3.8. Gantt chart



3.9. Key milestones

No	Activities	Week
1	Selection of materials for the research	07-03-2014
2	Completion of welding tools fabrication	18-04-2014
3	Completion of configurations in preparation for FSW	20-06-2014
4	Completion of mechanical testing for microstructural analysis and mechanical properties	18-07-2014

4. RESULTS & DISCUSSION

The experiment begins with fabricating the tool needed for the project. As discussed, the selected material will be nylon and aluminium while the tool is H13. Below is the selected material for this project that has been bought.

Materials	Dimension	Unit
Tool Steel	Diameter: 25mm Length: 100 mm	2
Aluminum	200 mm x 150 mm x 10 mm	5
Nylon	200 mm x 150 mm x 10 mm	5

Table 4.1. Selected Material

4.1. Fabrication of welding tool

The tool was fabricated from the raw H13 Tool Steel using Bridgeport Romi Power Path 15 based on these designs. The coding was done by technician assistant who is in charge of the machine. Figure 4.1 shows the raw material of the tool still followed by figure 4.2 which is the fabricated tool. The residual part left by the CNC machine was manually remove using conventional lathe machine.

Figure 4.1. Raw material of H13 tool steel

Figure 4.2 The fabricated tool after residuals were removed

Then, hardening process was conducted using the CARBOLITE heat treatment furnace. The steps for hardening are as follows; (1) preheat at 750°C for two hours,(2) dwelling at 1010°C for one hour and (3) cooling by air quench. Then the oxide layer on material have been removed by using sand paper. Figure 4-5 shows the graph of the hardening process while figure 4-6 shows the machine used.

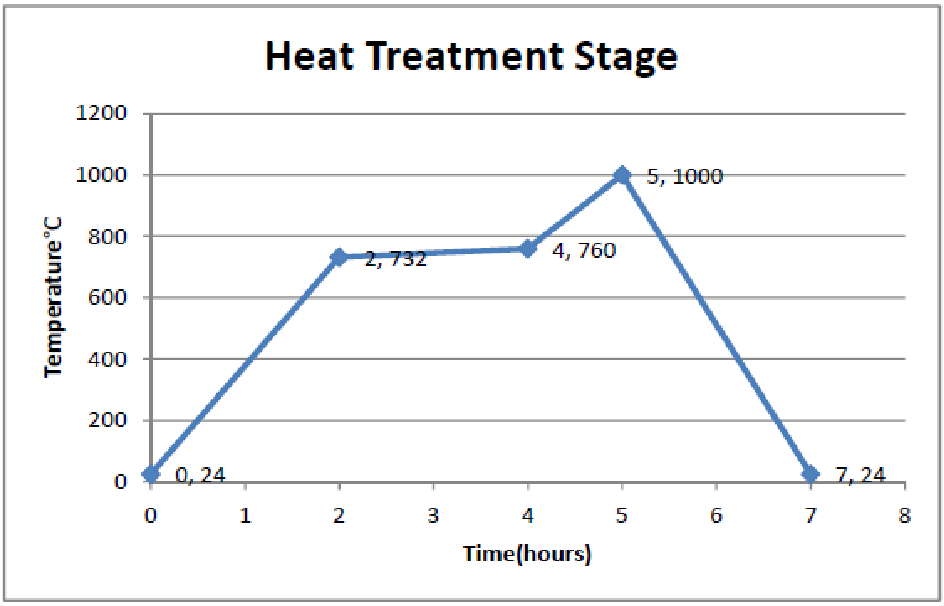


Figure 4.3 Graph of hardening process

The heat treatment process begins with the preheating process. It help relieve the stress and reorganize the grain structure. This was done by two step increment of temperature beginning at 732 C for 2 hours and 760 C for the next hour.[26] This was then followed by the austenitizing stage which is to further increase the temperature to 1000 C. At this stage, the hardening effect was achieved by transforming ferrite into austenite. As the temperature elevated to austenite temperature, pearlite is the first structure to be transformed into austenite state, then ferrite. The next phase is quenching. Usually, this phase is done by using a media such as water, oil or air. [26]For this project, the media chosen was air. The tool was left to cool down by itself until it reaches the room temperature. By using air, thermal shock is lower therefore thermal stress could be evaded. Figure below shows the phase diagram for the transformation.

