CERTIFICATION OF APPROVAL

Effects of Process Parameters on Strength of Swept Friction Stir Spot Welded Plate

by

Mohd Aiman bin Kamaru zaman

9237

A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

Approved by,

____

(Dr. Mokhtar Awang)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
July 2010

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.

MOHD AIMAN KAMARU ZAMAN

ACKNOWLEDGEMENT

Alhamdulillah thank to Allah, I manage to complete my final year project within the period given.

First of all, I would like to acknowledge and express my gratitude to my supervisor, Dr. Mokhtar bin Awang for his patience, support, advices, continuous guidance and supervision in helping me during this tough period to complete this project. Not to forget to my Final Year Project's examiners, Dr. Azmi bin Abdul Wahab and Dr. Saravanan Karuppanan for their advices throughout the year.

Lots of thanks also go to my beloved parents, Mr. Kamaru zaman bin Asli and Mrs. Robiah binti Embong and all family members for their supports in mental, physical and financial aids. Thank you for the time you all spent to share all my tears and laughter.

This project would not be complete without the help from the technician group block 21. Warmest thanks to the Mr. Shaiful Hisham bin Samsudin, Mr Hafiz bin Safian and Mr Jani bin Alang Ahmad for the kindness, support, and guidance to prepare the welding sample throughout this semester.

Last but not least, I would like to express special appreciation and gratitude to all the technicians from mechanical engineering department, seniors, friends and all who have involved in my final year project. Thank you very much for your understanding, support and cooperation and a great thankful from me.

ABSTRACT

Swept friction stir spot welding is one of the variations of friction stir spot welding (FSSW). This technique is a solid state joining process that uses a specially designed tool rotates at certain point creates a spot, lap-weld without bulk melting. It causes frictional heating that softens a column of material underneath the tool. The softened material flows around the tool through extensive plastic deformation and is consolidated behind the tool to form a solid-state joint. The main objective of this study is to establish the relevant knowledge on the strength of the swept friction stir spot welded aluminum plate by changing process parameters of the welding. The only difference between the swept FSSW and FSSW is the welded area which is the swept FSSW consumes larger welded area than FSSW. The welding tool will be design and fabricated using MAZAK 5- axis machine and the material used for the welding tool is tool steel H13. 1mm aluminum alloy is used as welding material and the Octaspot tool path with radius 10mm will be applied to the welding process. This study will be focused on two process parameters which are tool rotational speed and welding traverse speed. Several test will be conducted to the welded plated which are lap shear test and Optical Microscopy. The result shows that tool rotational speed and welding traverse speed both affect the strength of the welding joint and swept FSSW gives stronger joint compared to FSSW.

TABLE OF CONTENT

ACKNOWLEDGEMENT iii

ABSTRACT iv

CHAPTER 1: INTRODUCTION 1

1.1 Background of the study 1

1.2 Types of Friction Stir Welding 3

1.3 Properties of Tool Steel H13 10

1.4 Problem statement. 12

1.5 Objective of study. 12

1.6 Scope of study 12

CHAPTER 2: LITERATURE RIVIEW 13

CHAPTER3: METHODOLOGY 17

3.1 Process plan 17

3.2 Design and Fabrication of the Swept FSSW Tool . 18

3.3 Heat Treatment for the tool 19

3.4 Trial Run 19

3.5 Welding Process 20

3.6 Check the welded material using OM . . . 20

3.7 Testing 21

3.8 Key Milestone 22

3.9 Flow chart for the FYP 23

CHAPTER 4: RESULT AND DISCUSSION 24

4.1 Design of the tool and fabrication process . . 24

4.2 Heat Treatment 25

4.3 Writing G-Code for the tool path 27

4.4 First run on Bridgeport CNC milling machine . . 28

4.5 Sample preparation on Bridgeport CNC milling machine 29

4.6 Lap Shear testing using Universal Testing Machine . 31

4.7 Discussion. 36

4.8 Check the diffusion using Optical Microscopy . . 39

CHAPTER 5: CONCLUSION 41

CHAPTER 6: RECOMMENDATION 42

REFERENCES

APPENDIX

LIST OF FIGURES AND TABLES

LIST OF FIGURES PAGES

Figure 1.1: Generic FSW Tool 1
Figure 1.2: FSW Tool while in the Workpiece 2
Figure 1.3: Rotational Speed vs. Tensile Strength . . . 4
Figure 1.4: Feed Rate vs. Tensile Strength 5
Figure 1.5: Plunge (Poke) FSSW 5
Figure 1.6: Refill FSSW 7
Figure 1.7: Stitch (Left) and Swing (Right) FSSW 8
Figure 1.8: Squircle swept FSSW 9
Figure 1.9: Octaspot™ swept FSSW 10
Figure 3.1: Dimension for Welding Plate 18
Figure 3.2: the raw material for the tool: AISI H13 19
Figure 3.3: the drawing of the tool 19
Figure 3.4: Lap Shear Test 22
Figure 3.5: flow chart for FYP I project 24
Figure 4.1: the fabrication process of the welding tool . . . 25
Figure 4.2: Simplified Fe-C Phase Diagram (Steel Portion) . . . 26
Figure 4.3: furnace for the heat treatment 27
Figure 4.4: the tool after undergone the heat treatment . . . 27
Figure 4.5: Circle shape tool path 27
Figure 4.6: Preparation before run the trial 29
Figure 4.7: Formation of the welding (penetration 1.5mm) . . . 29
Figure 4.8: Formation of the welding (penetration 1.6mm) . . . 30
Figure 4.9: sample of the swept FSSW welded plate 30
Figure 4.10: Lap shear test using Universal Testing Machine . . 31
Figure 4.11: Picture of the sample failure after the test . . 33
Figure 4.12: Maximum Lap Shear Load vs. Tool Rotational Speed . . 33
Figure 4.13: Maximum Lap Shear Load vs Welding Traverse Speed . 34
Figure 4.14: Comparison Maximum Lap Shear Load between . 34
Swept FSSW and FSSW

LIST OF FIGURES AND TABLES

LIST OF FIGURES PAGES

Figure 4.17: Preparation of the sample for mounting process . . 39

Figure 4.18: The image of the sample under Optical Microscopy . . 39

Figure 4.20: 'ring' shape behind welding sample 40

Figure 4.19: The red arrow shows the tip of the welding tool path . . 40

LIST OF TABLE

Table 3.1: milestone for FYP I 22

Table 3.2: Milestone for FYP II 22

Table 4.1: Process parameter to determine the effect of Rotational speed 29

Table 4.2: Process parameter to determine the effect of welding Traverse speed 30

Table 4.3: Process parameter for FSSW data comparison . . . 30

Table 4.4: Effect of the tool rotational speed 31

Table 4.5: Effect of the welding traverse speed 32

Table 4.6: Comparison data with FSSW 32

CHAPTER 1

INTRODUCTION

1.1 The Basics of Friction Stir Welding

1.1.1 The Beginning

Friction Stir Welding (FSW) was invented by Wayne Thomas and his team at The Welding Institute, Ltd. (TWI) in the United Kingdom. This is a relatively new process which was patented in 1991. While FSW has been implemented in several industries, much is yet to be understood and discovered about FSW and its related processes.

1.1.2 Friction Stir Welding Tool

This process requires a FSW tool, as shown in Figure 1.1. This tool is often called a pin tool. The tool must be made of a material that is wear resistance and harder than the material to be welded. It has two primary parts that interact with the workpiece or workpieces to be welded. The first part is the actual probe which is also called the pin, and the second is the shoulder.

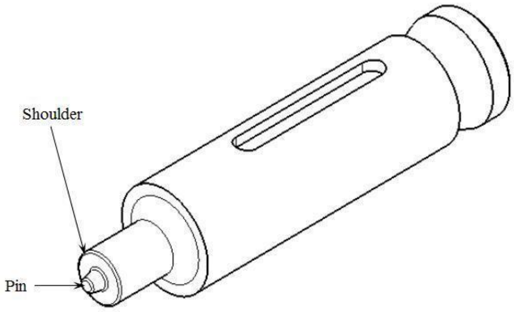


Figure 1.1 - Generic FSW Tool

In some applications, the FSW tool has a second shoulder. The second shoulder would be attached to the bottom end of the probe. The probe and this lower shoulder would move independently of the upper shoulder. This type of FSW tool is called a Bobbin tool or a Self-Reacting Tool.

1.1.3 The Fundamental Concept

The tool is rotated at a high speed and slowly plunged into the workpiece. Heat is created through friction and plastic deformation of the workpiece which softens the workpiece. The workpiece material can be mixed by the probe and shoulder once it has softened sufficiently. The shoulder keeps the plasticized material contained and creates the necessary forging pressure [2].

Advancing and retreating sides are created when the tool travels as illustrated in Figure 1.2. The side for which the edge of the tool is rotating in the same direction of travel of the tool is the advancing side. The retreating side is the opposite side. These differing motions create asymmetry in the weld.

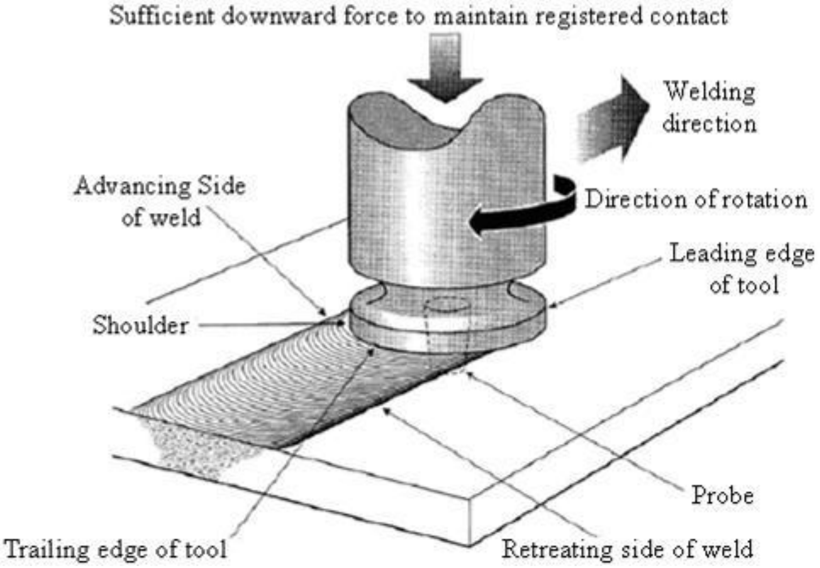


Figure 1.2 - FSW Tool while in the Workpiece [1]

1.2 Types of Friction Stir Welding

1.2.1 Friction Stir Processing

Friction stir welding is actually a subset of Friction Stir Processing (FSP). FSP is not a joining technology but rather uses techniques similar to those of FSW to control both grain size and grain distribution in the workpiece. FSP creates relatively uniform fine grains for material thicknesses that are greater than those that can be accommodated by conventional fine grain thermomechanical processes. [3]

1.2.2 Friction Stir Butt Welding

Butt welding is easily the most researched type of FSW. An issue that is common with butt welding is plate separation. The FSW tool will tend to push the sheets apart so rigid clamping is required. This configuration has an explicit joint line. This line must be followed closely or the joint will not form properly. Another potential problem when friction stir butt welding is lack of penetration. The FSW tool must be long enough to mix the workpiece throughout the thickness of the material, thus all the way to the backing plate. This typically requires the tool to be slightly shorter than the thickness of the workpiece. This difference is usually on the order of 0.005 to 0.015 inches depending on tool design and parent material thickness

1.2.3 Friction Stir Lap Welding

In contrast to butt welds, lap welds do not need a tool that nearly reaches the bottom of the bottom workpiece. It merely needs a tool that is long enough to reach the bottom workpiece and create a joint. One important aspect of lap welds is the faying surface. The faying surface is the occluded surface which is formed by the overlapping materials. The faying surface often will behave as a crack in lap welds. When the joint is under stress, the faying surface may grow through the joint until failure.

Vertical movement of material in lap welds is much more critical than in butt welds. As material moves up or down through the material thickness, it drags the faying surface interface with it, and this can create sheet thinning. The sheet thinning changes the Effective Sheet Thickness (EST). Cederqvist and Reynolds found that two critical factors influencing the strength of lap welds were the EST and the shape and sharpness of the sheet interface. A second pass of the FSW tool can help with these two issues. Regardless of the number of passes, the load path should be considered when designing for friction stir lap welding. The joint may have different load carrying capabilities depending on if the load path runs through the advancing side or retreating side. Thus, lap joints are often tested in both loading configurations.

1.2.4 Friction Stir Spot Welding

Friction Stir Spot Welding (FSSW) is a generic term. A single spot weld is one that creates a discrete, localized joint of limited size. Spot welds are typically intended to act in concert with other spot welds at the joints of a structure. T. Speller [30] has been conducted the study to maximize the joint strength of FSSW assembly by optimizing the control parameters in a statistically determined model. Below are the results of the study in term of RPM and feed rate.

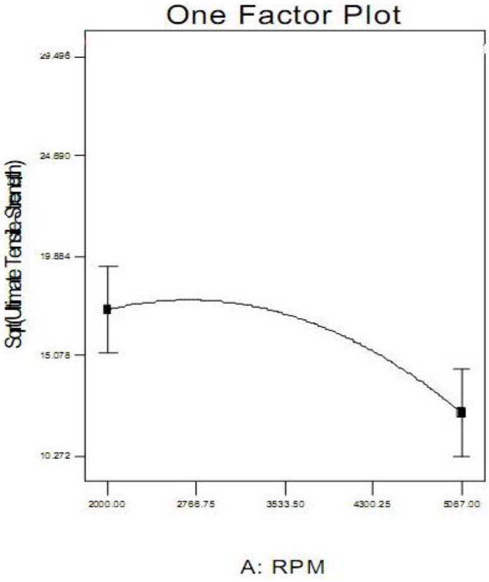


Figure 1.3: Rotational Speed vs. Tensile Strength

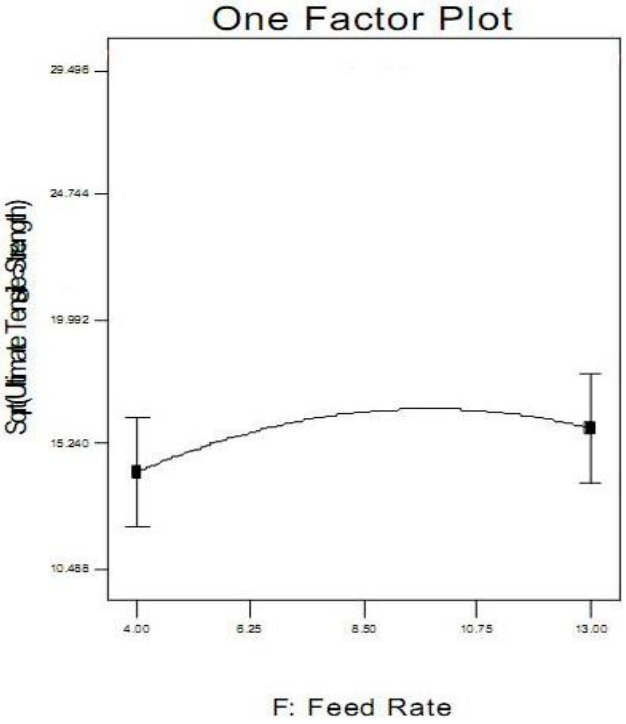


Figure 1.4: Feed Rate vs. Tensile Strength

1.2.4.1 Plunge Friction Stir Spot Welding

The plunge or poke spot weld is one that uses the conventional type of FSW tool. The tool is rotated and plunged into the material. It is held there for a short period of time then retracted, as ideally illustrated in Figure 1.5. [4, 5]

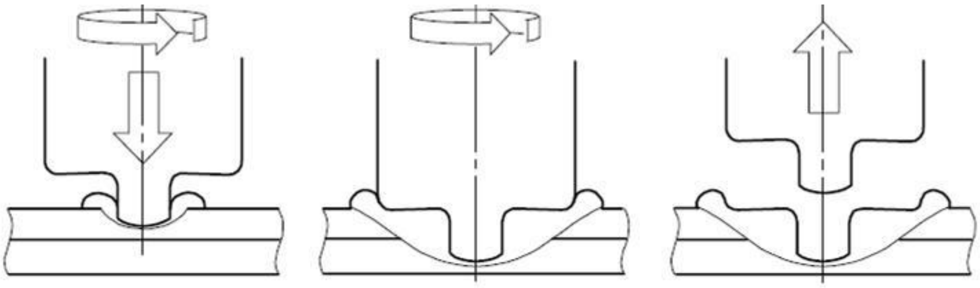

(a) Plunging (b) Bonding (c) Drawing out

Figure 1.5 – Schematic diagram of Plunge (Poke) FSSW [4]

Addison and Robelou [13] investigated which parameters were important in plunge FSSW through AA6061-T4 of 2 mm (0.080 inch) thickness. They found that the plunge rate had little effect on the strength of the weld joint while tool rotation speed was very important, with greater rotation speeds being better. Other factors, such as plunge depth, dwell time, and retraction rate, were evaluated and determined to be negligible.

