Study on Microstructure and Strength of Friction Stir Spot Welding On Copper Alloy Sheet

By

Nurfarahin binti Shamsudin

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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(MECHANICAL ENGINEERING)

Approved by,

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May 2011

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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ABSTRACT

Friction Stir Spot Welding is the derivative of Friction Stir Welding (FSSW). It is a solid-state joining process of metal sheets with the thickness not more than 3 mm. Most of the process is being used in the automotive industry. FSSW is a process without lateral movement of the tool compared to Friction Stir Welding. Two sheets of different combinations of material were welded by using the FSSW process. The thickness of the sheet 0.9 mm. The combinations of material are Aluminum alloy to Aluminum alloy, Copper Alloy to Copper Alloy and Copper Alloy to Aluminum alloy. For each of the combination, the tool rotational speed were varied with 2000, 3000, 4000 rpm each. Then, 3 samples of welded sheets with tool rotational speed of 3000 rpm were observed on the microstructure using the optical microscope. Three different welded areas of affected by the FSSW were seen under the microscope to be characterized. The other samples were taken to be tested on the tensile strength using the Universal Tensile Strength Machine. The load resulted from the test were calculated to get the value of tensile strength for the welding process.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the new modern advanced manufacturing industries, Friction Stir Spot Welding (FSSW) is broadly used as a technique process to join metals shaped into sheets with the thickness not more than 3 millimeters. This process is suitable for components which are flat and long (plates and sheets). The downward force and the rotational speed are maintained for an appropriate time to generate frictional heat. Then heated and softened material adjacent to the tool deforms plastically, and a solid state bond is made between the surfaces of the upper and lower sheets [1]. Friction stir spot welding was developed primarily for welding metals and alloys that had been difficult to weld using conventional fusion techniques. FSSW is widely used in the automotive industry especially in the production of doors, engine hoods and few other automotive components.

FSSW is a derivative of Friction Stir Welding process. It creates a spot, lap-weld without bulk melting. FSSW is more energy and cost savings. Normal spot welding process is the combination of frictional heating and mechanical deformation due to a rotating tool. Friction stir spot welding process consists of three phases; plunging, stirring and retraction as shown in Figure 1. It starts with tool spinning and slowly plunge the tool into a weld spot until the shoulder (junction between the cylindrical portion and the probe) contacts the top surface of the work piece. During the stirring phase, the two pieces of material are mixed together. After the penetration process reach the determined requirement, the process stops and the tool retracts away from the workpiece.

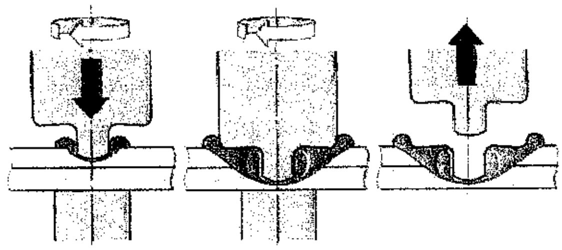


Figure 1: Three phases of Friction Stir Spot Welding Process [1]

1.2 Problem Statement

Study of friction stir spot welding on microstructure of the copper alloy had never been done in Universiti Teknologi Petronas before. As the process is well developed and being applied in various cases, an observation by experiment is needed to study how the overall shape of FSSW weld joint deforms for copper alloy plates. There has been a recent series of research done on the FSSW such as the study on microstructures and failure mechanism of spot friction welds in lap-shear specimens of aluminum and the study on the process parameters on weld joint strength of aluminum but the study and effect of friction stir spot welding onto the copper alloy plates had never been done widely.

Thus, the solution is to find the relationship between welding zones created onto copper alloy plates and subsequent microstructure formed in each welding zones need to be done to help understanding the mechanisms of this new material of workpiece joining process.

1.3 Objective

1. To study the microstructure and strength of the FSSW of welding zones of the material through the experiment.

1.4 Scope of study

For this project, a cylindrical-shouldered tool of Friction Stir Spot Welding is to be produced. The parameters of the tool are the tool material, radius of tool pin and radius of cylindrical shape with specified length of tool shoulder. Copper alloy (0.9 mm) will be used as the FSSW workpiece. While CNC Milling Bridgeport machine is the FSSW machine to do the process. For the tool production, Heat Treatment will be done to the welding tool to renovate and harden the material of the tool.

Other than that, the plunge testing was conducted to determine the suitable tool rotational speed and normal speeds to ensure successful and efficient welding cycle. The tool rotational speed will be the variable of this project to be compared on the strength properties of material after the FSSW process.

After the FSSW process, the sample of the FSSW welds will be examined and analyzed on its microstructural features by using the optical microstructure in UTP's lab. Based on the microstructural patterns of the material, the results will be related to the strength of the workpiece to the affected area by FSSW process. Table 1 summarized the selected equipment for FSSW process.

Table 1 Selected equipment for FSSW process.

FSSW Tool Material	Tool steel H13
FSSW workpiece	Copper alloy plates (0.9 mm)
FSSW machine	Bridge Port CNC Machine
Tool refurbishment	Heat treatment
Microscopic Examination Equipment	Optical Microscope

CHAPTER 2

LITERATURE REVIEW

2.1 Friction Stir Welding Tool Material

2.1.1 Tool material characteristics

Many different material characteristics could be considered important to friction stir, but ranking the material characteristics will depend on the workpiece material, expected life of the tool and the user's own experiences and preferences. Other than that, few practical considerations need to be included for the material selection of the tool.

The tool material must be able to withstand the compressive loads when the tool first makes contact with the workpiece. It must have sufficient compressive and shear strength at elevated temperature to prevent tool fracture or distortion for the duration of the friction stir weld. At a minimum, the candidate tool material should exhibit elevated temperature compressive yield strength higher than the expected normal forces of the tool.

Tool fracture toughness is very important during the plunge and dwell process. When the first time the tool touches the workpiece, the local stresses and strains produced can break a tool, even when mitigation methods are used. Based on the study, it is acceptable that during the tool plunge dwell periods are the causes of tool damage. Besides that, the tool rotational speed also needs to be considered when selecting a tool material. Low-fracture-toughness tools should only be used in friction stir machine that contain low spindle speed to avoid premature tool fracture.

Thermal expansion is a consideration in multimaterial tools. Large differences in the coefficient of thermal expansion (CTE) between the pin and the shoulder material lead to either expansion of the shoulder relative to the pin or expansion of the pin relative to the shoulder. Both of these situations increase the stresses between the pin and the shoulder, thus leading to tool failure [2].

When the pin and shoulder are made of one type of material, while the tool shank is a different material, it needs to be considered again to avoid any wear and damage either to the tool or workpiece. One way to reduce this situation is with a thermal barrier designed to prevent heat removal from the tool into the shank. The tool used for the same welding process on mild steel is PCBN tools. The material is successfully used for the linear friction stir welding and most of the high melting temperature materials.

2.1.2 Published tool material

For many studies have been done on friction stir welding, but most of the papers do not specify the tool material or claim the tool materials are proprietary. Even though that the specific alloys are not cited, effort was made to include the class of tool materials used. The exception is tool steels but not the specific alloy. Table 2 below, summarize the current tool materials used to friction stir the indicated materials and thicknesses.

Table 2 Summary of current friction stir welding tool materials [2].

Alloy	Thickness		Tool material
	mm	in.	
Aluminium alloys	<12	<0.5	Tool steel, WC-Co
	<26	<1.02	MP159
Magnesium alloys	<6	<2.0	Tool steel, WC
Copper and copper alloys	<50	<2.0	Nickel alloys, PCBN(a), Tungsten alloys
	<11	<0.4	Tool steel
Titanium alloys	<6	<0.24	Tungsten alloys
Stainless steel	<6	<0.24	PCBN, tungsten alloys
Low-alloy steel	<10	<0.4	WC, PCBN
Nickel alloys	<6	<0.24	PCBN

(a) PCBN, polycrystalline cubic boron nitride

For many stir welding process, tool steel is the most common tool material used. This is because a majority of the published FSW literature is on aluminum alloys, which are easily friction stirred with tool steels. The benefits to use tool steel as friction stir tooling material are easy availability and machinability, low cost and established material characteristics. AISI H13 is a chromium-molybdenum hot-worked air-hardening steel and is known for good elevated-temperature strength, thermal fatigue resistance and wear resistance.