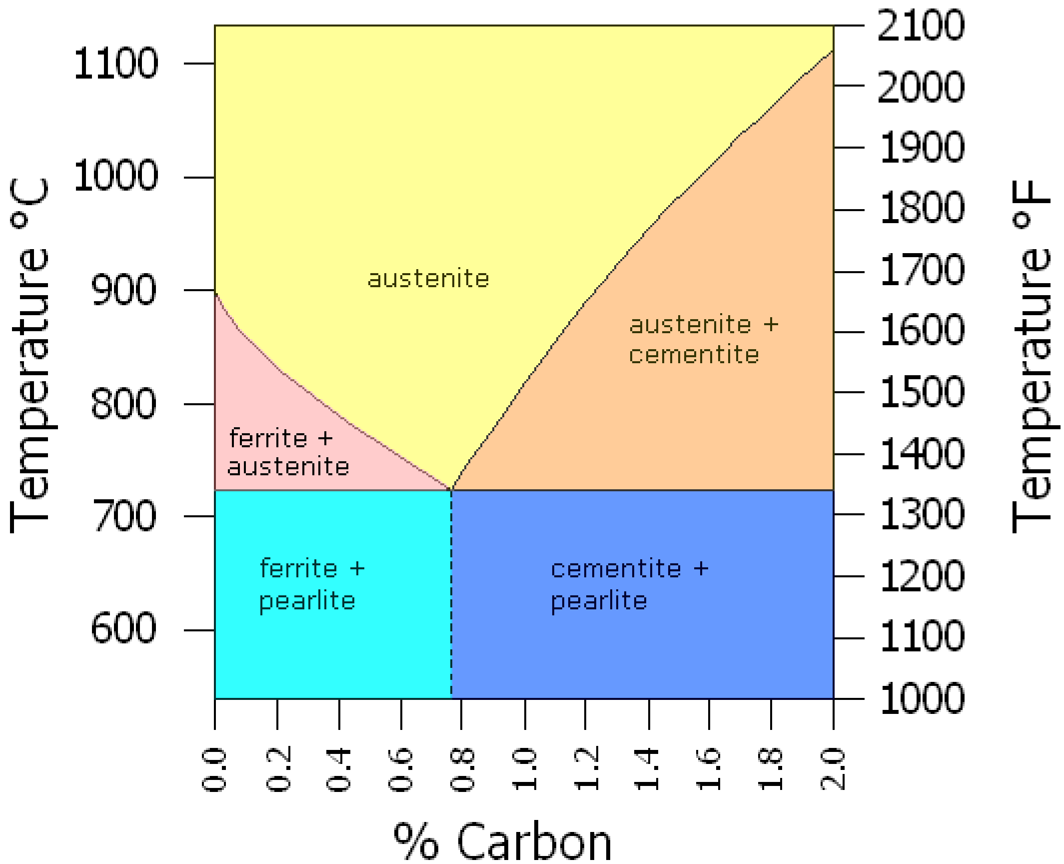


Figure 4.4 Phase diagram for H13 Tool Steel heat treatment process

4.2. Fabrication of Work piece

The work piece was planned to have a general dimension of 200x100x10 mm. However, when the materials arrived, it was decided that it is more economical to cut the work piece into pieces with dimensions of 100 x 50 x 10 mm. This is done with a band saw. Next step is to create the shape for the work piece into several configuration. This was done on a conventional milling machine. Problem arise where the tool to create configuration B is not available, therefore it will be excluded from the first trial due to time constraint. The lap joint configuration is also excluded from the trial because the jig provided cannot accommodate the thickness of the lap join configuration which is 10 mm + 10 mm. Figures below shows the specimens cut into respective configurations.