Tweedy et [6]. al also investigated the significant parameters of FSSW. This work was done with AA2024-T3 and AA7075-T6 of 1 mm (0.040 inch) thickness. Similarly to the Addison and Robelou results, plunge rate had no significant effect on the strength of the joint, and the tool rotation speed was very significant. However, converse to Addison's and Robelou's findings, they found that the strength of the joint decreased when rotation speeds exceeded 1000 RPM. They postulated that this may be an effect of the FSW tool design. Other important factors were plunge depth and dwell time. Once the FSW tool plunges to a certain depth, the joint strength for deeper plunges does not change significantly. The tool does not create strong joints at depths less than this. The data shows that the tool must also dwell in the material long enough to sufficiently mix the material. After it has reached this point, more mixing will not increase the joint strength. In fact, dwelling longer may weaken the joint due to overheating.

1.2.4.2 Refill Friction Stir Spot Welding

The plunge type FSSW leaves an exit hole when retracted. The GKSS research center in Germany developed a technique to eliminate the exit hole. Their friction stir spot welding technique, called Refill FSSW, utilizes a probe that moves independently of the shoulder. Figure 1.6 illustrates the tool and procedure for Refill FSSW. A non-rotating clamping ring is lowered on to the material, securing it in place. Next, the rotating shoulder and probe touch the surface of the material. The probe is then plunged into the material as the shoulder is lifted from the surface.

The displaced material from the probe fills the void under the shoulder. The probe is then retracted as the shoulder move into flush contact with the surface. Next, the rotation ceases while the shoulder and probe maintain forging pressure. Finally, the clamping ring, shoulder, and probe are retracted from the surface. An alternate method begins with an initial plunge with the shoulder while retracting with probe. The shoulder would then retract while the probe plunges. This alternate method creates a larger nugget and is potentially stronger [8].

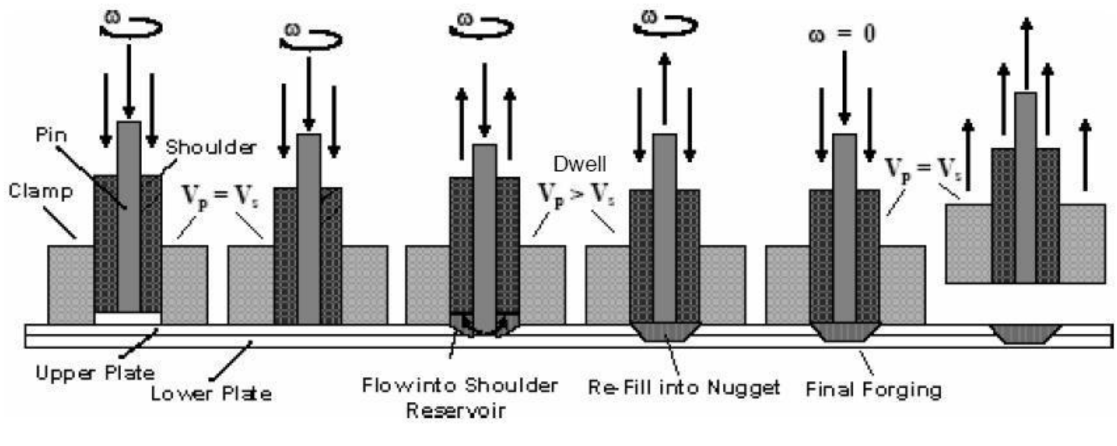


Figure 1.6 – Schematic diagram of Refill FSSW [7]

1.2.4.3 Stitch and Swing Friction Stir Spot Welding

Other types of FSSW include Stitch FSSW, developed by the GKSS research center, and Swing FSSW, developed by Hitachi. These processes involve the typical plunge with a standard FSW tool.

The tool is then translated or rotated in the material as illustrated in Figure 1.7. This creates an elongated spot with a corresponding increase in shear area. Typically, these two forms of FSSW result in increased spot weld strength.

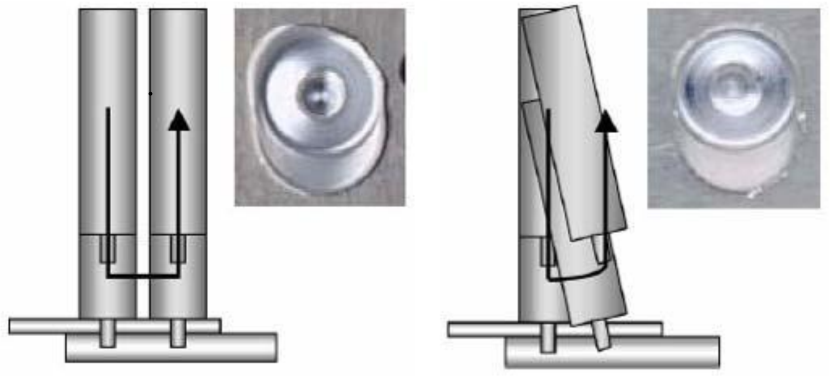


Figure 1.7 – Stitch (Left) and Swing (Right) FSSW [9]

1.2.4.4 Swept Friction Stir Spot Welding

This method was first attempted by TWI with their Squircle™ pattern, shown in Figure 1.8. Swept FSSW has since been attempted with success at Wichita State University (WSU). WSU's pattern is the Octaspot™. The research presented in this thesis utilized the Octaspot™ swept FSSW method. The advantage of the swept spot weld over the traditional plunge spot welds is the increased joint strength that results from increased shear area. [6]

Vertical translation of the joint interface usually occurs while forming the spot welds. This alters the surface between the top and bottom sheets creating an upturned or downturned interface. Consequently, this decreases the effective sheet thickness. Both of these results are detrimental in linear lap welds. This translation of the interface is typically consumed during a swept spot weld. The resulting interface will have little or no upturn or downturn [6].

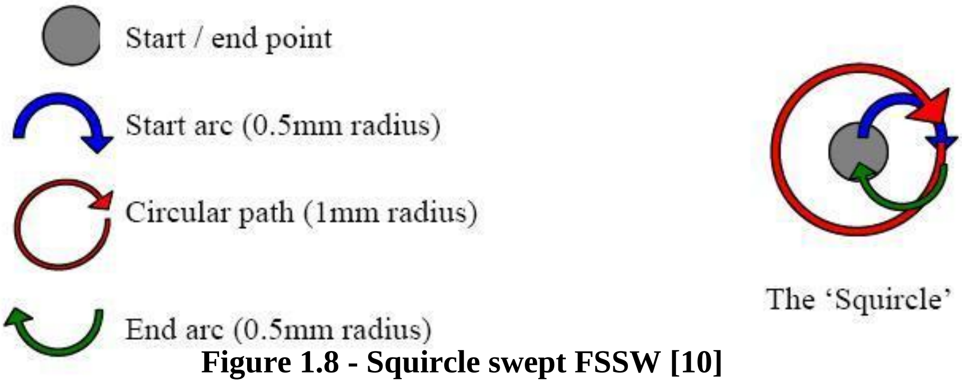


Figure 1.8 - Squircle swept FSSW [10]

The Octaspot™ Swept FSSW pattern, illustrated in Figure 1.9, involves several steps. The first step is a plunge into the material. The tool is moved to the periphery of the tool path in the next step. Then the tool is traversed around the periphery for at least 360 degrees, 450 degrees for this experiment. Once this orbit is completed, the tool is moved back to the center of the spot weld and retracts

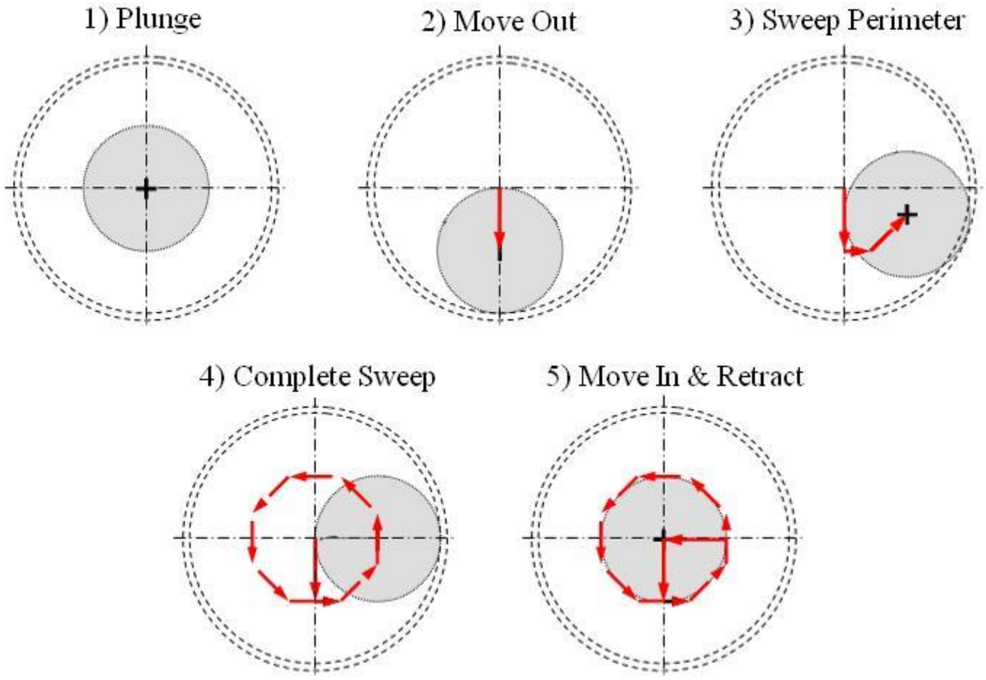


Figure 1.9 – Octaspot™ swept FSSW [10]

Tweedy et al investigated the critical parameters of swept FSSW. They found, in their work with 2024-T3 to 2024-T3 aluminum sheets, that placing the advancing side of the FSW tool, as opposed to the retreating side, on the outside of the tool path improved the strength of the lap joint. Also, they found less variability of joint strength when using load control rather than position control during the spot weld process. They reported that plunging on the periphery of the spot weld tool path rather than the center increased the spot weld strength. However, they were unable to statistically determine the individual importance of tool rotation speed, welding speed, tilt angle, or plunge depth/forge load due to a large degree of coupling of these parameters in their results.

1.3 The material for the welding tool

The material for the welding tool has been choose base on the previous literature review and other experiment that has been conducted. From the literature review, the common material for the welding tool is tool steel H13 or AISI H13. It has the criteria of high thermal shock resistance and has higher toughness.

1.3.1 Properties of Tool Steel H13 (AISI H13)

Steel is the common name for a large family of iron alloys. Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes. Tool steels typically have excess carbides (carbon alloys) which make them hard and wear-resistant. Most tool steels are used in a heat-treated state, generally hardened and tempered. [16]

Tool steel also refers to a variety of carbon and alloy steels that are particularly well suited to b made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperature (red hardness) [17]. With carbon content between 0.7% and 1.4%, tool steel is manufactured under carefully controlled conditions to produce the required quality [18].

The typical elastic modulus of tool steels at room temperature (25°C) ranges from 190 to 210 GPa. The typical density of tool steels ranges from 7.72 to 8.0 g/cm3. The typical tensile strength varies between 640 and 2000 MPa. The wide range of ultimate tensile strength is largely due to different heat treatment conditions.

AISI H13 is a Chromium Hot Work Steel grade Tool Steel. It is composed of (in weight percentage) 0.32-0.45% Carbon (C), 0.20-0.50% Manganese (Mn), 0.80-1.20% Silicon (Si), 4.75-5.50% Chromium (Cr), 0.3% Nickel (Ni), 1.10-1.75% Molybdenum (Mo), 0.80-1.20% Vanadium (V), 0.25% Copper (Cu), 0.03% Phosphorus (P), 0.03% Sulfur (S), and the base metal Iron (Fe). Other designations of AISI H13 tool steel include UNS T20813 and AISI H13. [16]

The characteristic of the material is: [16]

- A high level of resistance to thermal shock and thermal fatigue
- Good high-temperature strength
- Excellent toughness and ductility in all directions
- Good machinability and polishability
- Excellent through-hardening properties
- Good dimensional stability during hardening

1.4 Problem statement

The current FSSW technique is still not strong enough to join the plate because the contact surface area is smaller. While Swept FSSW will give larger contact surface area of the welded plate thus, will give more strength compared with FSSW. The knowledge of the swept FSSW technique also is still minor in the local industry and the student. This study will lead to enhance the understanding about the welding technique and the effect of it to the welded material.

1.5 Objective of the study

The objective of this study is to investigate the effect of the process parameter on the strength of the swept friction stir spot welded plate which is aluminum alloy.

1.6 Scope of the study

The study will be focuses on the aluminum plate because so far, the majority of the research and development efforts on FSSW have been on aluminum alloys. Because Al alloys are easy to deform at relatively low temperatures (below about 550°C) they are relatively easy to friction stir welding. Indeed, the development of FSSW for Al alloys has been quite successful.

Octaspot tool path also will be applied to this welding process with radius 10mm. the depth of penetration is set to 1.6mm and dwell time for the tool is 2 seconds.

There a few types of welding tool that can be use to perform swept FSSW, which are Psi tool, counterflow tool with thread, counterflow with tapered flats. For this study, the author will choose almost alike Psi tool but without three flat and two vertical flutes on the pin. The process parameter that will be evaluated in this study is tool rotational speed and welding traverse speed.

CHAPTER 2

LITERATURE REVIEW

Swept friction stir spot welding is a new technique that has been introduced to the manufacturing industry. There are a few researches that have been done regarding the technique especially to investigate the effect of the swept FSSW to the mechanical properties of the welded plate. This process begins with simple plunge. The tool is then translated or rotated in the material. These create a larger weld zone than a simple plunge and retract the spot. The increase in shear area typically results in an increase in spot strength.

Swept FSSW has been under significant development at Wichita State University (WSU) since 2005. WSU's pattern was dubbed the Octaspot as shown in the figure 1.7, and the based closely on TWI's pattern [13]. An advantage of swept spot over the plunge spot is the increase strength primarily due to the resulting increased shear area. The flow of material during the plunge and dwell of typical spot can create an upturn of the sheet interface. The thinning of the effective sheet thickness typically correlated with decrease in strength or at least a loss of peel strength, the sweeping pattern of Swept FSSW may consume this interface upturn leaving a nearly straight joint [15].

At WSU, an experiment has been conducted to study the corrosion and fatigue evaluation of swept FSSW through sealant and surface treatment. This is conducted through 1mm thick aluminum alloy 2024-T3 sheets. The weld is made using a fixed pin tool called a Psi tool. The Psi tool has a concave shoulder, and the pin has three flat and two vertical flutes. The rotational speed is fixed at 1500rpm and the octaspot travel diameter was 4.06mm. Pr-1432 GP sealant was applied and the welding took place after applying the sealant. The sealant was allowed to partially cure for4 24 hour prior to welding. The result show the sealant were effective to prevent crevice corrosion in this experiment also, the result indicate that the sealant and surface treatment have little influence on the fatigue characteristic of FSSW [15].

WSU has done extensive development of the swept FSSW. The first swept FSSW was first demonstrated successfully with thin gauge 1 mm aluminum 2024-T3 sheet [12]. The pattern has also been used to weld through surface treatment as well as a couple of industrial faying surface sealant.

They also have conducted the evaluation of Swept FSSW in aluminum 2219-T6. The purpose of the investigation to evaluate the effects of swept FSSW on tensile strength and fatigue life in 2219-T6 material with a faying surface gasket compound. The aluminum sheets were 2.5 mm thick and the top of sheet was chromic acid anodized while the bottom sheet was sulfuric acid anodized. There are three types of the welding tool is being used which are psi tool, counterflow tool with thread and counterflow with tapered flats. The three tools have the common pin and shoulder geometries. The result of the welding has been compared with the 4 spot riveted coupons carried an average load of 16.5 kN. This strength is much less than the FSSW are capable. The result shows swept FSSW is capable of producing sound joints through 0.1 inch 2219-T6 with a faying surface gasket compound and surface treatment. It was also shown that the strength alone is not reliable predictor of fatigue performance. When compared to riveting, swept FSSW has potential to be much stronger while maintaining comparable fatigue properties. [14]

Jeremy Micah Brown from the Wichita University, 2009 [10] also has conducted the experiment on investigating the effect of the sealant and surface treatment on the faying surface of Swept Friction Stir Spot Welding. The effects that Jeremy evaluate is ultimate strength, fatigue life and corrosion resistance of the joints. He also used three types of the welding tool geometry which are psi, threaded counterflow and modified trivex. The results shows that Psi geometry tool gives the most significant result in produce highest strength specimen compare to other tool geometry while the threaded counterflow produce the second highest and modified trivex is the lowest.

Result shows that the sealant may help increasing the strength of the coupons. However, the sealant also tended to increase the standard deviations of the coupons. Generally, the surface treatments decreased the static joints strength of the specimens. The sealant and surface treatment had little effect on fatigue life except for having slightly shorter life at the high loads. These experiment shows that swept friction stir spot welding can be performed successfully with material related with treated surfaces and sealant at the faying surface. There was only a small drop in strength and minimal impact on the fatigue life from the sealant and surface treatment and both of them maintained most their corrosion resistance towards the corrosion.