Based on a feasibility study of friction stir spot welding of advanced high-strength steels, the tool was made polycrystalline cubic boron nitride (PCBN), a material that has been successfully used for linear friction stir welding of steel and other high melting temperature materials. A single tool was used in this study. This single tool made over one hundred welds without any noticeable degradation or wear.

2.2 Friction Stir Welding

2.2.1 History of friction stir welding (FSW)

The earliest reference to the use of frictional heat for solid-phase welding and forming appeared over a century ago in a United States patent. A period of fifty years then passed before any significant advancement in friction technology took-place namely a British patent in 1941 that introduced what is now known as friction surfacing. Yet another fifty years went by before friction stir welding (FSW) was invented at The Welding Institute (TWI). This comparatively recent innovation has permitted friction technology to be used to produce continuous welded seams for plate fabrication, particularly in light alloys.

Although initially FSW was confined to relatively soft workpiece materials such as lead, zinc, magnesium and a range of aluminium alloy materials, the feasibility of joining copper, low carbon chromium steel, and carbon steel has been demonstrated. This range of harder workpiece materials has proved possible by continuing to maintain a suitable differential between the hardness and the elevated temperature properties of the tool compared with the workpiece materials.

Friction stir welding can be regarded as an autogenous keyhole joining technique without the creation of liquid metal. The consolidated weld material is thus free of typical fusion welding defects. No consumable filler material of profiled edge preparation is normally necessary. Already FSW is a practical technique for welding aluminium-based materials, ranging in plate thickness from 0.8mm to 75 mm and is in commercial production. Low distortion, cost effective, FSW joints are produced, with excellent mechanical properties being achieved in several aluminium alloys.

2.2.2 Friction stir welding principles

In principle, FSW could be applied for welding of all solid metallic materials. The practical restriction is primarily the integrity issue of the tool during FSW of high temperature materials. For example, during FSW of steels, the local operating temperature generated by both friction and deformation needs to be at 1100-1200 degree Celsius so that the workpiece material is sufficiently plasticized for stirring and welding [3].

In friction stir welding (FSW) a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. Frictional heat is generated between the wear resistant welding tool and the material of the workpieces. This heat causes the latter to soften without reaching the melting point and allows traversing of the tool along the weld line. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase bond between the two pieces. The process can be regarded as a solid phase keyhole welding technique since a hole to accommodate the probe is generated, then filled during the welding sequence [4]. The process of friction stir welding rotary is shown in the Figure 2.

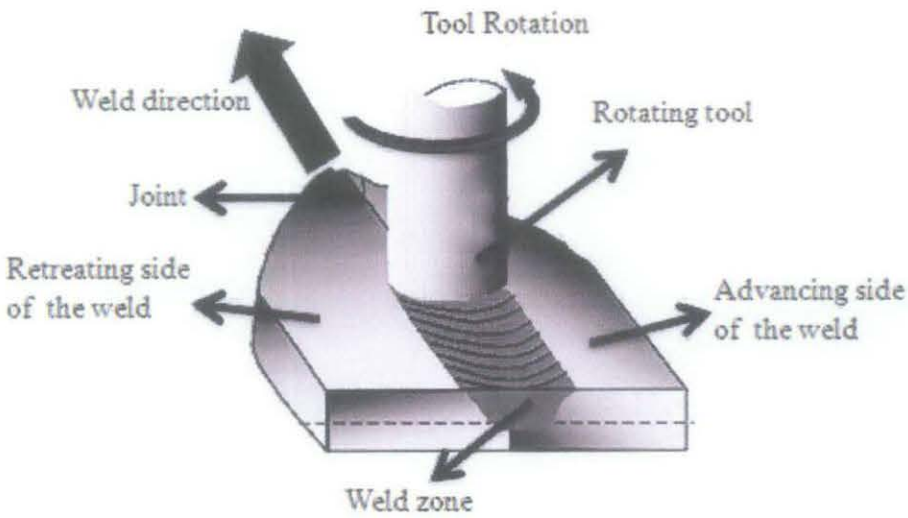


Figure 2: Friction stir welding rotary process [5]

2.2.3 Microstructural general analysis

The information regarding the microstructure analysis is based solely from aluminium alloys. However, this information has become the proof from work on other materials that the behaviour of aluminium alloys is not typical of most metallic materials thus the scheme cannot be broadened to encompass all materials.

Figure 3 shows the microstructural regions in which welds aluminium are divided into four regions as below:

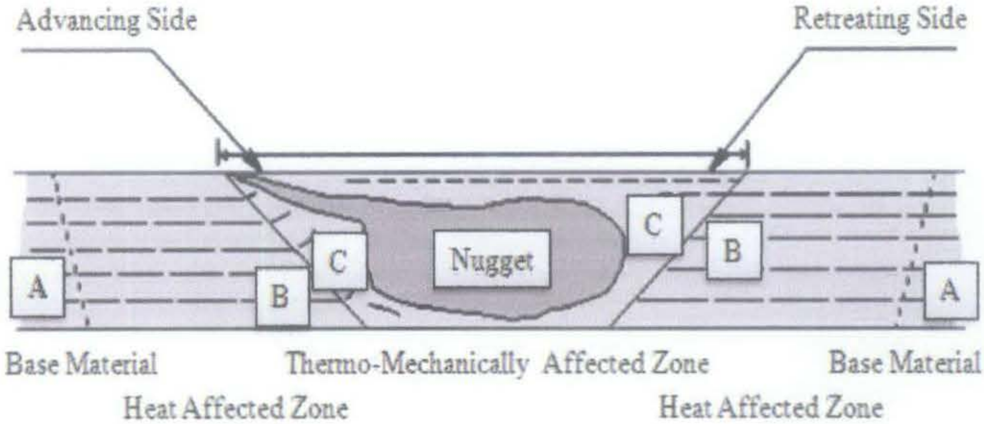
A. Unaffected material

B. Heat affected zone (HAZ)

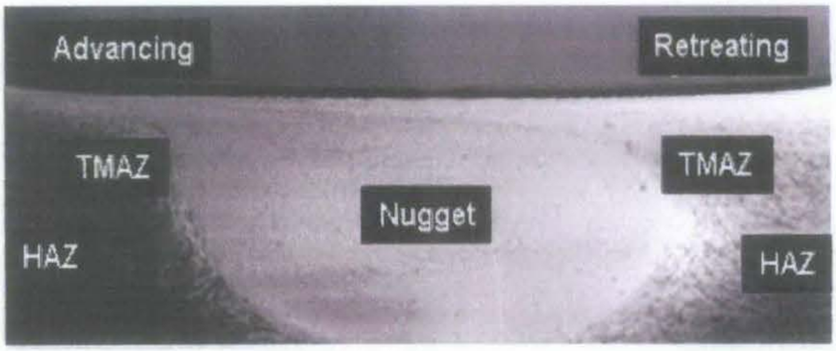
C. Thermo-mechanically affected zone (TMAZ)

D. Weld nugget (Part of thermo-mechanically affected zone)

In the heat affected zone, properties and microstructure are affected by the heat from the weld even though mechanical deformation is not there. The grain structures are kept the same with the base material. On the other hand, the thermo-mechanically affected zone shows characteristics is due to the recrystallization did not happen in the zone because of not enough deformation strain. In weld nugget, intense plastic deformation and frictional heating during FSW result in recrystallized fine-grained microstructure. [6]



(a)



(b)

Figure 3: (a) Schematic diagram of microstructural zones in friction stir welds in aluminum (b) micrograph showing various micro-structural zones [6]

2.3 Friction Stir Spot Welding (FSSW)

2.3.1 Background of the friction stir spot welding

Friction Stir Spot Welding (FSSW) is the derivative from friction stir welding (FSW). It has become the most efficient joining process in automotive and transportation industry such as trains, airplanes and boats. In particular, it is extensively used to fasten sheet steels for automotive applications. The strength of the structures is dependent on the strength of the spot weld itself.