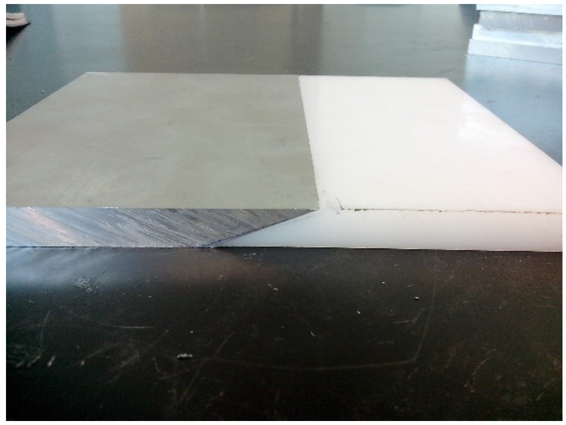


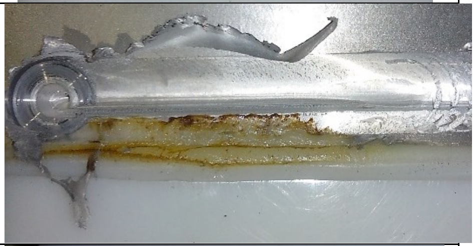
Figure 4.5 Configuration A

Figure 4.6 Configuration C

4.3. Friction Stir Welding Process

The FSW have been conducted at Block 16 by using CNC milling machine Bridgepot as shown in Figure 3.3. The machine was conducted by a technician who was in charge of this equipment. The parameters used for the welding process are very important as the results can be analyzed by the manipulative and constant variables. The manipulative variable in this project is the travel speed of the welding tool while the constant variables are the spindle speed (rpm), plunge feed rate (mm/min), depth of plunge, dwell time, inclination angle and metal plates side. The details of parameters are as shown below as well as the results.

No	Config	Tool rotation speed (rpm)	Feed rate (mm/min)	Plunging depth (mm)	Dwell time (s^{-1})	Tool tip (mm)	Results
1	A	1400	25	6.1	20	6	
2	A	1000	50	6.1	15	6	
3	A	800	40	3.1	15	3	

4	C	800	40	3.2	15	3	
5	C	800	40	6.2	15	6	
6	C	1800	75	6.1	15	6	
7	C	2000	100	6.1	10	6	

8	C	1500	60	6.1	15	6	
9	C	1800	60	6.1	15	6	
10	C	1800	60	6.1	15	6	

Table 4.2. Summarized result of the first trial run

4.4. Visual inspection

This test involved configuration A with a tool tip length of 6 mm. The parameter was revised from literature [1]. Severe burr and flashing can be observed in all the test which can be seen in the table above and local frictional heat at the contact between shoulder and work-piece surfaces causes the adjoining thermoplastic to be softened. This leads to deformation of the upper work-piece when the rotating tool exerts force on the weld due to softening of underlying support plate. Welding forces are associated with rotation speed and travel speed. The produced forging pressure on the weld increases by increasing tilt angle or travel speed. Both burr formation and flashing are due to soften thermoplastic sheet and high welding forces exerting on the work-piece. During test 1, the nylon plate melted extensively causing it to run all over the jig, halting the full weld process. Hovanski mentioned in his research that joining dissimilar materials with significantly different properties (e.g., melting temperatures and densities) is problematic for most welding methods, because the lower temperature melting material can liquefy and be removed from the desired bonding area before the higher melting temperature material melts and before the weld can form. In general, conventional FSW between dissimilar materials yields unstable lap weld joints due to the vastly different melt temperatures and flow stress properties of the materials. [27]

Test 2 was done on the same workpiece but on the other edge of it. Rotation speed was reduced to 1000 rpm in hope that the melting will reduce and good joint could be achieve. Though the melting seemed to reduced, it caused marks along the tool tip where the stir is supposed to take placed. This is caused by the melted of the nylon sheet, overflowing to the side of the joint instead of stirring with the melted aluminum. The tool tip was changed to 3 mm, to test another theory. According to Wallop, the tool tip does not need to penetrate the lower plate (nylon) in order to achieve good joining. He mentioned in his journal that the heat generated by the friction between tool tip and the above plate (aluminum) should be sufficient for optimized melting of both plate and stirring process could occur.

During test 3, the formation of welding path looked better and with significant reduced in flashing, burr and melted plastic overflowing. The rpm was also lowered for this test since previous test indicates that too much heat is generated by the tip. However, halfway through the welding process, it can be seen that the aluminum does not melt properly. This was considered as the effect of using a tool tip that did not penetrate the second plate. It could also be caused by the reduction of welding speed. After the workpice was removed from the jig, the joint strength was test by lightly pulling them apart however, it cannot stand even the lowest force exerted on it and detached. Insufficient welding forces leads to low heat generation and poor joint quality. From one of Obaditch's research, he mentioned that under penetration (also referred to as lack of penetration or "LOP") can lead to non-welded portions along the seam, thus reducing the strength of the weld [28]. The theory is insufficient heat on the aluminum plate though the nylon sheet seemed to receive enough heat. The angled surface of the configuration was predicted to be among the reason that uniform heat distribution along the welding path could not be achieve.