CHAPTER 3

METHODOLOGY

3.1 Process Plan

During this project, there will be a few laboratory works are needed. The tool for swept FSSW is not available in the UTP's lab thus, the tool need to be design and fabricated by the author. The material that will be used for the welding tool is tool steel H13 which is also not available in the UTP. The author needs to purchase it from the outside. The material will be fabricated into the tool shape using the MAZAK CNC Lathe machine with the help from the technician from the lab. The tool then will be heated inside the heating chamber for annealing process to strengthen and increase its life.

The welding plate, aluminum alloy also need to be purchased from the outside source and the suggested dimension for the plate 120mm x 30mm and the thickness is 1mm. the tool will be clamped inside the Bridgeport CNC Milling machine to performed the welding operation to the plate. The rotational speed and traverse speed of the tool will be change for every welding spot to see the effect of the rotational speed to the strength of the welded plate.

The inspection of the welded plate will be done in the material lab to test the strength, and other mechanical properties of the welded plate.

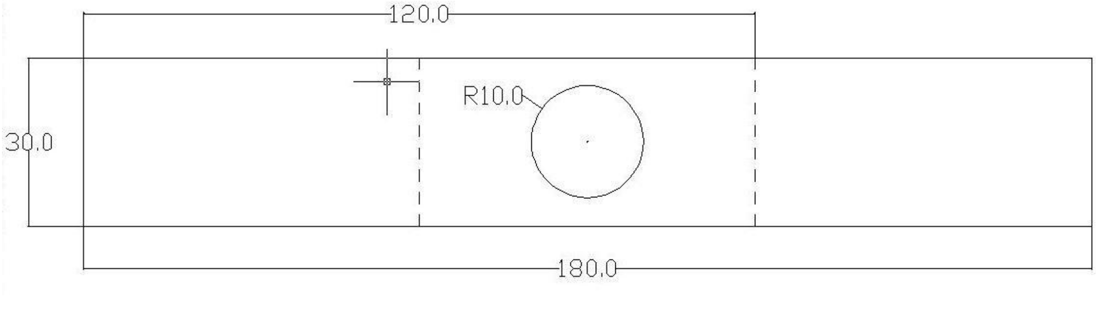


Figure 3.1: Dimension for Welding Plate

3.2 Design and Fabrication of the Swept Friction Stir Spot Welding Tool

The design of the tool is one of the critical factors that can affect the welding quality and the result. It is desirable that the tool can sustained the heat from the friction, strong, hard wearing and low thermal conductivity in order to minimize the heat loss and thermal fatigue. For that, AISI H13 has been choose as the raw material for the welding tool and from the literature review, many FSSW welding tools is made from AISI H13.

Figure 3.2: the raw material for the tool: AISI H13

After the material is available, the design is made using AutoCAD. The swept FSSW tool needs a special design in order to run onto the work piece. For this project, it is decided that the design of the tool is a basic design that is used before for conducting the FSSW technique. The shoulder diameter for the tool is 10mm, the pin diameter is 1.5mm and the pin thickness is 1.5mm. The length of the tool is around 70mm. after the design is completed, the raw material is sent to the Laboratory in building 16 for the fabrication process using MAZAK CNC Lathe Machine.

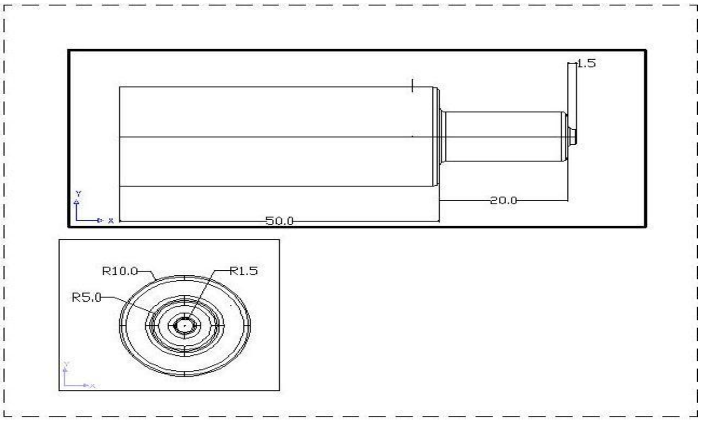


Figure 3.3: the drawing of the tool

3.3 Heat Treatment for the tool

After the tool is completely fabricated using the CNC machine, it needs to undergo the heat treatment process in the heating furnace at the Laboratory in building 17. This method is needed to alter the physical and chemical properties of the material to make the tool stronger. For this project, the procedures of the heat treatment as follow: [22]

1. Swept FSSW tool was inserted in the tube furnace and preheated initially for 2 hours to raise the temperature from 75ºF (room temperature, 25ºC) to 1350ºF (732ºC).

2. Next, the tool was continued preheated slowly from 1350ºF to 1400ºF (723ºC - 760ºC) for another 2 hours.

3. Then the temperature is rise to 1800ºF (1000ºC) for 1 hour.

4. Finally it was cooled down to room temperature 75ºF for 2 hours.

3.4 Trial Run

After the tool is gone through the heat treatment, a few trial runs will conducted to test the either swept friction stir spot welding can be performed here in UTP. The first trial will be conducted using the conventional milling machine in the laboratory building 21 due to the problems occur in MAZAK multiaxis machine. The objective of this trial is to test either this conventional machine can performed swept process during the welding is conducted on the aluminum plate.

The aluminum plate also will be clamped using special fixture to prevent it from moving during welding process. The suggested rotational speed of the spindle is 2500rpm and during the process, the value of rotational speed will be adjusted if the suggested value cannot be applied to the aluminum plate.

3.5 Welding Process

After the trial run using conventional milling machine, it is found out that there are two problems occur using that machine. The first is the tool movement cannot be done in circle because of limitation for the spindle to move in circle and even the rectangular shape tool path is not perfect. Then the welding formation is not perfect. We can see the welding joint is not perfectly formed on the surface of the plate. Still, both of the plate is joining together. At this point, it shows that swept FSSW still can be performed, but need a more advance machine than conventional milling.

After a few discussions with the technician, they suggest that Bridgeport CNC machine maybe can do the job better than conventional machine before. The welding process will be done using that CNC machine at block N.

During the run, a few parameter will be vary to archive the objective of the study which is the rotational speed, traverse speed for z-axis and traverse speed for x and y-axis.

3.6 Check the welded material bonding using Optical Microscopy (OM)

Use Optical Microscopy to check the material bonding in the welded area. The sample will be cut into half at the welding area and will put under OM to check the material bonding. There will be mounting process on the sample, polishing and grinding and metal etching to get the clear view of microstructure around the welding area. The objective of this activity is to identify the diffusion area of the welded aluminum plate.

3.7 Testing

A test will be conducted to measure the strength of the welded aluminum plate using swept friction stir spot welding technique. The test will be conducted is Lap Shear test:

3.7.1 Lap Shear test

Lap shear test is to determine the maximum lap shear load that the welding sample can endure before it breaks or fail. It is one of the indicators to determine the strength of the welding joint especially for lap welding sample. For this experiment, Universal Testing Machine will be used to conduct lap shear test. Before start the test, the sample will be put at the middle between the clamping arms. Sand paper is used to wrap the clamping area for both sides (upper and lower) to prevent the sample slip during the test. Clamping area is mark for each samples to make sure the load is exerted equally for both side and to prevent the dissimilarities that can affect the result for each test. After sample is ready, the test will be run and graph of the load and sample elongation will be monitor to see when the sample starts to break. After the exerted load turn to zero, the test will be stop and take out the sample from the clamping arms to check the failure point of the sample. The maximum lap shear load will be recorded.

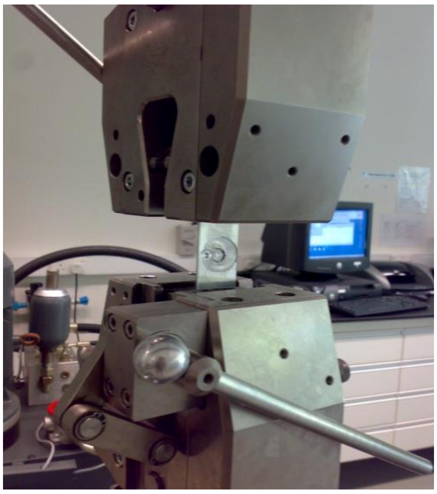


Figure 3.4: Lap Shear test

3.8 Key Milestone

The milestone for this FYP I is listed in the Table 3.1 below:

Table 3.1: Milestone for FYP I

No	Detail/week	5	6	7	8	9	10	11	12	13
1.	Literature Review	1/3								
2.	Finding raw material	5/3								
3.	Designing the tool		11/3							
4.	Fabricate the tool			18/3						
5.	Heat treatment for the tool					30/3				
6.	Prelim trial on Conventional CNC							13/4		

The milestone for the FYP II project is listed as in the Table 3.2 below:

Table 3.2: Milestone for FYP II

No	Detail/week	4	5	6	7	8	9	10	11	12	13
1.	Prepare fixture or jig	1/8									
2.	Design tool path and write G-code	5/8									
3.	Setup the Bridgeport CNC machine			19/8							
4.	Run the welding			22/8							
5.	Lap Shear test						13/9				
6.	Optical Microscopy								25/9		
7.	Report writing										10/10

3.9 Flow chart for the FYP project

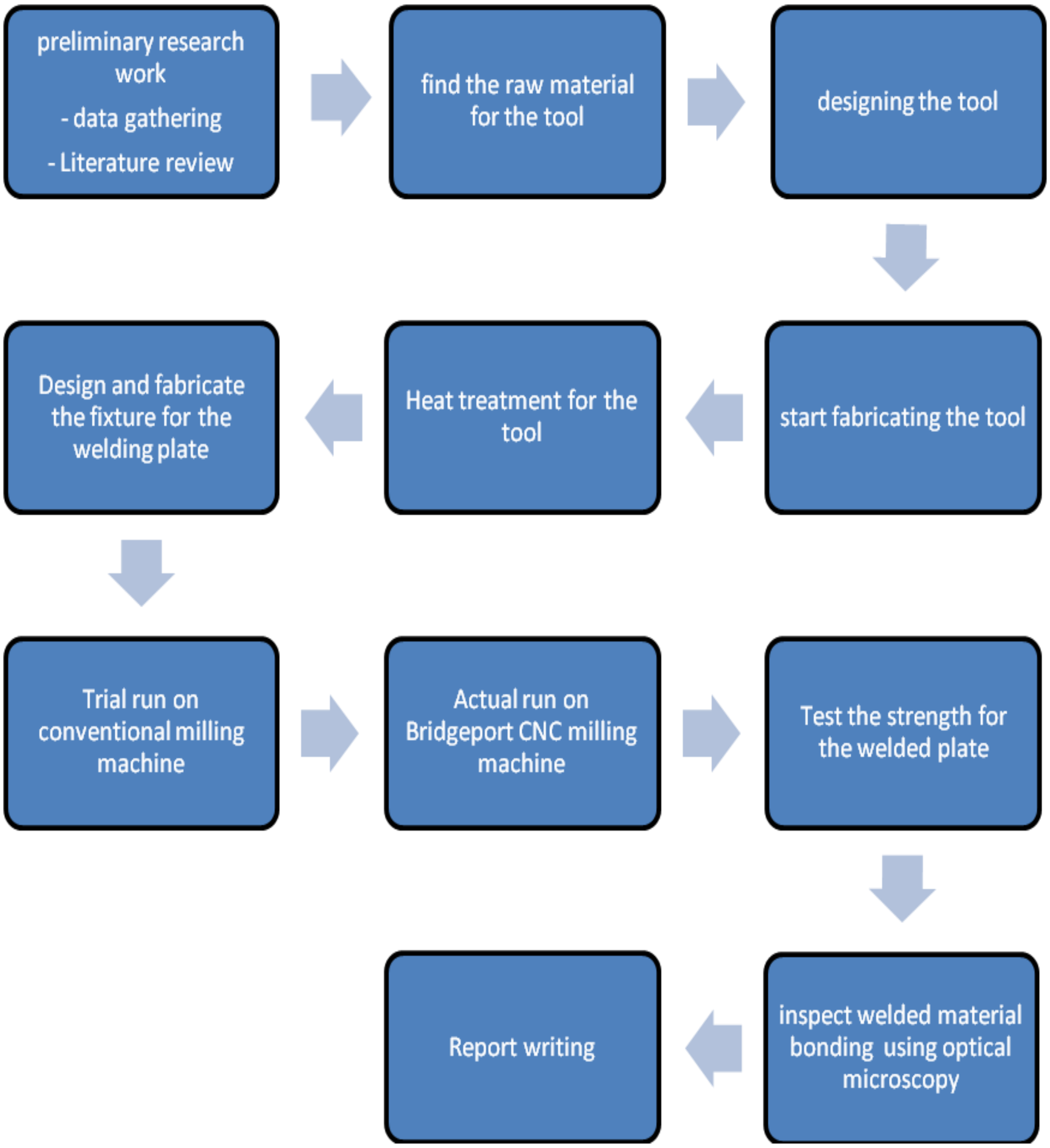


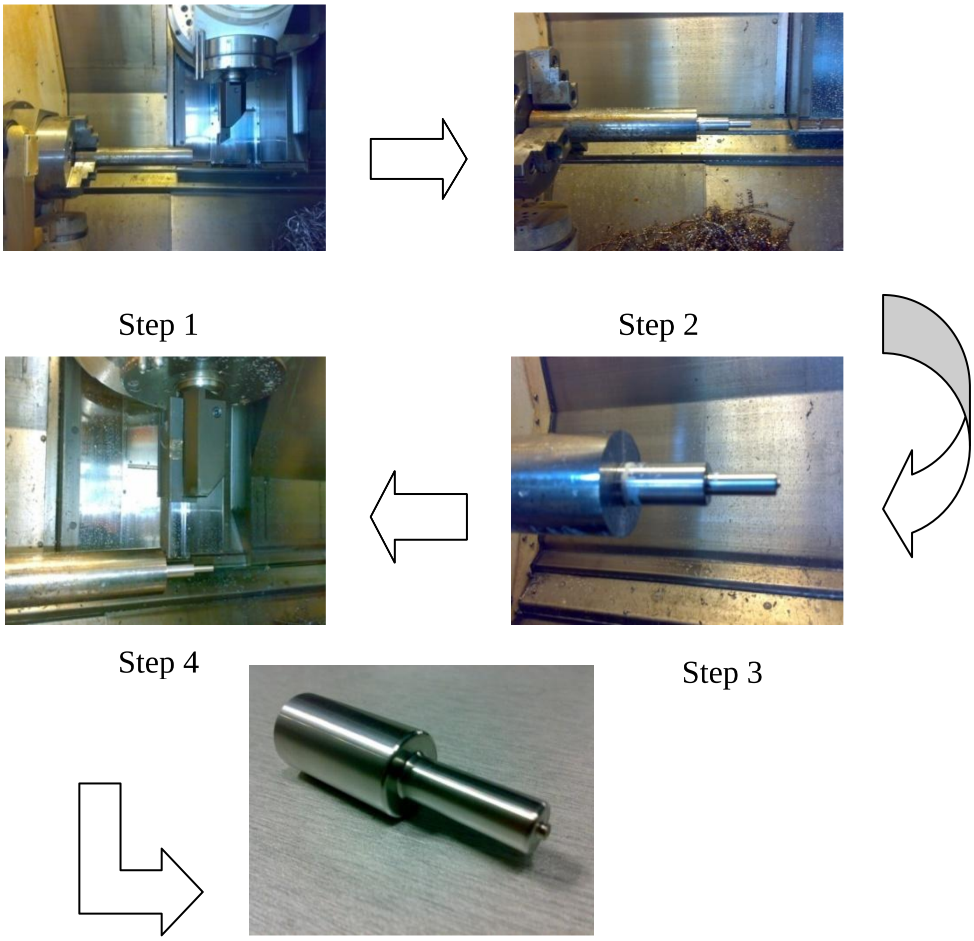
Figure 3.5: flow chart for FYP I project

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Design of the tool and fabrication process.

The tool design has been made using the AutoCAD software according the dimension discussed in the methodology section before. The general assembly drawing of the tool can be refer to appendices. The design is taken to the laboratory for fabrication process using the CNC MAZAK Lathe Machine as shown in the figure below.



Step 1

Step 2

Step 4

Step 3

Final Product

Figure 4.1: the fabrication process of the welding tool

4.2 Heat treatment

When the fabrication is completed, the tool is ready to undergo the heat treatment to strengthen the tool itself. Why we need the heat treatment because Tool steel is normally delivered in the soft annealed condition. This is to make the material easy to machine with cutting tools and to give it a microstructure suitable for hardening. The microstructure consists of a soft matrix in which carbides are embedded. Carbides are compounds of carbon and these alloying elements and are characterized by very high hardness. Higher carbide content means higher resistance to wear. [24]

In soft annealed tool steel, most of the alloying elements are bound up with carbon in carbides. In addition to these there are the alloying elements cobalt and nickel, which do not form carbides but are instead dissolved in the matrix. When the steel is heated for hardening, the basic idea is to dissolve the carbides to such a degree that the matrix acquires an alloying content that gives the hardening effect without becoming coarse grained and brittle. [23]

The heat treatment of the tool is carried out in the furnace and there are some changes to the color of the tool due to the oxidation process during heat treatment.