The process is applied to a lap joint consisting of upper and lower sheets. A rotating tool with a probe is plunged into the material from the top surface for a certain time to generate frictional heat. At the same time, a backing plate contacts the lower sheet from the bottom side to support the downward force. Heated and softened material and softened material adjacent to the tool causes a plastic flow. In addition, the tool shoulder gives a strong compressive force to the material. After the tool is drawn away from the material, a solid-phase bond is made between the upper and lower sheets. [4]

The upper surface of the weld looks like a button with a hole, and the bottom surface is kept almost flat. The illustration can be seen in Figure 4 below. In the cross section, there is a hole that is made by the probe and reaches into the lower sheet. In general, strength is higher at higher revolutions per minute and shorter weld time.

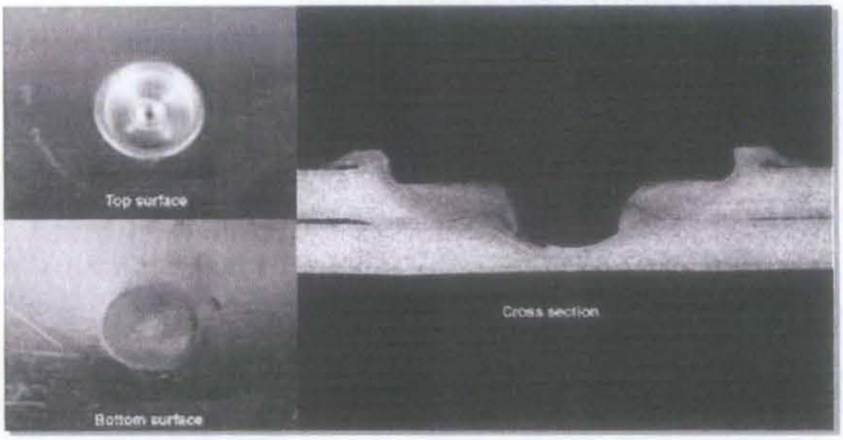


Figure 4: Spot friction stir welding appearance and cross section [5]

There are few fatigue tests of spot welds in automotive steels several specimens of sizes have been carried out by researchers. Those studies were conducted with tensile-shear and peel-tension specimen geometries. There are not so many of studies done on the cross-tension geometry. Prior to that, a present study [7] on the tensile and fatigue tests were conducted on cross-tension specimens of cold mild steel alloy sheet. The specimen is varied according different welding currents and times. Also, the parameters for estimating the fatigue life of cross-tension specimens are being looking for.

There are few ways to vary the parameters to see the relationship between the parameters with the spot weld joint. The rotational speed for the time of spot weld process is being constant while the maximum displacement of the tool, the penetration depth can be differed to produce several weld joints. This relationship of parameters is demonstrated in the Figure 5 below. As being shown, the displacement increases linearly from time, t_0 until it reaches the maximum displacement at time, t_1. The normal force generally increases with the increase of displacement. [1]

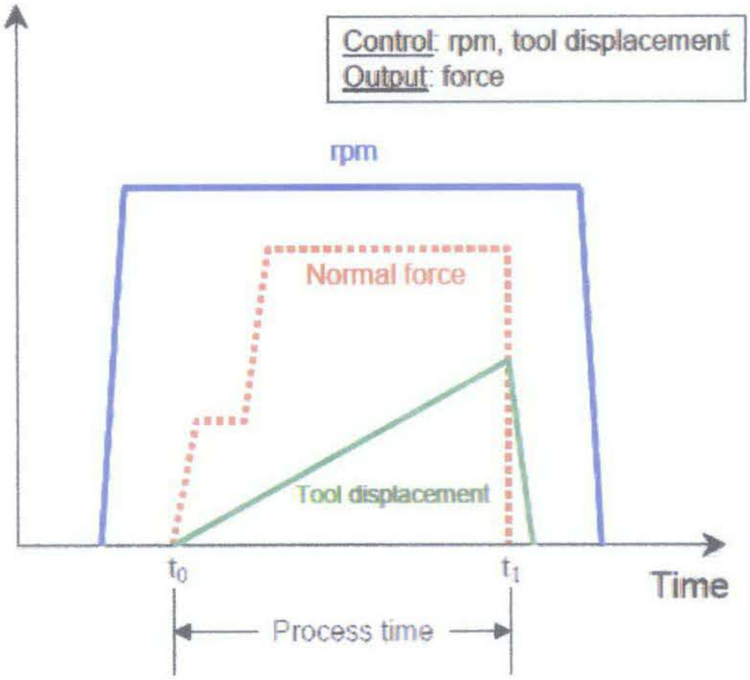


Figure 5: A schematic plot of the process parameters (rpm, normal force, and tool displacement) as a function of time. [8]

2.3.2 Friction stir spot welding principles

The process is applied to join two thin metal sheets. A rotating tool with a probe pin plunges into the upper sheet and a backing plate beneath the lower sheet supports the downward force. The rotational speed is maintained for an appropriate time to generate frictional heat. Then, heated and softened material adjacent to the tool deforms plastically, and a solid state bond is made between the surfaces of the upper and lower sheets. The rotating tool with a probe pin is introduced into the two blanks to be joined, supported by a proper backplate.

First, the tool is positioned perpendicular to the work surface, and it starts to rotate. Next, the tool is pushed against the surface of the top sheet. Friction heats the materials, and the pin enters the softened metal. After the pin has plunged completely into the workpiece, the tool continues to spin and apply pressure for a set length of time. Lastly, the materials around the pin are stirred together, and the lapped plates are metallurgically unified. At that point, the tool is extracted from the sheets.

2.3.3 Material Selection

- Tool material

Applications for FSSW include substitution for rivets and resistance spot welding and the elimination of fixturing by tacking parts prior to FSW. There are two different FSSW methods: one that retains the exit hole produced by the FSSW tool, sometimes referred to as "poke or plunge" FSSW, and the other one that fills in the exit hole, known as "filled" FSSW. The filled method requires three main parts which are pin, shoulder and outside retaining clamp. Poke or plunge spot welds are produced by plunging and retracting the FSSW tool. Due to the simple control and implementation, this type of FSSW has seen more research than the filled exit hole. Based on previous study on FSW, tool steel material is the normal type of material used for the process. More detail about tool material is being discussed under the friction stir welding tool.

- FSSW workpiece

There is no experimental study have been done to the copper alloy thin plate material. Most of FSSW study is focusing to aluminium material. The Al 6061-T6 has higher apparent viscosity than other aluminium alloy which then increases the stir zone width. The stir zone width also is large when applying the plunge testing.

2.3.4 FSSW Process Parameters

- Tool rotational speed

According the study of an experimental study on microstructure of friction stir spot weld, the process starts with 1500 rpm and it increased to 3000 RPM. The energy resulting from tool rotation do not increases when higher rotational speed setting are applied since lower torque values are produced during friction stir spot welding.

- Penetration depths

The result indicated form the Microstructures and Failure Mechanisms of Spot Friction

Welds in Lap-Shear Specimens of Aluminum 5754 Sheets [1] in order to understand the effect of tool penetration depth on the joint strength is that the concave tool produced slightly stronger than the flat tool. The joint strength did not change for the two depths for the flat tool whereas the joint strength slightly increases as the penetration depth increase. The penetration depth can be varied to produce different welds. In this experiment, the penetration depth is increased from 1.85mm to 1.95mm.