Test 4 was done on configuration C to test this hypothesis. However, the same result was achieve and the joint was unable to withstand force and detached. The next test was done with the same parameters but with the tool tip of 6 mm, which penetrates the lower plate. The joint achieved looked better relative to the first 4 joints. However, severe deformation on the above nylon side of the workpiece, discoloration and overmelting suggest that the heat is too much for the nylon to withstand. Nylon has an average melting point of 250℃ whilst aluminum has a melting point of 660℃. The major difference in melting point post challenge to create an optimized environment for both the material to melt accordingly, stirred, and form joints.

Test 6 was done on a much higher RPM and feed rate. One of the literature mentioned that high transverse velocity of the tool is critical to obtain desirable weld quality [29]. By increasing the feed rate and the RPM, a much better joint was achieved. The joint have minimal gap and it seems much sturdier than the rest of the joints.

The higher RPM seems to have created enough heat to stir the aluminum and the nylon, however, the joint that were created were coarse. Splashing and burring still exist and there were traces of the nylon degrading. On top of that, both the aluminum and the nylon does not retain their flat surfaces after the welding process. Although the joint is the best among the rest of the tests, is still possess the characteristics of a bad joint where the plate curves and the presence of gap. Despite using a customized jig, all the samples that were testing still have the curves and slight deformation in terms of their initially flat surface.

The rest of the tests were done revolving around the same parameters but no result as good as test 6 was achieved. Test number 10 done on a butt joint configuration, shows both material did not stir. The aluminum did not melt sufficiently leaving the nylon part destroyed and deformed.

Preparation was then made to cut the cross section of the joint to inspect the quality of the joint from within. However, during the process, the samples could not withstand the pressure exerted by the band saw, and the joint detached. The welding was not strong enough to keep both the plates together throughout the cutting process. All the samples tested faced the same problem, therefore the process was halted.

4.5. Universal tensile test

The tensile test was propose to investigate the strength of joints created by this process. The planned procedure is to cut the workpiece with the EDM machine for the aluminium part, and using a regular saw to cut the remaining nylon part of the joint. Upon cutting process, the wire snaps right after it touches the nylon. Due to the nature of the configuration, the aluminium which is now overlapped with nylon, was not cut. This stops the plan to test the joint using the tensile machine. To proceed, cutting technique using water jet and laser were considered however both this method was not available in Perak at the time being. Due to the time constraint, it was decided that the tensile test would have to be abandoned.

5. CONCLUSION & RECOMMENDATION

From the tests, it can be said that with the 6 mm tool tip, the aluminum gain enough heat to melt but the nylon gain excessive heat which caused severe deformation and overflowing. With the 3mm tip and reduced rpm, the heat generated on the nylon sheet is relatively better but the aluminum does not receive enough heat. Therefore it can be concluded that the tip has to penetrate the second layer of the workpiece in order for it to gain enough heat to plasticize and attached. The configuration does not play a major role in this research because neither of the configuration impacted the result. However a butt joint configuration shows very bad result compared to the rest of the configuration. It can be said that the configuration resembling lap joint creates better result compares to butt joint. The research shows that within the limited scope of time and resources, the FSW cannot be proved as the novel method to join Aluminum and Nylon since no good joint were achieved.

The strength of the joint wasn't tested with the Tensile test due to the fact that no good joint were achieved. Other than that, there were no available method to cut the samples into desired shape for testing. There is also a problem of limited time and resources. The variables that is currently being tested is the joint configuration, tool rotation speed, feed rate, dwell time, and length of tool tip. The limited number of workpiece and the long time taken to create the different configuration would disturb the experiment since many of the variables was forced to be tested simultaneously. This would lead to an unaccurate analysis.

The variables and scope should be reduced so that the experiment could be done more orderly and accurate result could be achieved within the limited time frame. Other than that, either the water jet cutting machine or the laser welding machine should be installed to ensure that the workpiece can be cut without jeopadising its properties or putting too much force on the joint. More research should be done on the friction stir welding on metal and polymer with thick plate. Most of the literature listed used thinner plate between 2mm – 3mm. This explains why this research's result varies greatly with the literature listed.