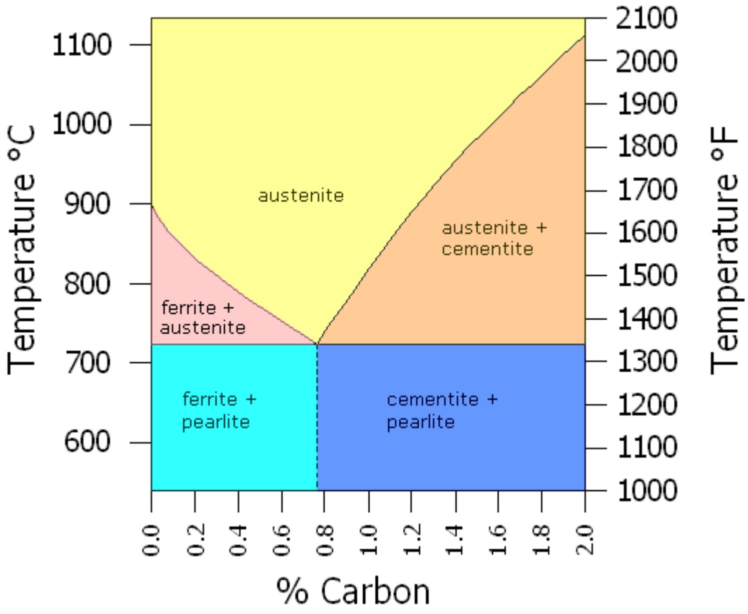


Figure 4.2: Simplified Fe-C Phase Diagram (Steel Portion) [25]

As the tool is heated above the critical temperature, about 1350°F (724°C), it undergoes a phase change, recrystallizing as austenite. Continued heating to the hardening temperature, 1350-1400°F (724-760°C). Then the temperature is rose to 1800°F (1000°C) to ensure complete conversion to austenite. At this point the steel is no longer magnetic, and its color is cherry-red.

Then the austenitic steel is cooled (quenched), a new crystal structure, martensite, is formed. Martensite is characterized by an angular needle-like structure and very high hardness.

While martensitic steel is extremely hard, it is also extremely brittle and will break, chip, and crumble with the slightest shock. Furthermore, internal stresses remain in the tool from the sudden quenching; these will also facilitate breakage of the tool. Tempering relieves these stresses and causes partial decomposition of the martensite into ferrite and cementite. The amount of this partial phase change is controlled by the tempering temperature. The tempered steel is not as hard as pure martensite, but is much tougher. [25]

Figure 4.3: Furnace for the heat treatment

Figure 4.4: The tool after undergone the heat treatment

4.3 Write the G-code to program the tool path on plate (BODY ONLY)

Before start the welding process using the CNC machine, tool path must be design to get the desired pattern of welding. For this sample, circle shape or octaspot like design will be applied. There are 5 major contact point must be put together to form the tool path. At first, the tool will be plunge into plate in z-axis 1.5mm depth at traverse speed of 50mm/min. Then the tool will travel from the point 1 to point 2 in x-axis about 10mm. then it will travel to point 3, 4, 5 and back to point 2 to complete the 20mm diameter circle shape. The tool will travel along the point at constant traverse speed of 50mm/min (in x and y-axis).

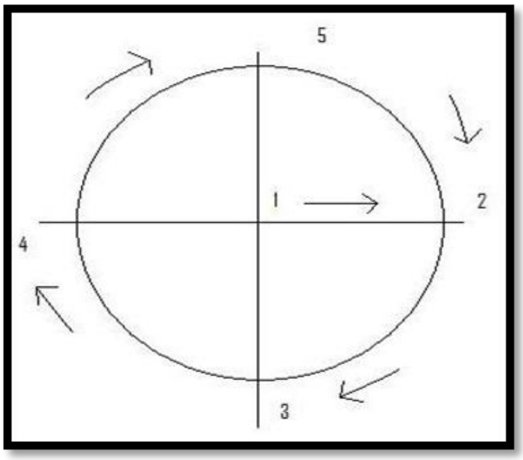


Figure 4.5: Circle shape tool path

Table 4.1: Tool Path Description

No.	G-code	Description
0	G1 X0 Y0 Z100	Ready position
1	G1 X0 Y0 Z-1.5	Tool plunge at depth 1.5mm
2	G1 X10 Y0	Tool moves 10mm to the right linearly
3	G2 X0 Y-10 R10	Tool make a circular movement to point 3
4	G2 X-10 Y0 R10	Tool make a circular movement to point 4
5	G2 X0 Y10 R10	Tool make a circular movement to point 5
2	G2 X10 Y0	Tool make a circular movement to point 2

G1 for Linear movement

G2 for circular movement

4.4 Running the 1st trial on Bridgeport CNC machine

After the code has been inserted in the Bridgeport CNC milling machine, it is ready to run the trial on aluminum plate. The plate is clamped tightly on the special custom jig using screw and nut as in the picture below. Then the welding process takes the place.

Jig is clamping the sample

Clamp the jig inside the machine

Move the tool to the right position

Mark the center of the sample

Figure 4.6: Preparation before run the trial

4.4.1 Result of the trial

The first trial using CNC machine is quite successful. Both of the plate perfectly welded, tool is moved smoothly and there are no problems occur during the welding process. But the surface of the welded spot is quite rough and we can see the new welding formation is not perfectly formed.

Figure 4.7: Formation of the welding (penetration 1.5mm)

4.5 Sample preparation on Bridgeport CNC Milling machine

From the earlier trial, it is found that welding formation is not goes smoothly. We suspected that maybe tool shoulder is not penetrating deep enough on plate surface. For this trial, the tool will plunge in 1.6mm depth. The result shows better welding formation and smoother surface of the welded spot.

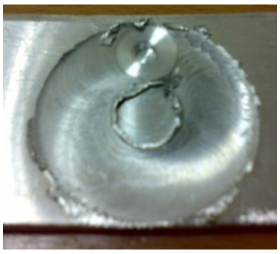


Figure 4.8: Formation of the welding (penetration 1.6mm)

4.5.1 Effect of Rotational Speed

Then it is decided to plunge the tool at 1.6mm depth which gives better welding formation because the shoulder is perfectly touching the surface at that depth. The process will goes on but we vary the rotational speed of spindle from 2000 rpm up to 3500 rpm as shown in Table 4.2.

Table 4.2: Process parameter to determine the effect of rotational speed

No.	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Traverse speed (y and x-axis) (mm/min)	condition
1	2000	50	50	good
2	2500	50	50	good
3	3000	50	50	good
4	3500	50	50	good

Figure 4.9: sample of the swept FSSW welded plate

4.5.2 Effect of welding traverse speed

After finish preparing all the welding samples for different rotational speed, we proceed to next step which is vary the feed rate of the tool in x and y-axis as shown in Table 4.3. The purpose of this is to investigate the effect of the traverse speed to the strength of the welding plate and the smoothness of welding formation. 4 welding sample will be produce from this process at constant spindle speed which is 3000 rpm.

Table 4.3: Process parameter to determine the effect of welding traverse speed

No	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Traverse speed (x and y-axis) (mm/min)	Condition
1	3000	50	40	Good
2	3000	50	50	Good
3	3000	50	60	Good
4	3000	50	70	Good

4.5.3 Comparing with FSSW data

One of the objectives of this study is to compare the strength of the joint between swept FSSW and FSSW. The strength data for FSSW is already prepared by Syazwan [29] and all I have to do is preparing the sample with the same parameter (Table 4.4) as what have he done before and compare the results. The parameter that has been applied on FSSW is the previous student varies the rotational speed and use constant traverse speed (z-axis). So, we run the welding process with the same parameter and will compare the results after the lap shear test.

Table 4.4: Process parameter for FSSW data comparison

No	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Traverse speed (x and y-axis) (mm/min)	Condition
1	4000	55	50	Good
2	5000	55	50	Good
3	6000	55	50	Good

4.6 Lap Shear testing using Universal Testing Machine.

After all the samples with different process parameter are ready, all of them will undergo the lap shear testing using Universal Testing Machine (UTM) in the lab. The sample will be clamp by the machine and the machine will pull the sample until the sample is break or fail. Before start the test, all the parameters (load, extension and stroke) will be check at zero value to avoid the any error that can affect the result. All of the sample also will be clamped at the same length and sand paper is used to prevent the sample is slip during the test.

Figure 4.10: Lap shear test using Universal Testing Machine

Result of the test

4.6.1 Effect of the tool rotational speed

Table 4.5: Result for maximum lap shear test - Effect of the tool rotational speed

No.	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Welding traverse speed (y and x-axis) (mm/min)	Maximum lap shear load, kN
1	2000	50	50	4.164
2	2500	50	50	3.767
3	3000	50	50	3.640
4	3500	50	50	3.672

4.6.2 Effect of the welding traverse speed

Table 4.6: Result for maximum lap shear test - Effect of the welding traverse speed

No	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Welding traverse speed (x and y-axis) (mm/min)	Maximum lap shear load, kN
1	3000	50	40	3.598
2	3000	50	50	3.640
3	3000	50	60	3.886
4	3000	50	70	4.481

4.6.3 Comparison data with FSSW

Table 4.7: Result for maximum lap shear test - Comparison swept FSSW with FSSW data

No	Rotational speed (rpm)	Traverse speed (z-axis) (mm/min)	Traverse speed (x and y-axis) (mm/min)	Maximum lap shear load for swept FSSW, kN	Maximum lap shear load, for FSSW, kN
1	4000	55	50	3.482	1.846
2	5000	55	50	3.390	1.850
3	6000	55	50	3.353	1.754

From the figure below, we can see that the failure point of the sample is around the welding area either front or back of the sample. From that, we can conclude that the most weaken area of the welding is at the edge of the circle where most of the sample fail at that point.

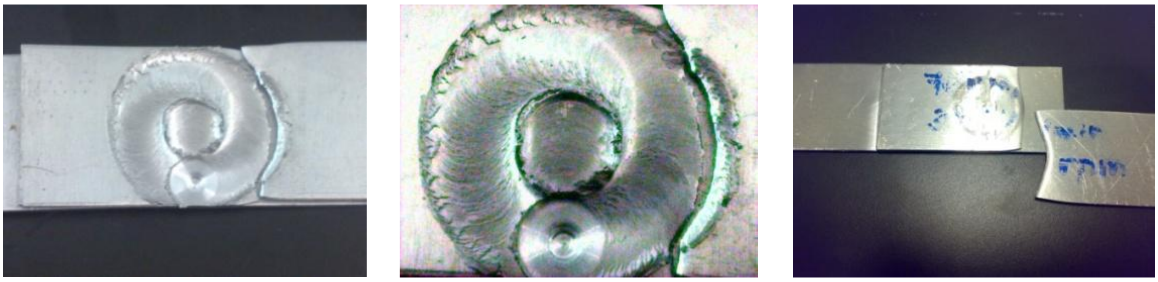


Figure 4.11: Picture of the sample failure after the test

The data for the results of the sample for each criterion is shown in the graphs above:

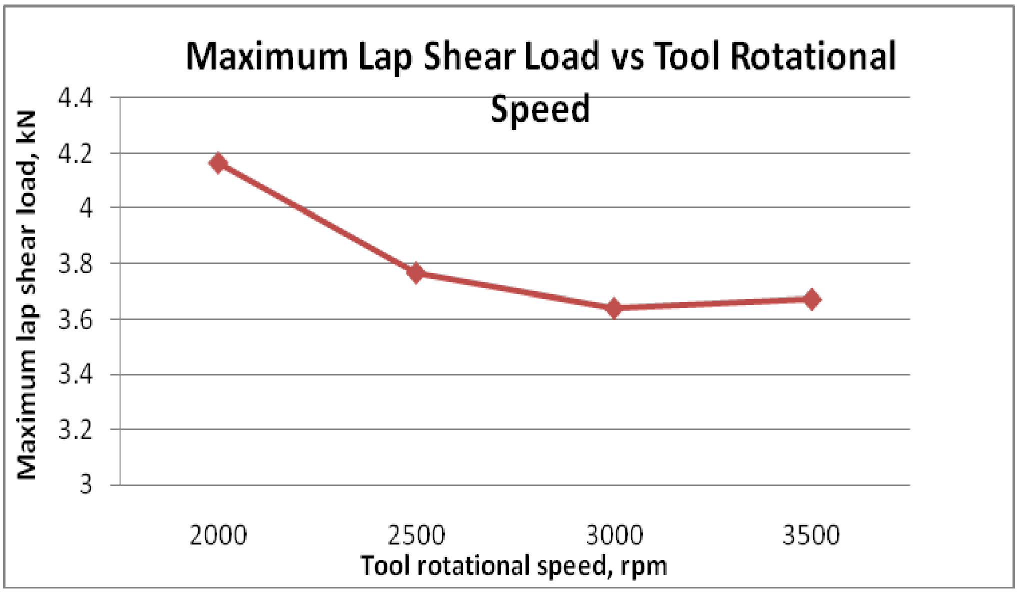


Figure 4.12: Maximum Lap Shear Load vs Tool Rotational Speed

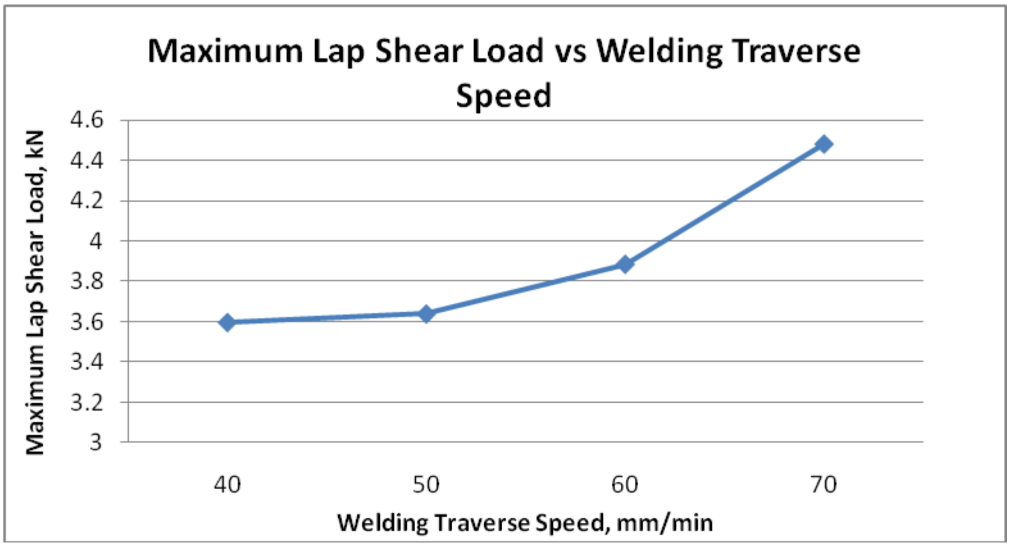


Figure 4.13: Maximum Lap Shear Load vs Welding Traverse Speed

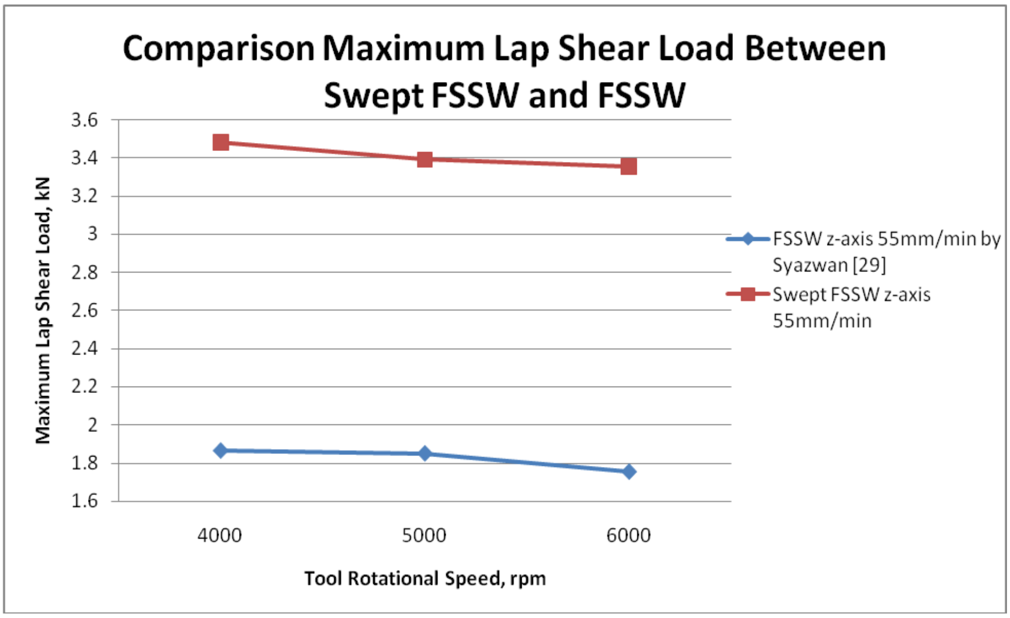


Figure 4.14: Comparison Maximum Lap Shear Load between Swept FSSW and FSSW

4.7 Discussion

4.7.1 Effect of the rotational speed

As we can see from the graph above, tool rotational speed and welding traverse speed are both affect the strength of the welding joint. Increasing in rotational speed will decreasing the value of maximum lap shear load from 2000 rpm to 3000 rpm. Then a little bit increase when the speed is set to 3500 rpm. In FSSW, tool rotation speed results in stirring and mixing of material around the rotating pin which in turn increase the temperature of the metal. It appears to be the most significant process variable since it tends to influence the transitional velocity. It is known that the maximum temperature was observed to be a strong function of rotation speed. When the rotational speed increases, the heat input within the stirred zone also increases due to the higher friction heat which in turn result in more intense stirring and mixing of materials as in mention in the formula of Heat Index (HI) [26]

$$HI = \frac{\omega^2}{v}$$

ω = tool rotational speed, rpm

V = welding traverse speed, mm/min

As the heat is increasing, the strength was reduced due to the formation of defects and overaging in heat-affected zone (HAZ). Higher rotation speeds could raise the strain rate and turbulence (abnormal stirring) in the material flow caused a tunnel defect at the weld nugget.