- Dwell time

The tool shoulder will be contacted with the upper surface of the copper alloy thin plates during the friction stir spot welding cycle. It would therefore be expected that much of the energy generated during the spot welding operation will start from the rotating pin as it penetrates into the contacting sheets. The two overlapped copper alloy thin plates are produced as the tool shoulder remains in contact with stir zone material for almost the entire welding operation. Then, the tool shoulder would have their influence on energy generation during long weld the overlapped thin plates.

2.3.5 Microstructural specification

The solid-phase nature of FSSW process, using the tool will give a characteristic microstructures profile. The FSSW areas that will be affected are:

1. Stir zone – this part (part of thermo-mechanically affected zone) is a zone where the material is strongly deformed when the pin of the tool plunge into the material during welding process.

2. Thermo-mechanically affected zone – occurs on either side of the stir zone. In this region the strain and temperature are lower and the effect of the welding on the microstructure is smaller.

The cross section of affected regions by the frictions stir spot welding generally can be seen in Figure 6.

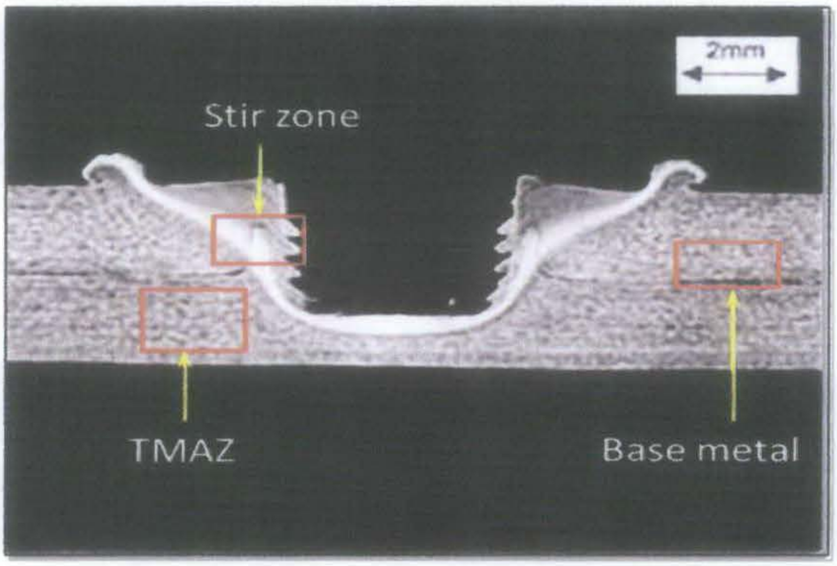


Figure 6: Cross section of spot welded zone [5]

When the tool is rotating and plunging into the upper and lower sheet, the material of Aluminum 6061-T6 from the experiment of microstructure and failure mechanism of friction stir spot welding [16] under the tool shoulder near the probe pin is stirred. Outside the stir zone, the interfacial surface of the upper and lower sheets is distorted into a macroscopic curved interface as shown in region IV in Figure 7(a) below. Due to the compression of pin probe onto the sheet, the thickness of the upper sheet material decreases. In Figure 7(b), a micrograph of the base metal shows relatively coarse grain. A close-up view of region I indicates that the microstructure has less coarse grain in the heat affecting zone (HAZ) than in the base metal (BM). Region II shows finer and fuzzy grains in the thermo-mechanically affecting zone (TMAZ). While for the region III and IV, show very fine equiaxed grains in the stir zone. This is highly because of the stirring process and recystrallization. The curved interface of the close-up view of region IV becomes vague and disappears close to the stir zone. Material in the center of stir zone is hot worked during welding due to interactions with the tool.

It is been said [9] that the microstructural evidence indicates peak temperatures reached well into the austenite phase field, allowing appreciable grain growth. The microstructure of the stir zone was characterized by the presence of ferrite with aligned and nonaligned second phase, grain boundary ferrite and a ferrite/carbide aggregate which appears to be fine pearlite. Because of the increment distance from the centerline, the heat affected zone demonstrated a grain-coarsened area around the stir zone.

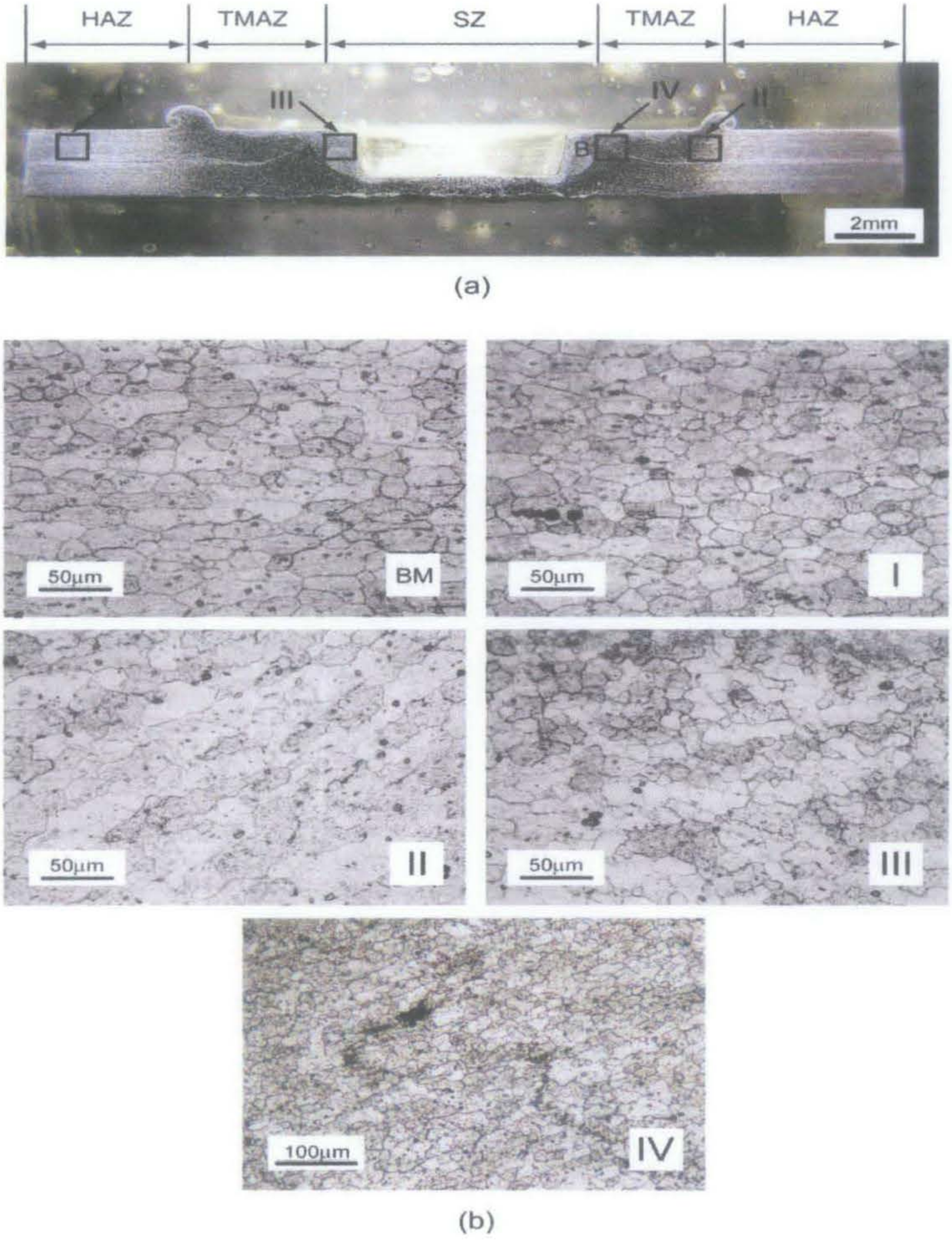


Figure 7: (a) A micrograph of the cross section of a friction stir spot weld made by the tool, (b) Close-up views of regions I, II, III and IV. [5]

2.3.6 Failure mode

From the previous paper [1], microstructures and failure mechanisms of friction stir spot welds in aluminum 6061-T6 lap-shear specimens were investigated based on experimental observations. A tool with a flat tool shoulder and a cone-shaped probe pin was used. After that, the results of microstructures for friction stir spot welds are then presented. Then, it was discussed about the failure mode and failure mechanism for these friction stir spot welds. A study of the processing parameters of holding time and constant downward force was carried out in order to obtain the friction stir spot welds of the lap-shear specimens failed in the circumferential failure mode under tensile tests.