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7. APPENDIX

Figure 7.1.CNC Lathe Bridgeport model Power Path-15

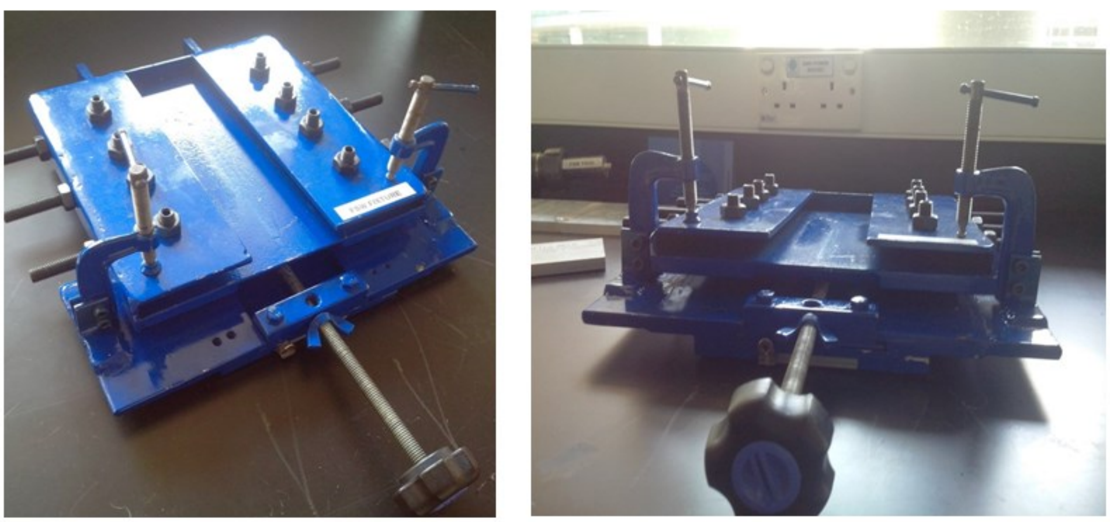

Figure 7.2. Fixture that will be used to support the plates during FSW process

Figure 7.3. CNC Milling Bridgeport model VMC 2216 to perform FSW

Figure 7.4. Horizontal Band Saw Machine

Figure 7.5. Conventional Lathe Machine

Figure 7.6CARBOLITE Heat Treatment Furnace for surface hardening of welding tools

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Zeugnis-Nr. / Certificate no. / No. de certificat: 174531

Bescheinigung über Werkstoffprüfung nach EN 10204
Certificate of material tests according to EN 10204
Certificat des essais des matériaux selon EN 10204
3.1.B

Die Lieferung entspricht den vereinbarten Lieferbedingungen.
The above mentioned material have been delivered in accordance with the terms of the order.
La livraison correspond aux conditions de livraison convenues.

BGH
EDELSTAHL FREITAL

BGH Edelstahl Freital GmbH, Postfach 10 15 66, D-01691 Freital

KIM ANN ENGINEERING PTE. LTD

3-C, JOO KOON CIRCLE
629035 SINGAPORE
Singapur

Kunden-Bestell-Nr. / Customer order no. / Cde. no. du client: P 4636/03-A OPO31139

BGH-Auftrags-Nr. / BGH works no. / BGH référence: 42817701/49476

Zeichen des Lieferwerkes / Trade mark / Signe du fournisseur

Stempel des Werkssachverständigen / Inspector's stamp / Poinçon de l'inspecteur

Erzeugnisform / Product	Stab, rund, geschält / Round bars,peeled
Werkstoff / Quality	1.2344 X 40 CrMoV 5 1
Anforderungen / Requirements	DIN 17350 10/80

Besichtigung und Maßnachprüfung / Inspection and dimensional control / Inspection et contrôle de dimension	Erschmelzung/Nachbehandlung / Meltingprocess/secondary refining / Mode d'élaboration/traitement ultérieur	Verwechslungsprüfung (spectroanalytisch) / Identification test (spectral-analysis) / examination d'identification(analyse spectrale)
ohne Beanstandung / without objection	E - LF/VD	ohne Beanstandung / without objection

Pos. / Item	Anzahl / Quantity	Abmessung / Dimension	Gewicht kg / Weight kg	Schmelz-Nr. / Heat-No.
1	79	25,00 RD	1498	16485

Schmelze / Heat %	C	Si	Mn	P	S	Cr	Mo	V
16485	0,380	1,04	0,34	0,020	0,003	5,05	1,26	0,921