4.7.2 Effect of the welding traverse speed

The graph above shown that as the welding speed is increasing, the maximum lap shear load of the welding joints also increasing. Higher welding speeds are associated with low heat inputs, which result in faster cooling rates of the welded joint. This can significantly reduce the extent of metallurgical transformations taking place during welding and hence the local strength of individual regions varies across the weld zone. Traverse speed also associated with the heat dissipation of the welding process. Increasing the traverse speed increases heat dissipation rate because the heated Swept FSSW zone is quickly brought into cool base metal, resulting in reduced temperature and duration of thermal exposure in the HAZ. Increasing temperature can increase the rate of diffusion which may accelerate the dissolution and growth rates and therefore enhance particle coarsening. With increasing temperature, the maximum solute solubility in the matrix also increases and precipitates may dissolve to release solute in solid solution. Both these mechanisms increase the interparticle spacing and this in turn can soften the welding joint [27].

4.7.3 Comparison with FSSW

To compare the result from the previous FYP student doing the research on FSSW, the welding parameter is set same as FSSW which are the rotational speed will be varied from 4000 rpm, 5000 rpm and 6000 rpm and the plunge rate (z-axis traverse speed) is set to 55mm/min. From the graph, we can see that the maximum lap shear load of the swept FSSW is higher than FSSW for every tool rotational speed. The maximum load is almost twice as result from FSSW technique. This proves that swept FSSW will give stronger welding joint than FSSW. The advantage of the swept spot weld over the traditional plunge spot welds is the increased joint strength that results from increased shear area.

4.7.4 General discussion

The heat input and material flow behavior decides the quality (defective or defect free) of swept FSSW joints. The heat input is predominantly influenced by the swept FSSW process parameters such as tool rotation speed and welding speed. The heat input increases with increase in rotation speed and decreases with the increase in welding speed. At lower rotation speed, the heat input is not sufficient and also improper stirring causes a tunnel defect at the middle of the retreating side. Higher rotation speeds could raise the strain rate and turbulence (abnormal stirring) in the material flow caused a tunnel defect at the weld nugget. As the rotation speed increases, the strained region widens, and the location of the maximum strain finally moves to the retreating side from the advancing side of the joint [28]. Low welding speeds resulted in higher heat input and excess turbulence of the plasticized metal which caused a tunnel defect at the top of weld nugget. Higher welding speeds are associated with low heat inputs, which result in faster cooling rates of the welded joint.

The overaging of the HAZ is determined by both temperature and duration of thermal exposure during FSW, which are controlled by two competitive processes heat generation and heat dissipation. The heat generation is mainly determined by the tool rotation rate. The heat dissipation is mainly controlled by the tool traverse speed. Increasing the traverse speed increases heat dissipation rate because the heated FSW zone is quickly brought into cool base metal, resulting in reduced temperature and duration of thermal exposure in the HAZ.

4.8 Check the welded material bonding using Optical Microscopy (OM)

At first, the sample will be cut using abrasive cutter to small portion and then it will be mounted using mounting press machine. Mounting process will take about 15 minutes that consist of heating and cooling processes. After the sample is mounted, it will undergo grinding and polishing process to remove the scratch and to make sure the sample surface is smooth. After the sample is polished, etching process takes places. The sample will be washed using HCL and stir with water after 10 seconds. The sample then will be check using OM and find the diffusion area.

Cut the sample at the middle Sample that has been cut Mounted sample

Figure 4.15: Preparation of the sample for mounting process

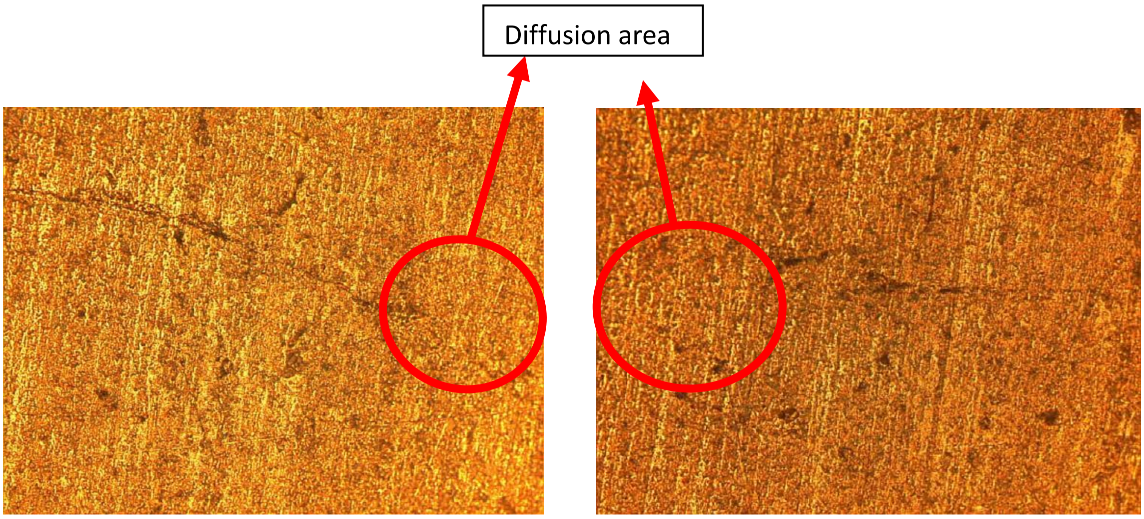


Figure 4.16: The image of the sample under Optical Microscopy

Circle in the diagram above show the straight line which is indicate the boundary between two plates (no diffusion). This line will end at the diffusion area where the bonding between the plates occurs. The view from OM shows that not all the welding area is diffuse each other. Only the area where the tip of the welding tool moves during welding process diffuse both plate (red arrow in the Figure 4.17)

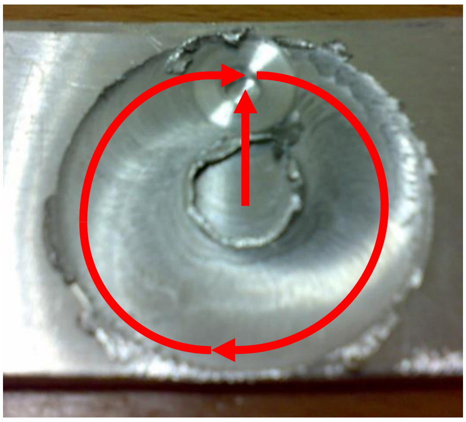


Figure 4.17: The red arrow shows the tip of the welding tool path

After the lap shear test, the entire sample failed at the edge of the welding area as shown in Figure 4.11. The microstructure view also proves that the diffusion at certain point only. The diffusion area is where the tip of the tool is moved which are at the center and along the side of circle. The diffusion path can be seen by bare eyes at the back of sample which are the 'ring' shape and small point at the center of sample in Figure 4.18.

Figure 4.18: 'ring' shape behind welding sample

CHAPTER 5

CONCLUSION

From the result above, the heat input and material flow behavior decides the quality (defective or defect free) of swept FSSW joints. This heat input is controlled by both tool rotational speed and welding traverse speed and will affect the strength of welding joint. Both of the parameters are related with heat generation and heat dissipation. Increasing welding traverse speed will increase the heat dissipation which result in faster cooling rates of the welded joint and thus increase the strength of the joint while increasing tool rotational speed will increase the heat generation and will reduce the strength of the welding joint. Both of the results are same with the results obtained by T. Speller [30] as mention in the introduction above. It is also found that swept FSSW has a stronger joint compare to FSSW due to increased joint strength that results from increased shear area.

.

CHAPTER 6

RECOMMENDATION

This project is still new in UTP and there are a lot of future work can be done to improve the results of the project. The tool path design for welding can be redesign to get smoother welding process and the G-code program during the welding process can be improve by including the instruction for dwell as the dwell process is done by manual before. For the lap shear test using Universal Testing Machine, more welding samples can be prepared for the each testing and take the average value to get more convincing and accuracy result. There are a lot of process parameters that can affect the strength of the welding joint. Future work can be focuses on the different parameters for example, depth of the tool penetration, forge load, type of the tool tip and dwell time. The microstructure of the welded area also can be study in detail using Optical Microscopy or Advanced Confocal Microscopy to get the clear picture of the diffusion structure of the welded plate.

REFERENCES

1. Courtesy of TWI, Ltd, http://www.twi.co.uk, retrieve on 2nd May 2010

2. Misra, R.S., Mahoney, M.W., “Introduction,” Chapter 1, Friction Stir Welding and Processing, Materials Park, OH, 2007, pp 1-5

3. Mahoney, M., “High Strain Rate Superplasticity in Thick Section 7050 Aluminum created by Friction Stir Processing,” Proceeding of 3rd International Friction Stir Welding Symposium, sponsored by TWI, ltd., Kobe, Japan, 27-28 September 2001

4. Sakano, R. “Development of Spot FSW Robot System for Automobile Body Members,” Proceeding of 3rd International Friction Stir Welding Symposium, sponsored by TWI, ltd., Kobe, Japan, 27-28 September 2001

5. Tomoyuki, I., “ Method and apparatus for joining,” U.S. Patent No. 6,601,751, August 5, 2003

6. Tweedy, B.M. “ Factors Affecting the Properties of Swept Friction Stir Spot Weld,” Proceedings of 2008 SAE World Congress, Detroit, MI, 2008

7. Oberembt, C. et al. “Screening for Process Variable Sensitivity in Refill Friction Stir Spot Welding of 6061 Aluminum sheet,” Friction Stir Welding and Processing IV. TMS 2007, Orlando, Florida, February 25 – March 1, 2007

8. Schilling, C. and dos Santos, J., “Method and Device for joining at Least Two Adjoining Work Pieces by Friction Welding”, U.S. Patent No.6,722,556, April 20, 2004

9. Pan, T., “Friction Stir Spot Welding (FSSW) – A Literature Review,” Proceedings of the 2007 SAE World Congress, Detroit

10. Jeremy M.B., “The Effect of Sealant and Surface Treatments on Faying Surface of Swept Friction Stir Spot Welding”. Thesis, Bachelor of science, Wichita State University, 2006

11. http://en.wikipedia.org/wiki/Friction_stir_welding, February 25, 2010

12. B. Tweedy et al, “Factors Affecting the properties of Swept Friction Stir Spot Welds,” Proceedings of the 2007 SAE World Congress, (Detroit, MI, USA), April 14-17, 2008

13. A.C. Addison and A.J. Robelou, “Friction stir spot welding: Principle Parameters and Their Effects,” Proceedings of 5th International Symposium on Friction Stir Welding (Metz, France), TWI, Sept 14-16, 2004

14. Rajiv S. Mishra, Murray W. Mahoney and Thomas J. Lienert, “Evaluation of Swept Friction Stir Spot Welding in Al 2219-T6,” Friction Stir Welding and Processing V (2009).

15. Rajiv S. Mishra, Murray W. Mahoney and Thomas J. Lienert, “Corrosion and fatigue evaluation of swept friction stir spot welding through sealant and surface treaments,” Friction Stir Welding and Processing V (2009).

16. http://www.efunda.com/glossary/materials/alloys/materials--alloys--steel--tool_steel--aisi_h13.cfm, April 30, 2010.

17. Strangwood, M., Berry JE; Cleugh, DP; Leonard, AJ; Threadgill, “Characterizations of the thermo mechanical effects on micro structural development in friction stir welded age hardening aluminum based alloys” First International Symposium on Friction Stir Welding, Thousand Oaks, Carlifonia,. Proceeding published by TWI, Abington 1999.

18. Murr, LE; Liu, G; McClure, JC, A TEM *study of precipitation and related microstructure in friction stir welded 6061 aluminum. Journal of Material Science*, 1988, Vol. 33, pp. 1243-1251.

19. ALCOA, “ Understanding Extruded Aluminum Alloy 6061”, Alcoa Engineering Products, Cressona, PA

20. http://en.wikipedia.org/wiki/6061_aluminium_alloy, Mei 1, 2010
21. http://www.hardnesstesters.com/microhardness-tester.htm, Mei 5, 2010

22. Wan Nur Ashikeen Meor Anuar Shuhaili, “ Study on Enhancement of Mechanical Properties of aluminum Alloy Corroded Plate”, Interim Report, Bachelor of Mechanical Engineering, Universiti Teknologi PETRONAS, July 2009

23. UDDEHOLM, “Heat Treatment of the Tool Steel”, Material Safety Data Sheet, 6th edition, December 2007

24. S.Z. Qamar, A.K. Sheikh, A.F.M. Arif, T. Perves, R.A. Siddiqui, “Heat treatment of Hot Work Die Steel”, Achieves of Material Science and Engineering, Volume 28, Issue 8, August 2007

25. http://www.threeplanes.net/toolsteel.html, Mei 6, 2010

26. S Yazdanian, Z W Chen, “Effect of Friction Stir Lap Welding Condition on Joint Strength of Aluminum Alloy 6060, AUT University, Auckland NZ, 2009.

27. M. Jayaraman, R. Sivasubramaniam, V. Balacubramaniam, “Effect of Process Parameter on Tensile Strength of Friction Stir welded cast LM6 Aluminum alloy joints”, September 2008.

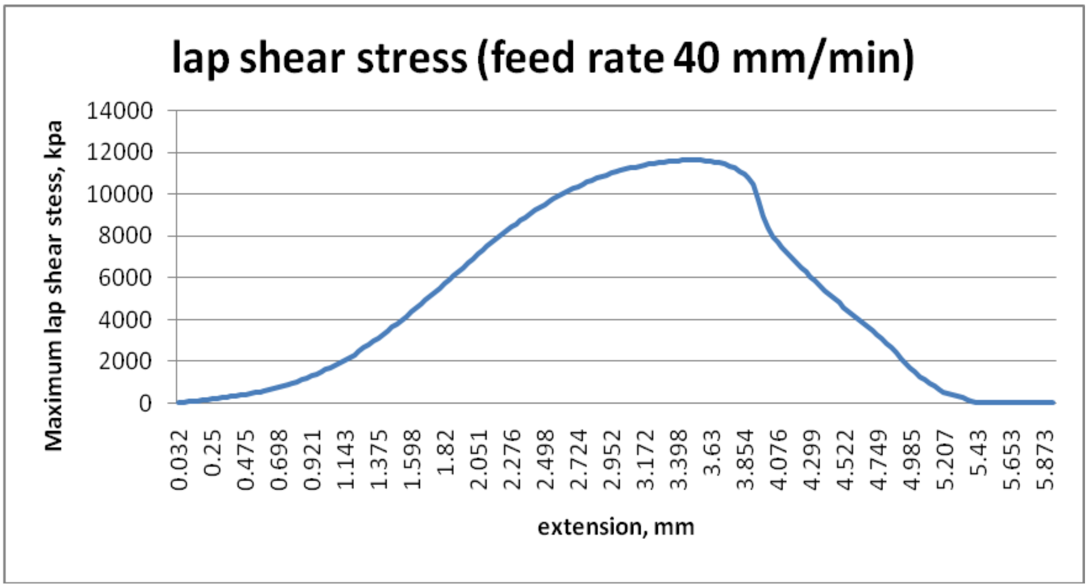
28. S. R. Ren, Z. Y. Ma, L. Q. Chen, “Effect of Welding Parameters on Tensile properties and fracture behavior of Friction Stir Welded Al-Mg-Si alloy”, Institute Metal Research, China, August 2006.