Fig. 8 shows a failed lap-shear friction stir spot weld specimen and close-up views of the friction stir spot weld in the failed lap-shear specimen. The circumferential failure mode or the nugget pullout failure mode can be seen on the lower sheet of the failed specimen in Figure 8(a). Figure 8(b) shows a top view of the failed friction stir spot weld. The hole diameter of the failure is almost the same as the diameter of tool shoulder. Figure 8(c) shows a top view of a friction stir spot weld on the lower sheet of 8 the failed specimen. From the Figures 8(a) and 8(c), a small portion near the left hand side of the remaining weld nugget is removed possibly due to tearing and rubbing of the upper sheet. Figures 8(a) and 8(c) show clearly the failure occurs very close to the outer circumference of the shoulder indentation.

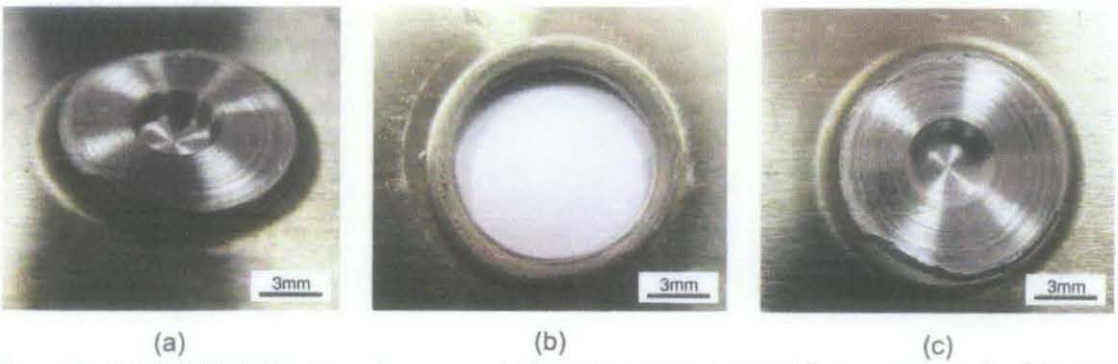


Figure 8: (a) A failed friction stir spot weld lap-shear specimen, (b) a top view of a friction stir spot weld on the upper sheet of the failed specimen, (c) a top view of a friction stir spot weld on the lower sheet of the failed specimen. [5]

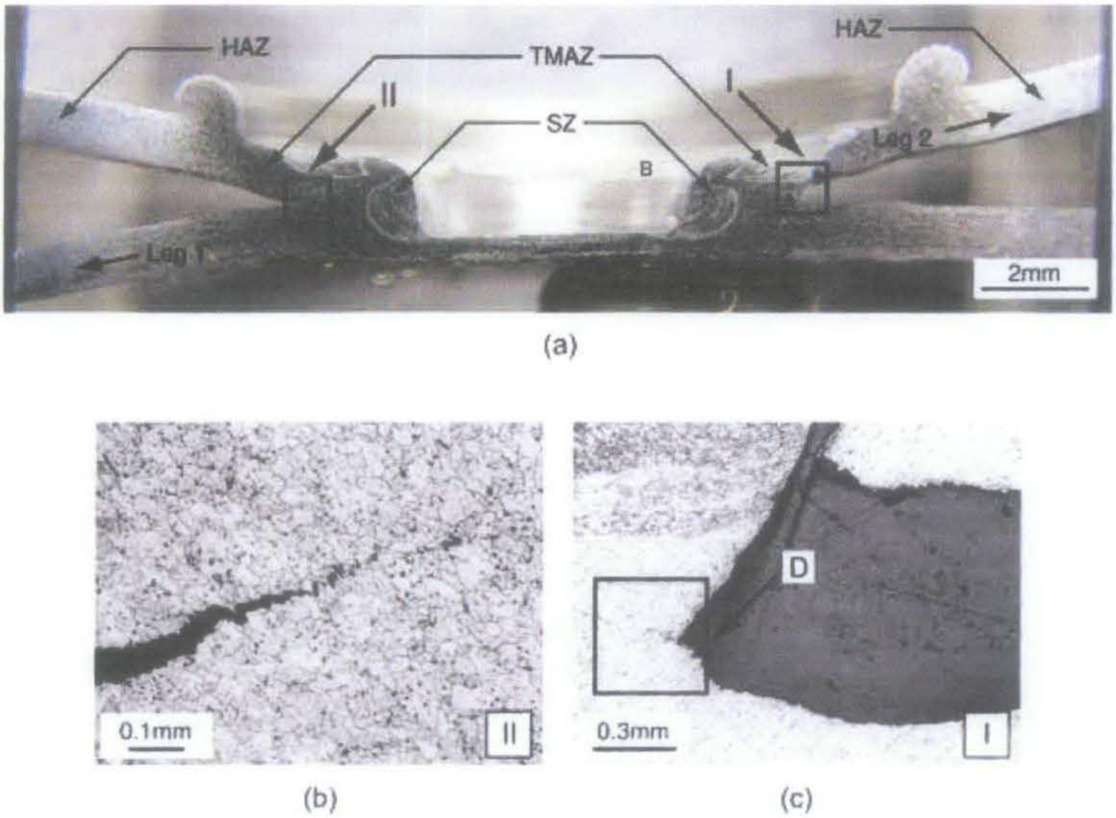


Figure 9: (a) Micrograph of the cross section of a friction stir spot weld in a failed lap-shear specimen, (b) a close-up view of region II, (c) a close-up view of region I. [5]

Figure 9 shows cross sectional view and close-up views of a friction stir spot weld in a failed lap-shear sample. The HAZ, the TMAZ, and the SZ areas are also shown indicated in Fig. 9(a). Figure 9(b) and Figure 9(c) are the close-up views of respected areas which are marked in the Figure 9(a). The failure of the friction stir spot weld in the lap-shear specimen may be initiated in the upper sheet near the middle part of the nugget, marked as point A and then propagates along the nugget circumference, marked as point B. [1] It is being said that the curved crack growth at the TMAZ area near point A is because of the asymmetrical weld nugget geometry and inhomogeneous material properties in the TMAZ.

2.4 Effect of Welding Parameters on Strength

Strength measurements of the welded zone area will be performed to reveal possible changes due to the change of microstructural profile of the material. The strength of FSSW process to the material will be compared based on the variable of the experiment which is the tool rotational speed. This experiment is to determine the effect of tool rotational speed to the strength of material that had been going through the process. The middle of both the top and the bottom sheets will be tested throughout the cross section. The samples were tested by using the universal testing machine. The sample will be tightly clamped at both end and a certain amount of load was applied to the sample and the maximum of load the sample can withstand will indicate the tensile strength of the joint after the pulling mechanism to determine its tensile strength. The machine used is as in the Figure 10.