Wärmebehandlungszustand / Condition of heat treat	weichgeglüht / soft annealed

Probe-Nr. / Test-No. / Soll/Req.	Lage	Temp. °C	Kerbschlagarbeit / Impact value	Probenform / Shape of test piece	Härte HB / Hardness
					<=235
439ID1					177

H13 TOOL STEEL MILL CERTIFICATE

KIM ANN INSPECTOR 8

Anlagen / Encl. / Annexe	Freital,den / Place and date / Lieu et date: 03.11.2003	Der Werkssachverständige / Works-Inspector / L'expert de l'usine: BERNDT

Appendix 1 - Tool steel properties

PE Polyethelyne

Technical Specifications
Polystone® G black/natural

Physical Properties	Units	Values
Density	g/cm^3	0.953
Mechanical Properties	**Units**	**Values**
Tensile strength	N/mm^2	22
Modulus of elasticity at tension	N/mm^2	800
Notched impact strength	-	12
Ball -thrust hardness 30 secs	N/mm^2	40
Shore hardness D Crystalline grain melting range	- °C	60 ~130
Thermal Properties	**Units**	**Values**
Thermal conductivity	W/M.K.	0.43
Coefficient of linear expansion between 20 ° C and 100 ° C	K^{-1}	2.10^{-4}
Vicat -VSP/A/50	°C	123
Softening point	°C	67
Fire behaviour	Class	HB
Insulation resistance	Ω/cm	$> 10^{16}$
Surface resistance	Ω	10^{15}
Electrical Properties	**Units**	**Values**
Dielectric strength	KV/mm	50
Track resistance	degree	KA 3 c
Electrical coefficient at $2 - 10^6$ Hz	-	2.5
Dielectric loss factor at 10^6 Hz	-	6.10^{-4}
Arc resistance	degree	L4

Appendix 2 - Nylon's properties

ALUMINIUM PLATE & SHEETS

GRADE: 1100, 5083 & 6061

<u>SPECIFIC CHARACTERISTICS & EXAMPLE OF APPLICATION</u>

a) Grade 1100

Relatively low strength but excellent in formability, weldability and corrosion resistance. For general vessels, architectural materials, electric appliances, various containers, printing boards and so on.

b) Grade 5083

An alloy having the highest strength among non-heat-treated alloys. Excellent in corrosion resistance and weldability. For materials for ships and vehicles, low temperature tanks, pressure vessels and so on.

c) Grade 6061 (T6)

Elements subject to high mechanical stress in structural engineering, ship-building, vehicle construction: appliances: electrical industry and for precisions parts; injection moulding and others.

<u>QUANLITY ASPECT</u>

i) Chemical Composition

Grade	Chemical Composition %										
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other		Al
									Each	Total	
1100	0.95 max		0.05-0.2	0.05 max	-	-	0.1 max	-	0.05 max	0.15 max	99.00 min
5083	0.4 max	0.4 max	0.1 max	0.4-1.0	4.0-4.9	0.05-0.25	0.25 max	0.15 max	0.05 max	0.15 max	Remainder
6061	0.40-0.8	0.7 max	0.15-0.4	0.15 max	0.8-1.2	0.04-0.35	0.25 max	0.15 max	0.05 max	0.15 max	Remainder

ii) Mechanical Properties

Grade	Temper Grade	Tensile Test				
		Thickness mm	Tensile Strength N/mm²	Proof Stree N/mm²	Elongation %	Hardness HB
1100	H14	0.2 or over, up to and incl. 0.3	120 min 145 max	-	1 min	
		over 0.3, up to and incl 0.5		-	2 min	
		over 0.5, up to and incl. 0.8		-	3 min	
		over 0.8, up to and incl 1.3		95 min	4 min	
		over 1.3, up to and incl 2.9		95 min	5 min	
		over 2.9, up toand incl 12		95 min	6 min	
5083	H321	4 or over, up to and incl. 13	305 min 385 max	215 min 295 max	12 min	85
		over 13, up to and incl. 40	305 min 385 max	215 min 295 max	11 min	
		over 40, up to and incl. 80	285 min 385 max	200 min 295 max	11 min	
6061	T6	0.4 or over, up to and incl. 0.5	295 min	-	8 min	95
		over 0.5, up to and incl. 6.5		245 min	10 min	

Table 7.1Appendix 3 - Aluminum properties