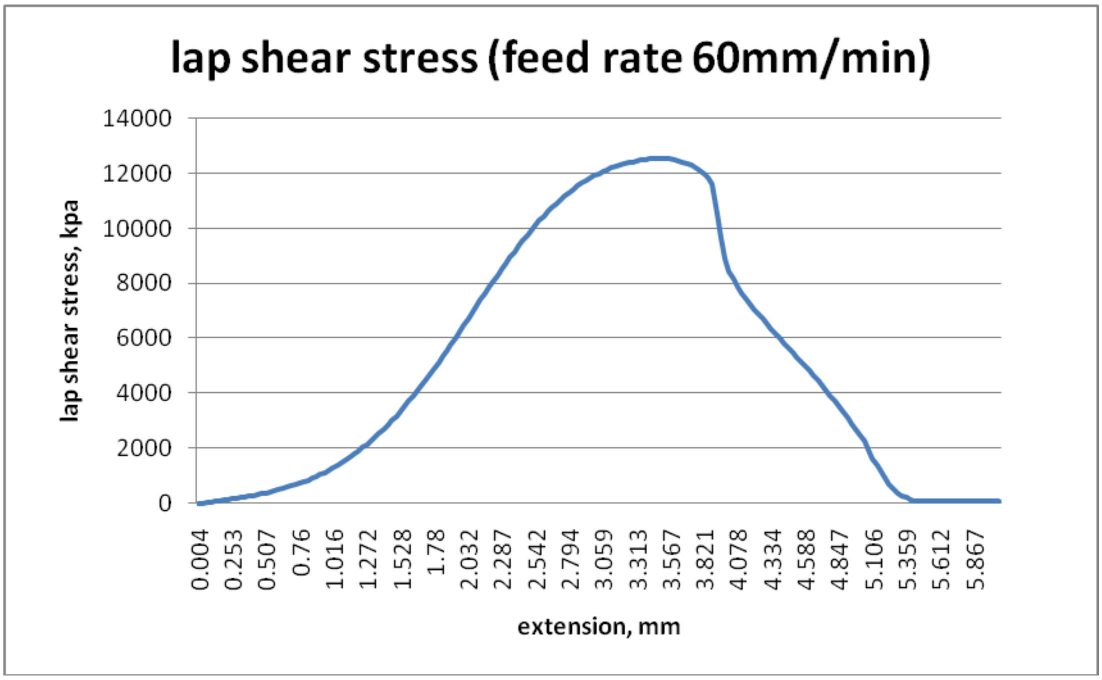
29. Mohd Syazwan Akmal Yaakob, “Experimental Study on Strength of Friction Stir Spot Welding”, Mechanical Engineering, Universiti Teknologi PETRONAS, January 2009

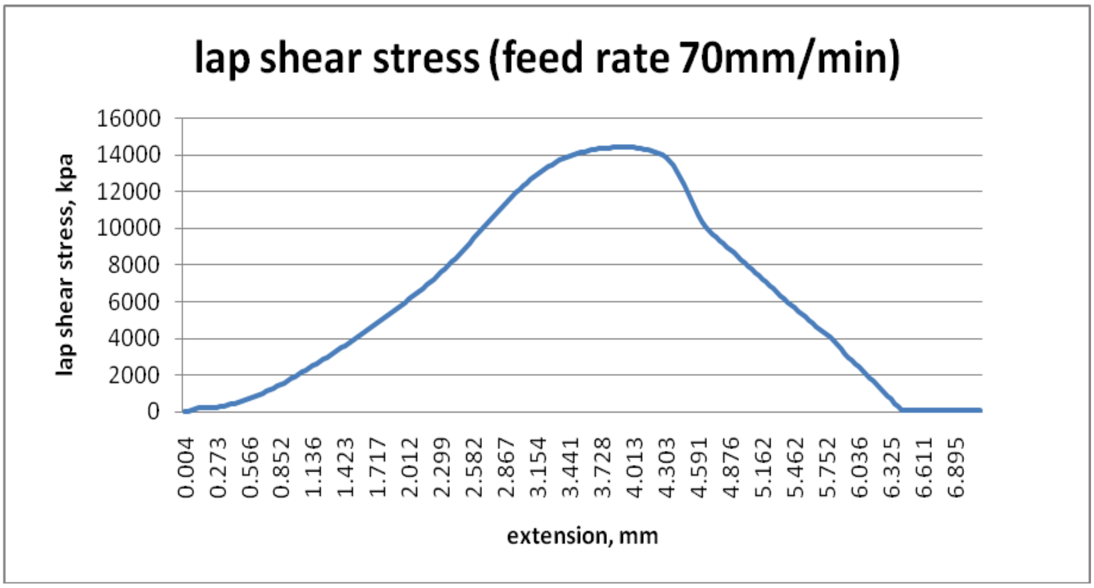
30. T. Speller Jr. “DOE 01 of Friction Stir Spot Welding Assembly (FSSA)” March 13, 2002

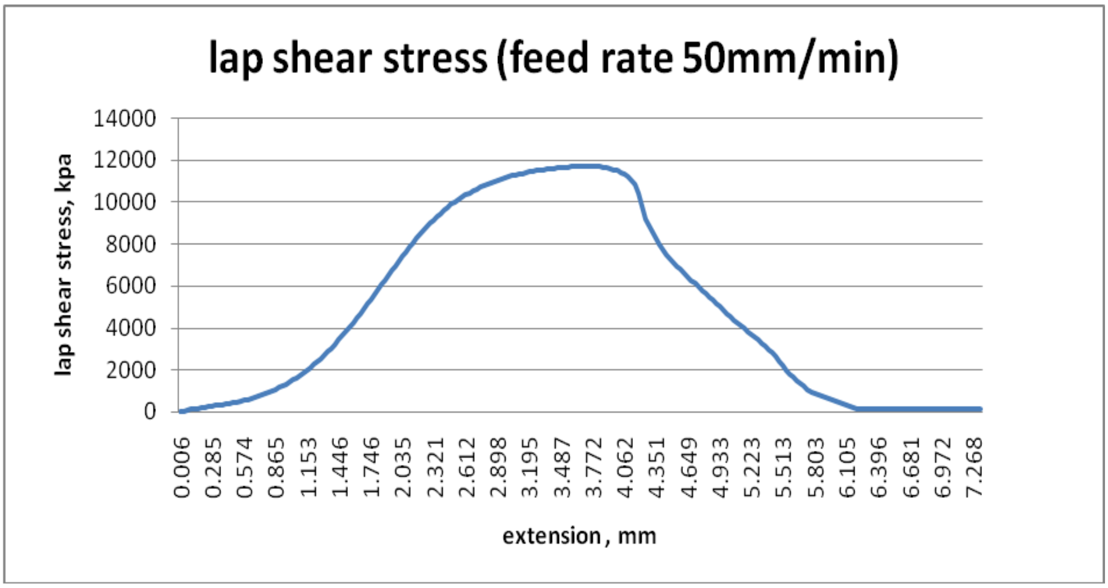
APPENDIX

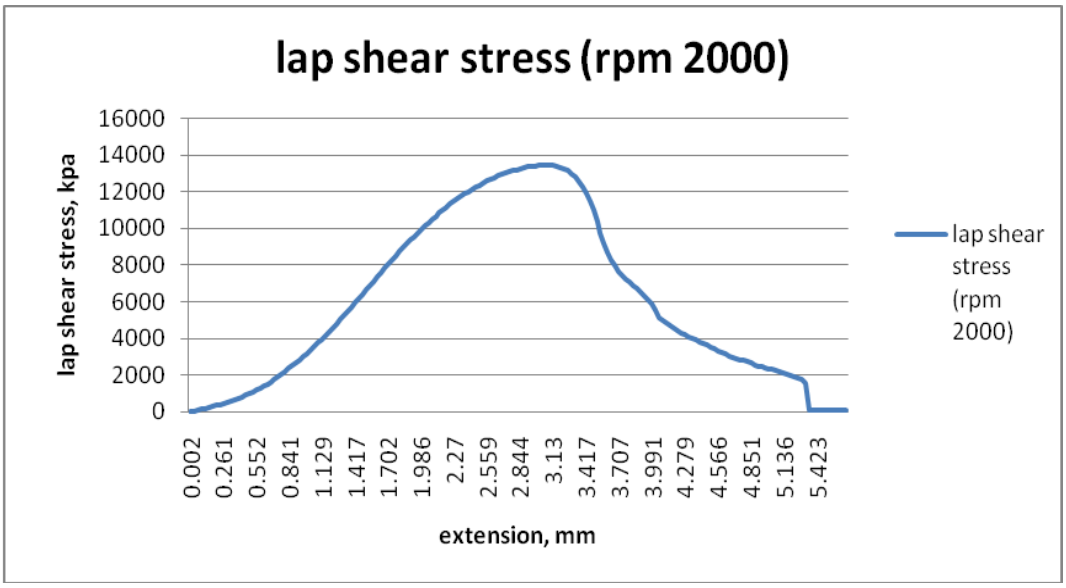
Lap Shear Test Result (Stress vs Extension)

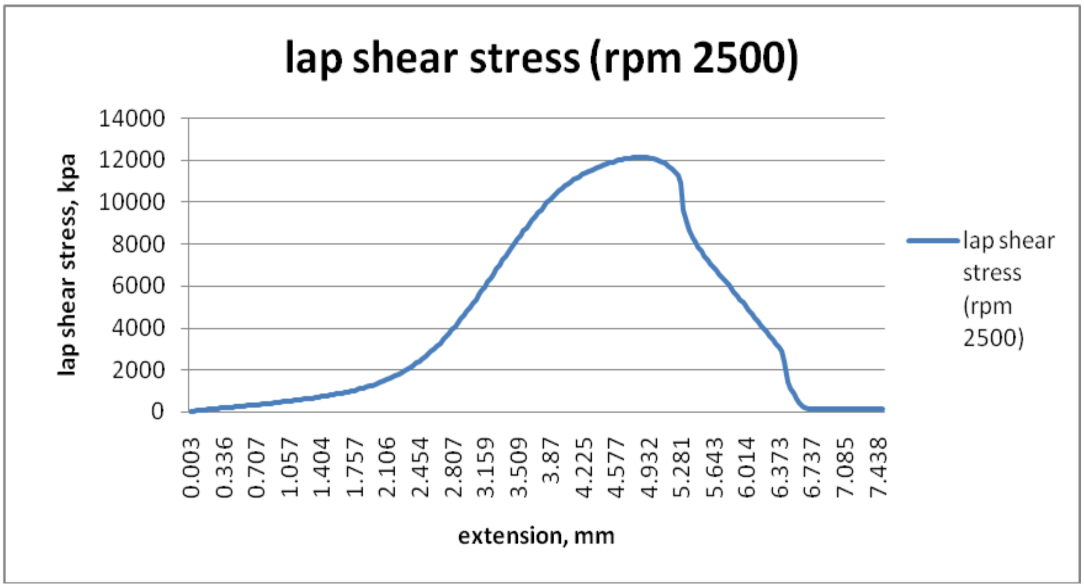


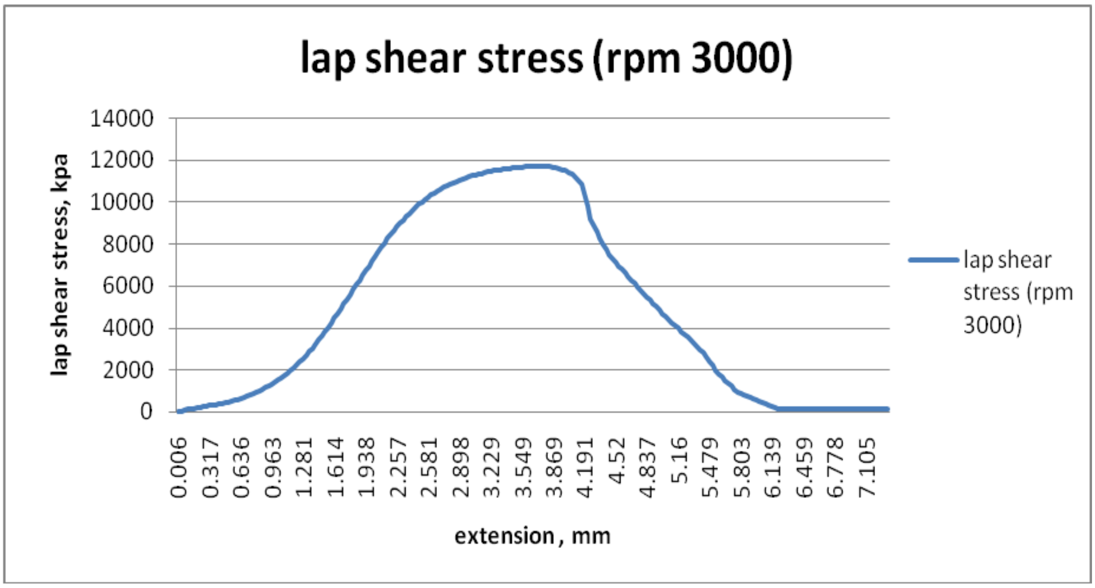


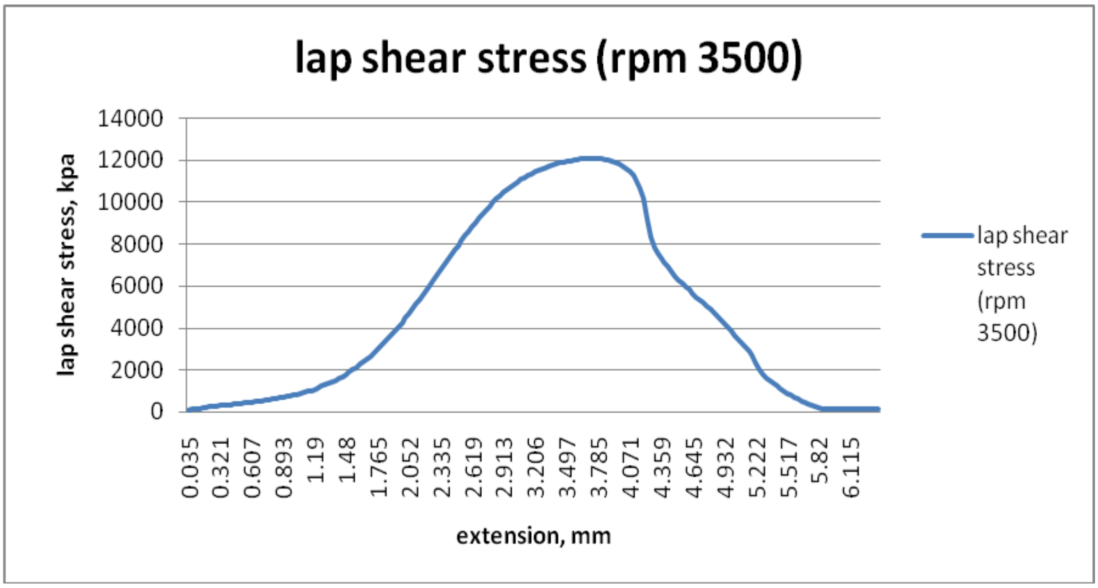

lap shear stress (feed rate 70mm/min)
lap shear stress, kpa
16000
14000
12000
10000
8000
6000
4000
2000
0
0.004
0.273
0.566
0.852
1.136
1.423
1.717
2.012
2.299
2.582
2.867
3.154
3.441
3.728
4.013
4.303
4.591
4.876
5.162
5.462
5.752
6.036
6.325
6.611
6.895
extension, mm

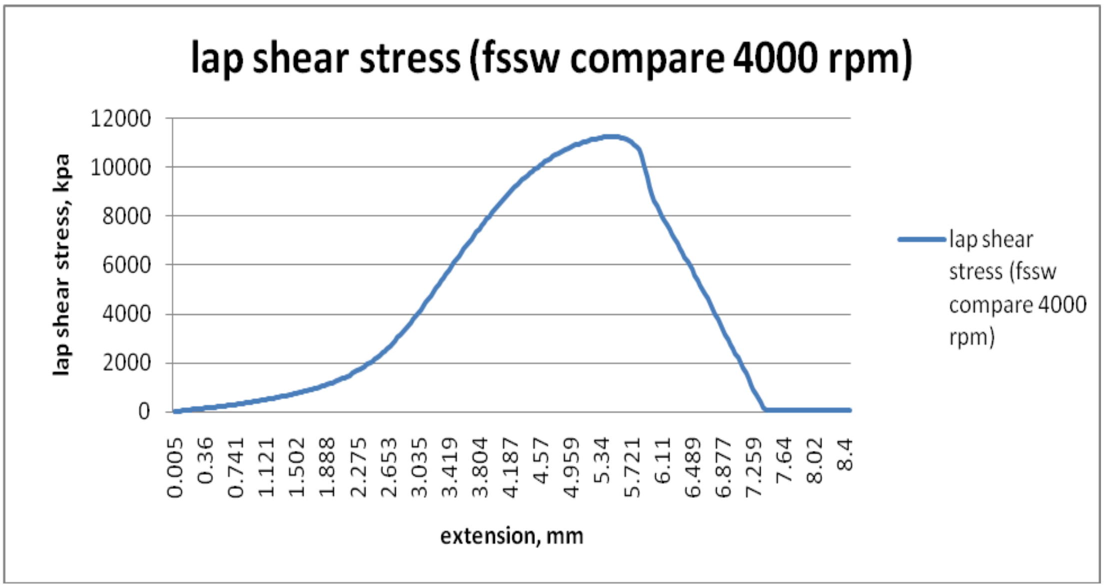

lap shear stress (feed rate 50mm/min)
lap shear stress, kpa
14000
12000
10000
8000
6000
4000
2000
0
0.006
0.285
0.574
0.865
1.153
1.446
1.746
2.035
2.321
2.612
2.898
3.195
3.487
3.772
4.062
4.351
4.649
4.933
5.223
5.513
5.803
6.105
6.396
6.681
6.972
7.268
extension , mm