Figure 10: Universal Testing Machine for Tensile Strength Test

Tensile strength testing involves taking a small sample with a fixed cross-section area, and then pulling it with a controlled, gradually increasing force until the sample breaks. The effect of welding parameters on mechanical properties of welded joints can be investigated using tensile shear test.

Every weld condition was tested in unguided lap shear showing only small deviations in strength, joined area and associated energy for samples with like parameters [10]. Different welding properties will led to a variance of joint properties with lap shear tensile strength. Among the parameter that associate to the variance of tensile strength are tool rotational speed, plunge rate and dwell time. Penetration depth is one of the biggest factors that affect the weld joint bonding area and strength. With the increasing of dwell time, it increases the lap shear strength. However, the tensile strength which affected by the welding parameter also should be considered for different type of tool and workpiece and also the plunging condition.

There is a comprehensive review article [11] discussing about the joining technology where the process parameter development and many kind of processes are used to join various type of material which not only limited to one type of joining material but also dissimilar metals such as steel to steel, steel to aluminum, and aluminum to magnesium. The strength is shown to be relied on the parameters mentioned above. With the increasing of processing time, the tool depth of penetration and the shear strength for 1.00 mm thickness of aluminum alloys will increase also [12]. On the other hand, the tool rotation speed also affect the joint strength, strain rate and temperature distribution.

Average of tensile properties of a study on FSW of mild steel [9] is given in the table below:

Table 3 Room Temperature Tensile Properties [9]

Material	Base metal	Friction Stir Weld (transverse orientation)
Yield strength	310 Mpa	331 Mpa
Tensile strength	463 Mpa	476 Mpa
Elongation to failure	40%	22%
Reduction in area	22%	31%

From the table, we can see that the welded joint samples failed compared to the base metal in regions of corresponding and it shows the comparison of yield and tensile strengths. This result specifies that the stir zone and heat affected zone have higher yield and tensile strengths than the parents metal.

CHAPTER 3

METHODOLOGY / PROJECT WORK

Figure 11 shows the flow chart of this project:

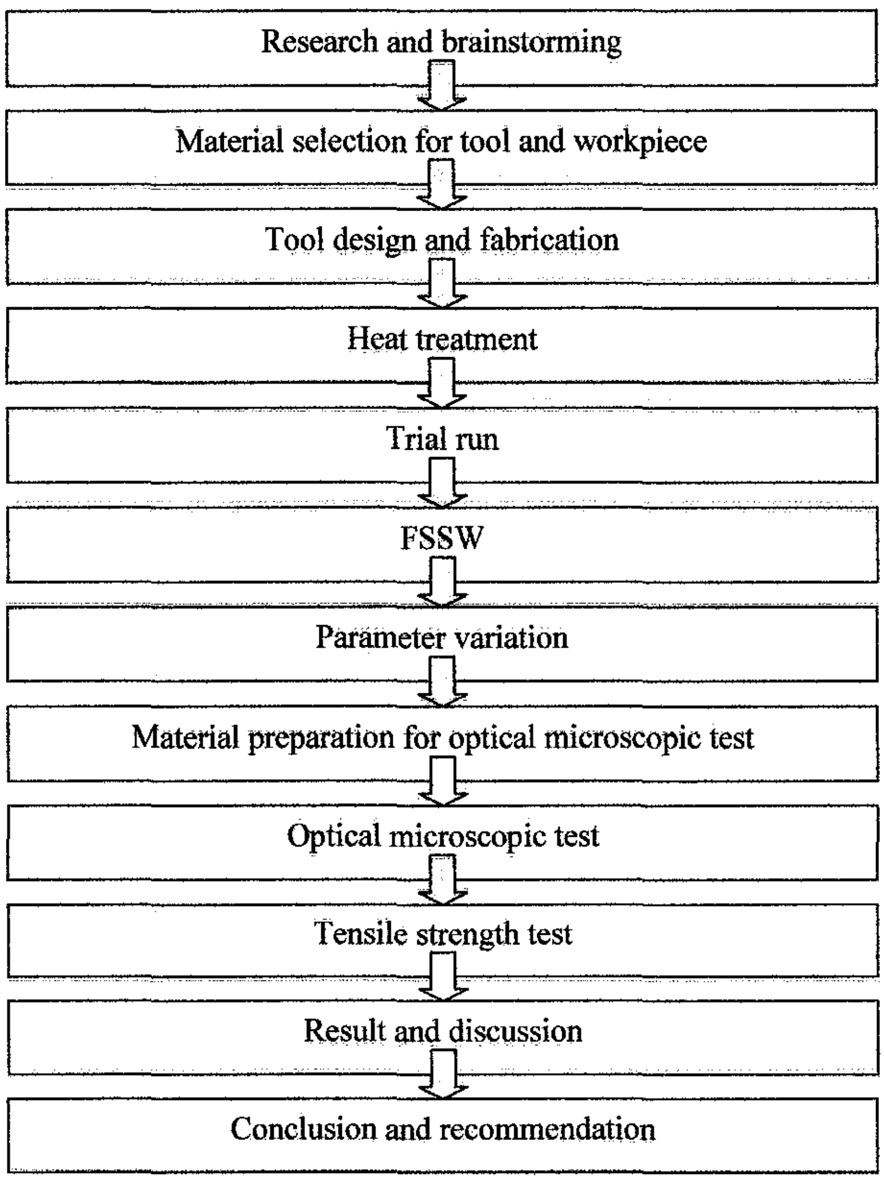


Figure 11: Flow chart of the methodology of the project for Friction Stir Spot Weld of copper alloy plate

3.1 Material selection

For the trial run process, the material chosen for the tool is AISI H13 which according to the previous study, the tool steel can withstand high temperature during welding process. Also, the studies proved that the maximum temperature during FSSW is estimated at 460°C for the Aluminum alloy 6061-T6 [4]. While for the thermal conductivity is higher at higher temperature. Further to that, it can conduct sufficient heat to the workpiece to get good joints. The material of the tool steel which is AISI H13 was purchased from the nearest hardware shop in Ipoh.

The properties and composition of tool steel H13 are shown in the tables below:

Table 4 Composition of H13 tool steel based on the specification given by the supplier

Element	Composition (%)
C	0.393
Mn	0.34
Si	1.03
Cr	5.02
Mo	1.27
V	0.94
P	0.023
S	0.001

Table 5 Properties condition of H13 tool steel at 25°C [1]

Element	Composition (%)
Treatment density (x1000kg/m□)	7.76
Poisson's Ratio	0.27-0.30
Elastic Modulus (Gpa)	190-210

A comprehensive published article [12], mentioned that process parameter development and variations of the process used to join not only aluminum alloys, but also dissimilar metals such as steel to steel, steel to aluminum, and aluminum to magnesium. Copper alloy material was chosen to be the workpiece for this process. Previous study of FSSW in Universiti Teknologi Petronas was done on Aluminum alloy 6061-T6 [13]. From this experiment, a study on microstructure on Copper alloy-Copper alloy, Copper alloy-

Aluminum alloy and Aluminum alloy will be done. Below is the comparison table of mechanical properties for Copper alloy, Magnesium alloy and Aluminum alloy [15].