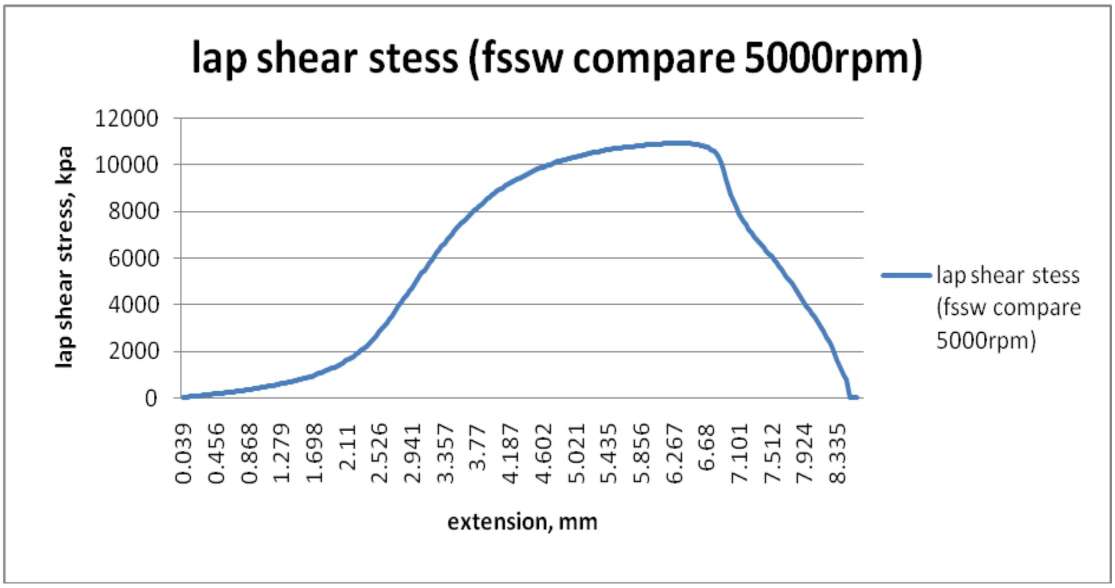

lap shear stress (rpm 2000)
lap shear stress, kpa
16000
14000
12000
10000
8000
6000
4000
2000
0
0.002
0.261
0.552
0.841
1.129
1.417
1.702
1.986
2.27
2.559
2.844
3.13
3.417
3.707
3.991
4.279
4.566
4.851
5.136
5.423
extension, mm
lap shear stress (rpm 2000)

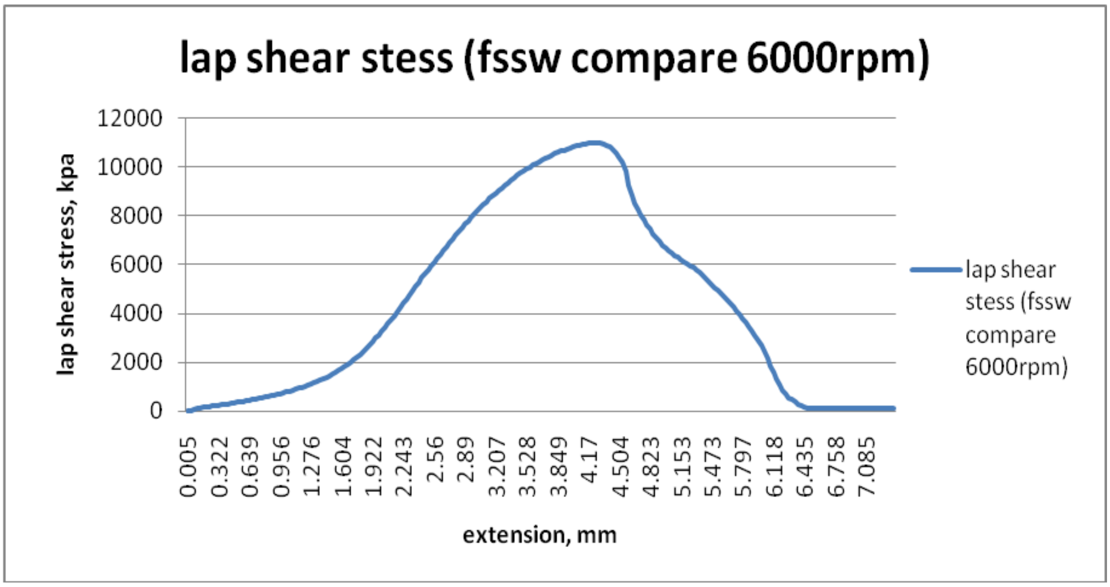

lap shear stress (rpm 2500)
lap shear stress, kpa
14000
12000
10000
8000
6000
4000
2000
0
0.003
0.336
0.707
1.057
1.404
1.757
2.106
2.454
2.807
3.159
3.509
3.87
4.225
4.577
4.932
5.281
5.643
6.014
6.373
6.737
7.085
7.438
extension, mm
lap shear stress (rpm 2500)


lap shear stress (rpm 3000)
lap shear stress, kpa
14000
12000
10000
8000
6000
4000
2000
0
0.006
0.317
0.636
0.963
1.281
1.614
1.938
2.257
2.581
2.898
3.229
3.549
3.869
4.191
4.52
4.837
5.16
5.479
5.803
6.139
6.459
6.778
7.105
extension , mm
lap shear stress (rpm 3000)

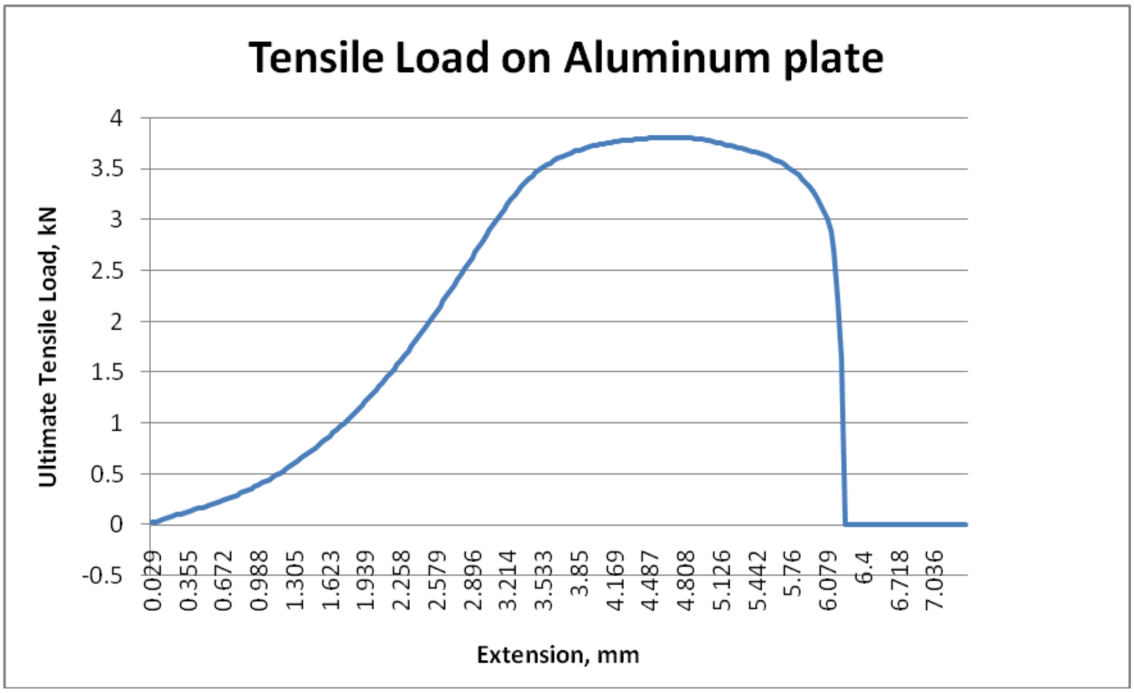

lap shear stress (rpm 3500)
lap shear stress, kpa
14000
12000
10000
8000
6000
4000
2000
0
0.035
0.321
0.607
0.893
1.19
1.48
1.765
2.052
2.335
2.619
2.913
3.206
3.497
3.785
4.071
4.359
4.645
4.932
5.222
5.517
5.82
6.115
extension, mm
lap shear stress (rpm 3500)

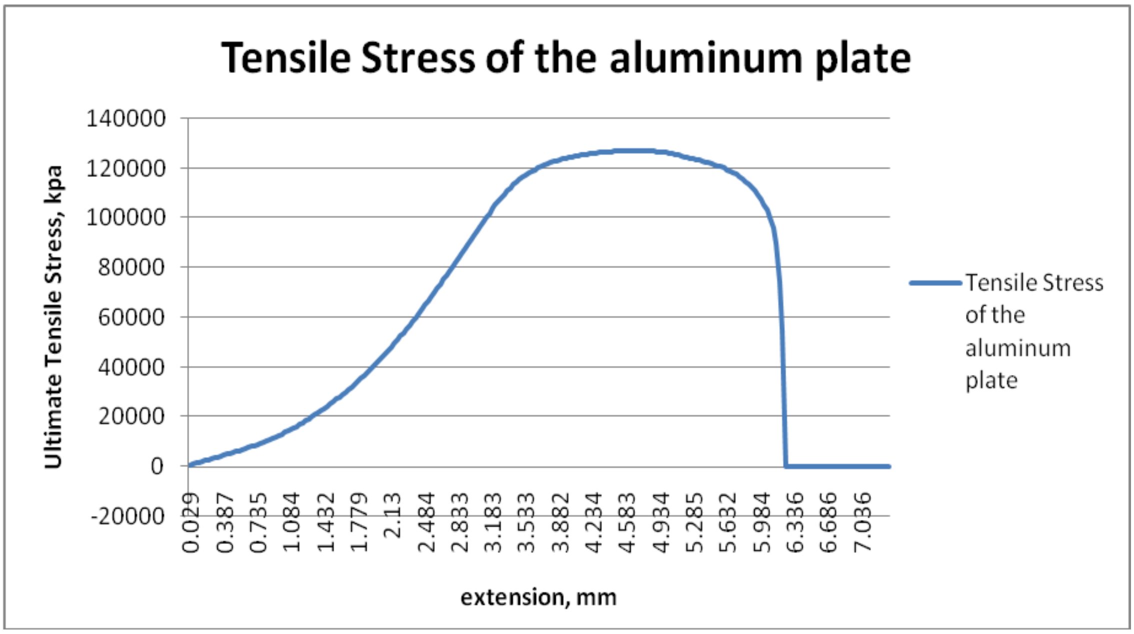

lap shear stress (fssw compare 4000 rpm)
lap shear stress, kpa
12000
10000
8000
6000
4000
2000
0
0.005
0.36
0.741
1.121
1.502
1.888
2.275
2.653
3.035
3.419
3.804
4.187
4.57
4.959
5.34
5.721
6.11
6.489
6.877
7.259
7.64
8.02
8.4
extension, mm
lap shear stress (fssw compare 4000 rpm)


lap shear stess (fssw compare 5000rpm)
lap shear stress, kpa
12000
10000
8000
6000
4000
2000
0
0.039
0.456
0.868
1.279
1.698
2.11
2.526
2.941
3.357
3.77
4.187
4.602
5.021
5.435
5.856
6.267
6.68
7.101
7.512
7.924
8.335
extension, mm
lap shear stess (fssw compare 5000rpm)

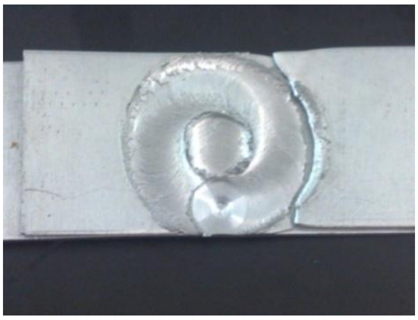

lap shear stess (fssw compare 6000rpm)
lap shear stress, kpa
12000
10000
8000
6000
4000
2000
0
0.005
0.322
0.639
0.956
1.276
1.604
1.922
2.243
2.56
2.89
3.207
3.528
3.849
4.17
4.504
4.823
5.153
5.473
5.797
6.118
6.435
6.758
7.085
extension, mm
lap shear stess (fssw compare 6000rpm)

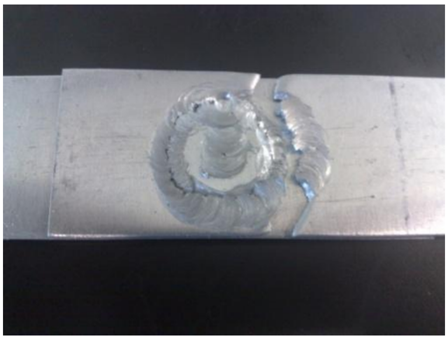
Results of the tensile test on Aluminum plate.

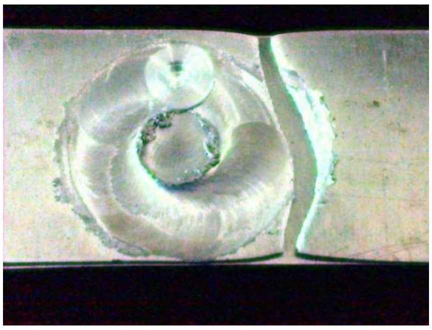


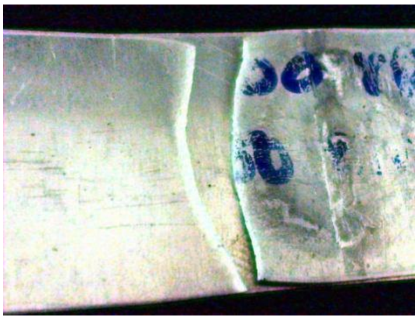


Picture of the welding sample after lap shear test



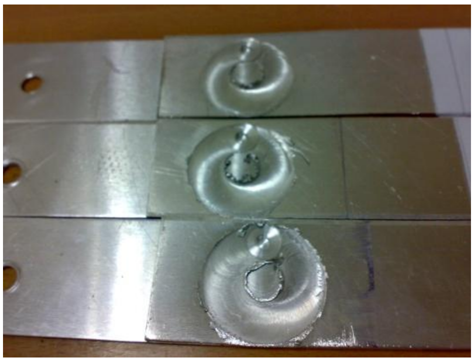




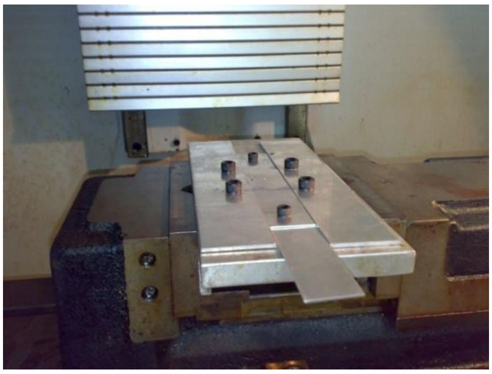


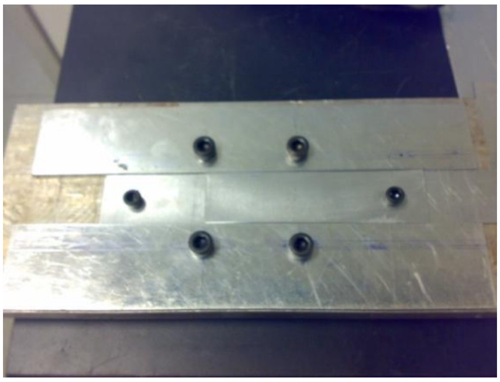
Sample with 1.5mm penetration of the tool

Sample with tool penetration 1.6mm

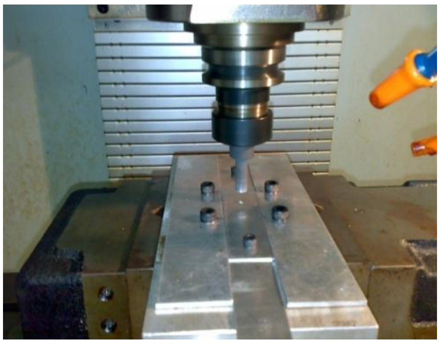


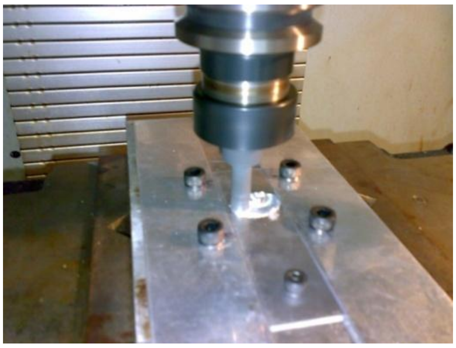
Picture of the jig used to clamp the sample during welding process





Welding process

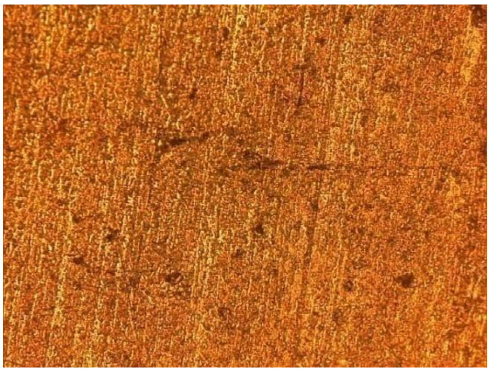




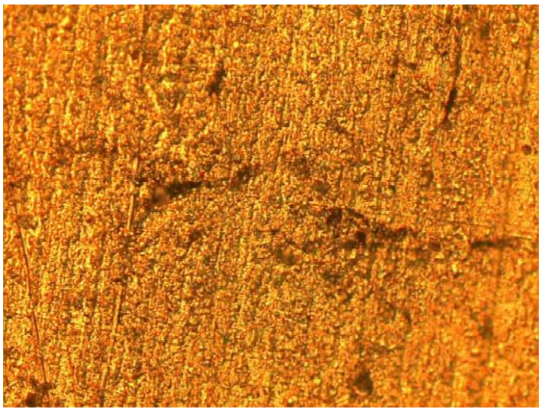
Mounting process

Optical Microscopy (Left point of the sample)

10x magnifications

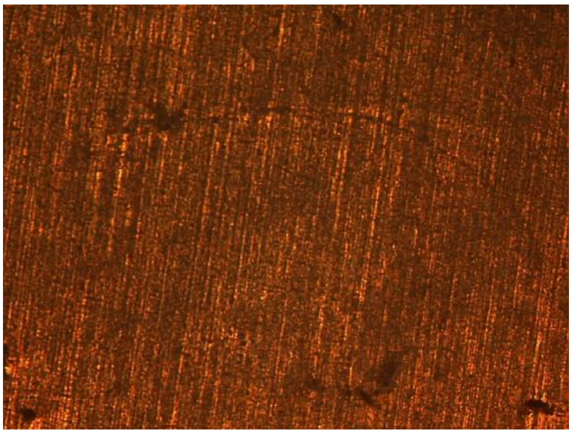


50x magnifications

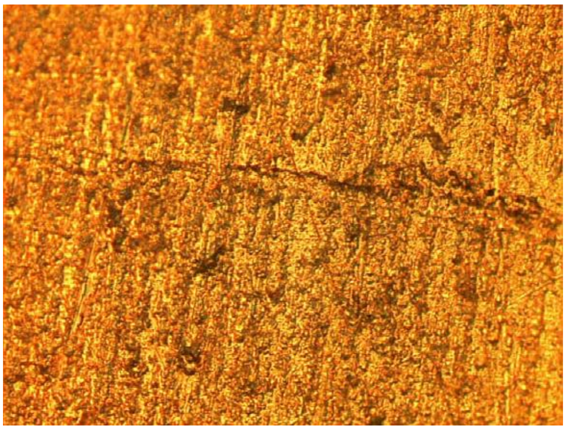


100 x magnifications

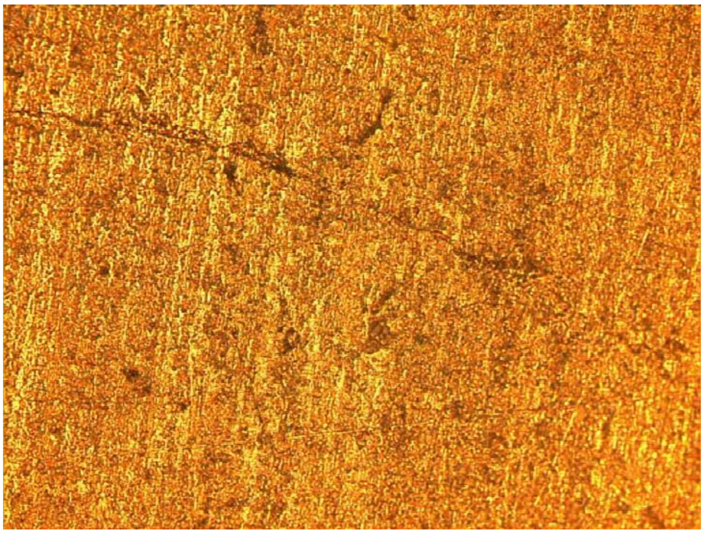
Optical Microscopy (middle point of the sample)



10x magnifications

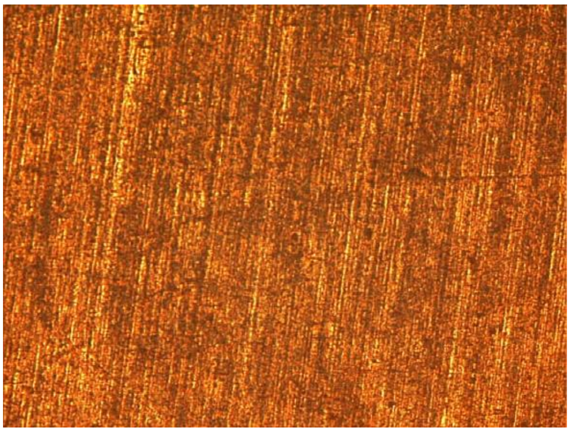


50x magnifications

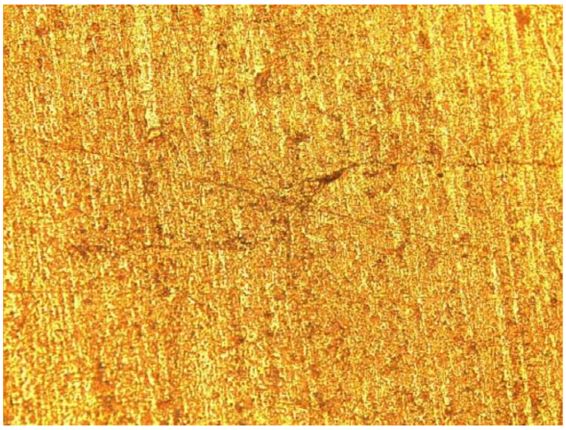


100x magnifications

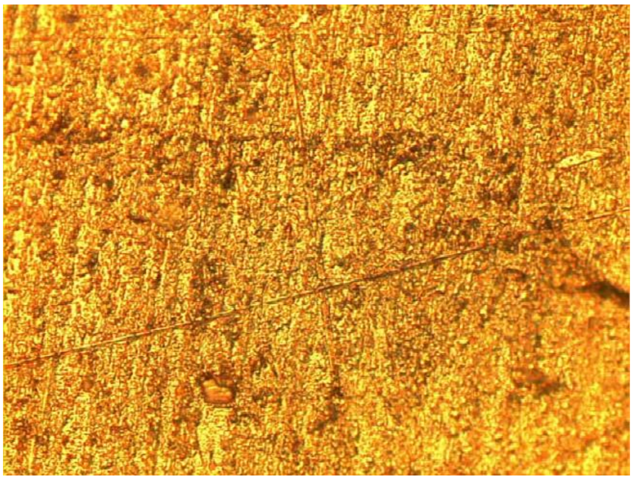
Optical Microscopy (right point of the sample)



10x magnifications

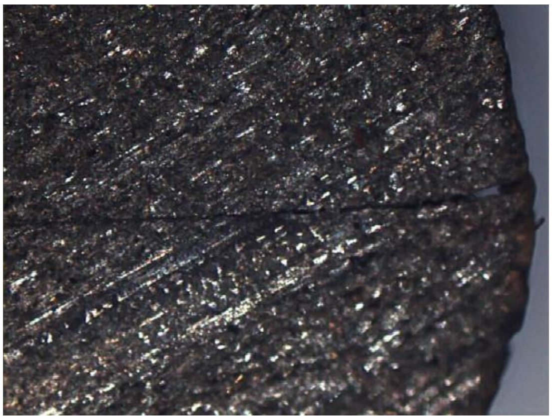


50x magnifications

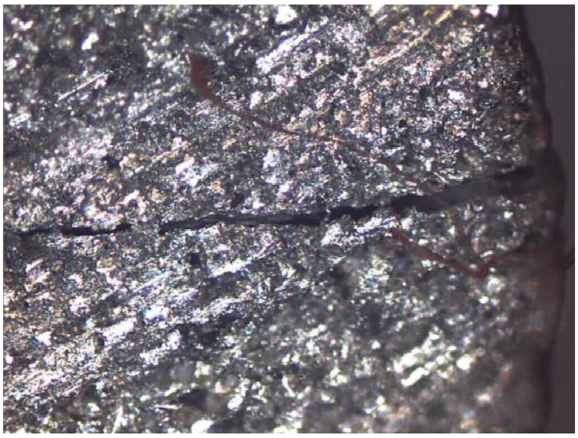


100x magnifications

Optical Microscopy (Bare sample without polish and mounting)

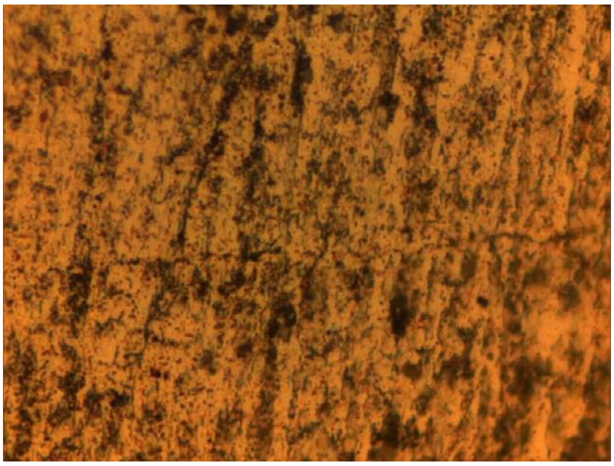


10x magnifications

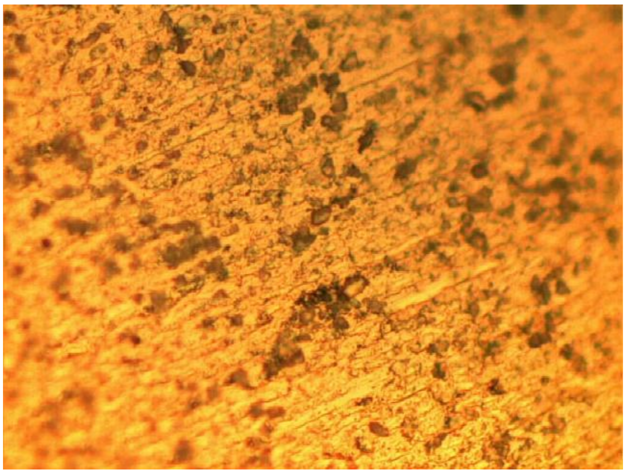


50x magnifications

Optical Microscopy (diffusion area and non-diffusion area)

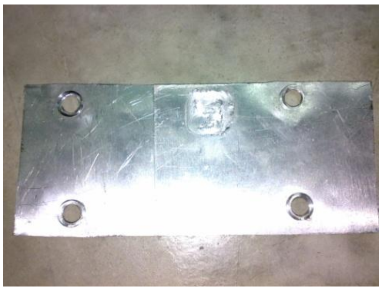


Non-diffusion area



Diffusion area

Trial run using conventional Milling machine



Sample for XRF machine

Result material composition using XRF

Measurement method: STG2-S4-Check

O	Al	Si	S	Cl	Ti	V
0.6 KCps	3851 KCps	2.6 KCps	0.3 KCps	0.5 KCps	0.7 KCps	0.5 KCps
46.7	52.42	0.0568	0.003	0.013	0.003	0.001

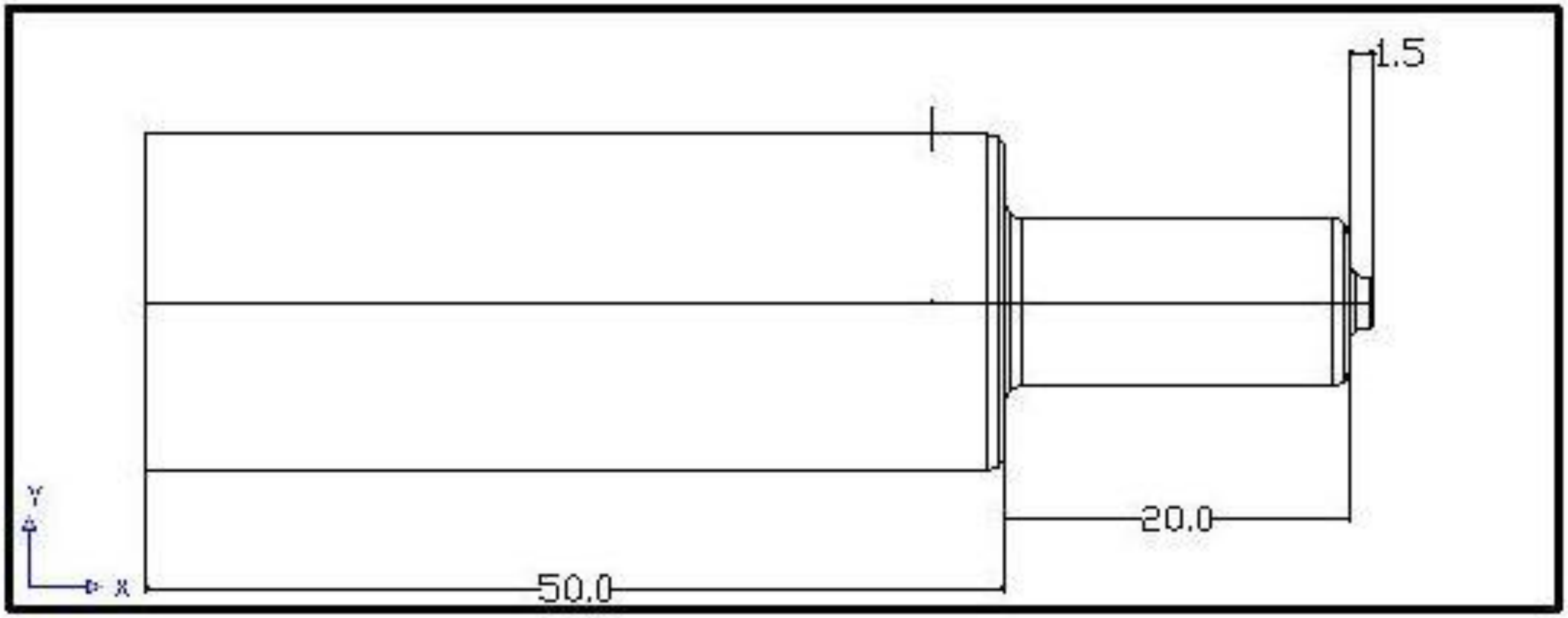
Fe	Cu	Ga	Ar	TiO2
93.1 KCps	33.0 KCps	6.8 KCps		0.7 KCps
0.1090	0.0047	0.0032	0.4572	0.005

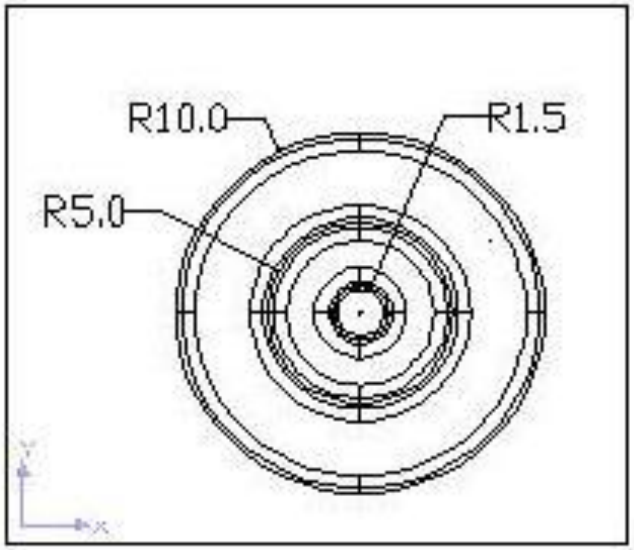
APPENDIX 1: Gantt Chart for FYP I

NO.	DETAIL/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection project topic	🟨													
	-Propose topic														
	-Confirm of topic selection														
2	Preliminary research work		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		
	-data gathering														
	-identify technique and tool														
	-find related literature review														
3	Submission of preliminary report					●									
4	Project work					🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		
	-find the material						🟨	🟨							
	- Design and fabricate the tool								🟨	🟨	🟨				
5	Submission of progress report								●						
6	seminar								●						
7	Continue project work														
	-Heat Treatment for the tool												🟨		
	-Testing the tool (trial run)													🟨	🟨
8	Preparation for interim report					🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
9	Submission of interim report final draft														●
10	Oral presentation														●

● Milestone

🟨 Process


1.5
20.0
50.0
Y
X


R10.0
R1.5
R5.0
Y
X