Table 6 Comparison table of mechanical properties

Material	Yield strength (Mpa)	Tensile strength (Mpa)	Thermal conductivity (W/m-K)
Aluminum alloy 6061-T6	276	310	180
Copper alloy	125	340	115
Magnesium alloy	220	290	96

The Copper alloy sheet is not available in UTP, thus it need to be purchased from the nearest hardware shop. The material also had gone the FE SEM process to determine the composition of the material. Figure 12 shows the level of elements in Copper alloy sheet. Table 6 below is the table about the element contained in the Copper alloy sheet:

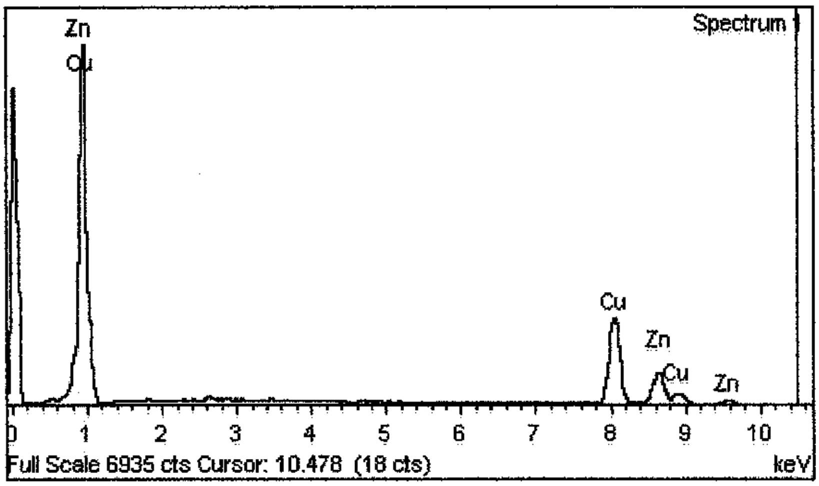


Figure 12: Level of element in Copper alloy sheet

Table 7 Element in Copper alloy sheet

Element	Weight (%)	Atomic (%)
Cu	67.39	68.01
Zn	32.61	31.99

3.2 Designing the tool steel

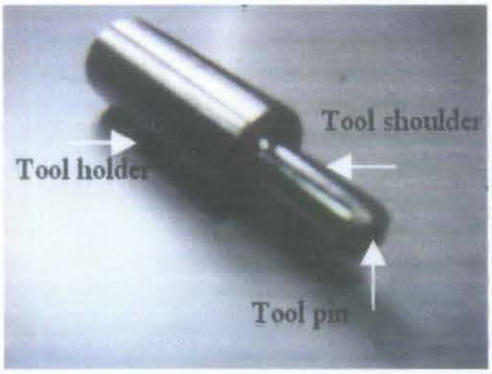


Figure 13: Profiles of Friction Stir Spot Welding (FSSW) tool

There were three main parts when designing the tool of FSSW that must be formed based on their function to the stir spot weld. Figure 13 is the profiles of FSSW H13 tool steel. Those three main parts function are as Table 6:

Table 8 Function of profiles on FSSW tool

Tool profiles	Function
Tool pin	Primary tool part that will exerted higher force to joint the two sheet of 2 mm sheets of copper alloy plate
Tool shoulder	Its surface will give more stirring effects to the weld joints and distribute force to the weld areas.
Tool holder	Must accommodate the minimum tool holder of CNC Bridgeport machine

Please refer to Appendix 1 for detail of the tool design

3.3 Fabrication of the tool steel

Thickness of the copper alloy plate is constant of 0.9 mm thick. When two pieces of copper alloy plate is combined, it will become 1.8 mm thick. The tool steel H13 was fabricated using the Bridgeport CNC machine with the specified dimensions as shown in Table 8 below.

Table 9 Dimensions of fabricated FSSW tool

Dimensions	Fabricated tool measurement (mm)
Length of tool	95.0
Diameter of tool pin	3.0
Diameter of tool shoulder	10.0
Diameter of tool holder	15.0

Next, it has undergone the heat treatment process as recommended to the tool steel because of its higher melting point. Figure 14 below shows the result of tool steel after the fabrication and heat treatment process.

Figure 14: Tool steel of FSSW process

3.4 Heat treatment

After the production of FSSW tool, it undergoes through the heat treatment process. The process is including the heating and cooling process for the purpose of surface hardening. Localized surface hardening can also be achieved in medium and high-carbon steels and some cast iron by rapid local heating and quenching. This heat treatment process is important for the tool because the heating and cooling process often occur during other manufacturing processes so that the tool is hardened enough to go through the welding process. The steps for heat treatment are:

1. The welding tool will be inserted in the Tube Furnace and preheated initially for 2 hours to raise the temperature from 0-1350°F [-17.78-732°C].
2. Next, the tool will be preheated continuously for 2 more hours; 1350-1400°F [732-760°C].
3. Then, the temperature will be raised to almost 1000 degree Celsius for 1 hour; 1800°F [1000°C].

4. Finally, it needs to go the cooling process for 2 hours at the room temperature; 75°F [24°C].

3.5 Plunge Test- Trial run and FSSW

The trial test of FSSW plunge test was conducted using CNC Bridge Port Machine to identify the key parameters of FSSW such as the rotational speed, plunge rate, plunge depth and the best dwell time to produce successful welding product. The thickness of the copper alloy plate is 0.9 mm. Hence, the two connected plate will be 1.8 mm in thickness at the joint plate.

The main important thing before conducting the FSSW process is a fixed and high strength of support in doing the welding process. Thus, the best clamping method must be determined to ensure that it can withstand high load of tool rotation and high speed during the process.

There are total of 3 sheets of Copper alloy thin plate. Two sheets are for joining and another one is used as a support for the upper joints. All the sheets are tightened with 8mm screw and closed by nuts below the support. The backplate support is used as the base to be clamped in the Bridgeport Machine. Other than that, two thick Aluminum plates are being used at both up and down side of the joints to support it from slipping. During the plunging process, the end of the 165 mm x 35 mm Copper alloy sheet slanting upward and affect the result of spot welding. As the solution to it, another Aluminum plate of 2 mm thickness is used to cover the end of the sheet.

After that, the workpiece is placed inside the Bridgeport Machine and the parameter is set up. The process is started with 2000 rpm, 50 mm/min for the move feed rate and the plunge depth is 1.6 mm thickness. Before plunging the tool, a point needs to be marked so that it would be easy to point the tool steel when it moved until it touched the center of the workpiece to perform the FSSW p€11121 All the parameters are being keyed in to the machine. Figure 15 shows the inside base to\ place the jig before the process start.

Figure 15: Before the FSSW process start

For this experiment, the tool rotational speed was varied with 2000, 3000 and 4000 rpm. The details for other parameters are recorded in the Table 9 below:

Table 10 Parameters for FSSW

Material	Tool rotational speed (rpm)	Feed rate (mm/min)	Plunge depth (mm)	Dwell time (s)
Copper alloy-Copper alloy	2000	50	1.7	7.0
Copper alloy-Copper alloy	3000	50	1.7	7.0
Copper alloy-Copper alloy	4000	50	1.7	7.0
Aluminum alloy-Aluminum alloy	2000	50	1.7	7.0
Aluminum alloy-Aluminum alloy	3000	50	1.7	7.0
Aluminum alloy-Aluminum alloy	4000	50	1.7	7.0
Copper alloy-Aluminum alloy	2000	50	1.7	7.0
Copper alloy-Aluminum alloy	3000	50	1.7	7.0
Copper alloy-Aluminum alloy	4000	50	1.7	7.0

3.6 Microstructure Experiment

After the FSSW, next process is to see the microstructure of stir zone, TMAZ and base metal. Before that, a few preparations need to be done to the workpiece. The process is shown in the Figure 16 below:

Figure 16: Chart of process before microstructure experiment

Sectioning is the cutting process of the weld joint area to make a cross-sectional square. It was done by using hand saw and cutting machine. The size for the cross-sectional area is 30 mm x 1.8 mm thickness of both specimens. As for the Aluminum alloy, it is easy to cut into the shape. However, the Copper alloy specimen is a bit ductile than Aluminum alloy and the result of cross-sectional area is not in shape. After that, the specimens were encapsulated in plastic resin using the Compression Mounting machine to ease the next process of grinding the specimen. Other than that, because of the specimen thickness is small, an adhesive paper material were being used to support the specimen stood on the mounting plate. The process of mounting is as follow:

1. Pressurizing at 4200psi
2. pre-heating up to 160°C
3. Quenching and cooling below 30°C

Grinding is the process to flatten damaged cut surface caused by cutting process by using hand saw. Because of the adhesive paper used to support the specimen, it left the round-mounted specimen with the irregular particle surface. By grinding process, it is able to remove the foreign particle on the specimens' surface. Grinding process was done on Silicon abrasive paper. There are few abrasive papers available with different grid. The grinding process started with 60 grit and followed by 120, 240, 280, 320, 400, 600, 800, 1200 and 4000 grit. The bigger the grit number, the smoothest surface of the specimen will be.

After grinding process is done, the specimens were polished to get the scratch-free surface. This is needed in able to see the microstructure under optical microscopic. The polishing procedures started by applying the diamond paste onto the specimen and were rubbed on a napped cloth which attached to the grind wheel. Figure 17 is the result after the mounting process encapsulated in plastic resin.

Figure 17: FSSW of Copper alloy-aluminum alloy

Etching is the last procedure before the microstructure testing. The advantage of doing the etching process is to reveal the presence of flaws or other discontinuities in the weld zone. For Copper alloy specimen, the etchant used is the aqueous ferric chloride while for Aluminum alloy, Keller's etchant was used until the grain structures were clearly visible. Before the etchants were applied to the specimen, the specimen had to be washed first using the distilled water and followed by methanol to make sure that no water component will be seen under the optical microscopic. The specimen had to wait for few seconds before it was washed again by distilled water and methanol. Then, it will be dried at the dryer.

Optical microscopic test could be done at lab Building 17, UTP using the available optical microscope. However, good specimen is required for the microstructure to be seen under optical microscope. If there is any scratch, then the microstructure cannot be viewed. Also, if the specimen is not well polished or not well etched, the process needed to be repeated because it will give problem to view the microstructure. The specimen might be grinded, polished and etched several times to get a smooth surface and good result of microstructure view. Figure 18 is the optical microscope used to view the microstructure of the specimens.

Figure 18: Optical microscope

3.7 Tensile Strength Test

Tensile strength (TS) is the maximum stress that a material can withstand while being stretched or pulled before necking which is when the specimen's start to break. The tensile strength for spot weld joint of few sample were measured. The tensile strength tests were performed according to ASTM E8-00b Standard Test Methods for Tension Testing of Metallic Materials. However, the feed rate for tensile strength test should be started at the lowest speed rate possible to prevent any damage before the test. For this test, the feed rate used is 0.1 mm/min. Because the values of tensile strength for samples are unknown, the clamping process should be handled with care to avoid damage to the sample.

Samples from each combination of workpiece were taken for the tensile strength test. Machine used for tensile strength test is Universal Testing Machine which is available at Building 17. Parameters used for the tensile strength were constant for each sample with limit of load is 50 kN and the limit for stretching or pulling length is 100 mm.

CHAPTER 4

RESULTS AND DISCUSSION

Figure 19, 20 and 21 below show the results of spot weld joint from the Friction Stir Spot Welding (FSSW). For this experiment, three different combinations of materials were being used. For each of the combination, the tool rotational speeds also were varied started from 2000, 3000 and 4000 rpm.

Figure 19: Lap-shear spot friction weld specimen of Aluminum 6061-T6 with 4000 rpm

Figure 20: Lap-shear spot friction weld specimen of copper alloy with 4000 rpm

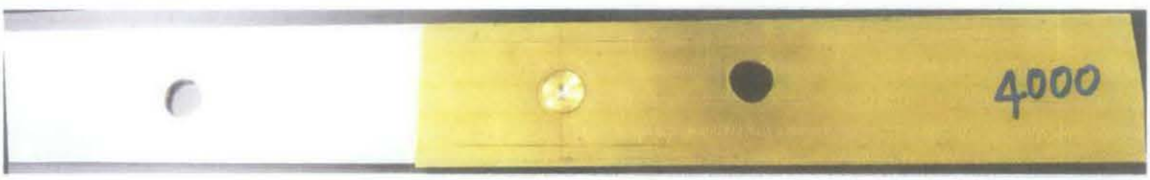


Figure 21: Lap-shear spot friction weld specimen of copper alloy and Aluminum 6061-T6 with 4000 rpm

There were two main parts of the spot weld joint results. First is the area affected by the tool shoulder and the other one is the area affected by the tool pin. The diameter for the area affected by the tool shoulder is 10 mm and the diameter of area produced by the tool pin is 3mm. Figure 22 shows the top spot weld joint of friction stir spot welding of aluminum alloy to aluminum alloy with tool rotational speed of 4000 rpm. Figure 23 is the close-up top view of friction stir spot weld joint of copper alloy sheet to copper alloy sheet. Result of weld joint of friction stir spot welding of copper alloy to aluminum alloy with the upper sheet is the copper alloy sheet is shown in Figure 24. After going through the plunging test with 1.7 mm penetration depth, the thickness reduced. Even though with 1.7 mm of penetration depth, the final thickness still less than the penetration depth value. This is due to short time during the dwell time after the plunging stage. For the next experiment on copper alloy, to get a good spot weld joint, make sure that the dwell time is a bit longer so that the material able to soften before forming the joint.

Figure 25 (a), (b) and (c) are the results of friction stir spot weld process onto the copper alloy to copper alloy sheet with tool rotational speed 2000, 3000 and 4000 rpm respectively

Figure 22: Close-up top view of spot friction weld on the upper sheet of aluminium-aluminium with 4000 rpm tool rotational speed

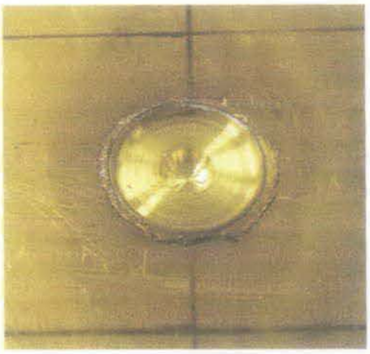
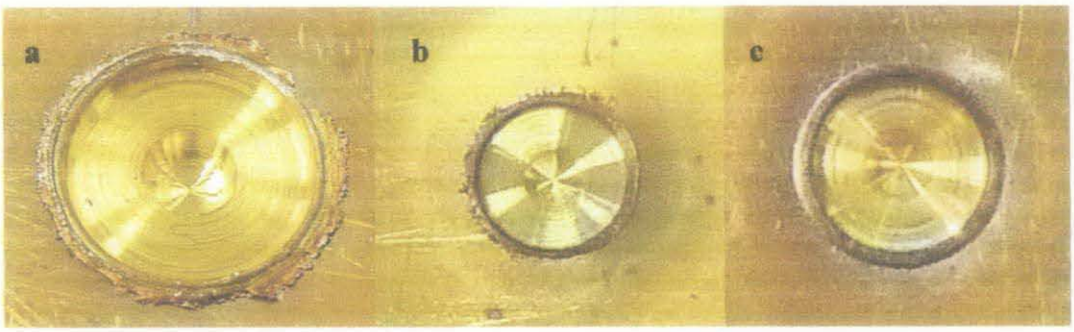


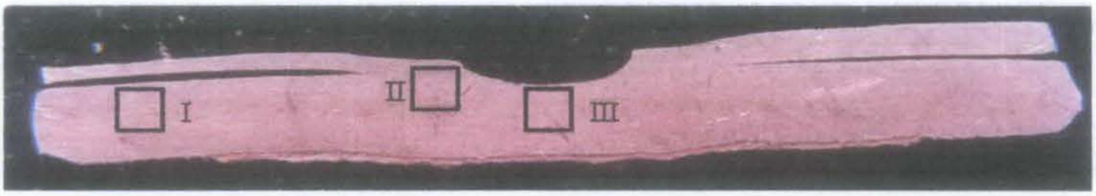
Figure 23: Close-up top view of spot friction weld on the upper sheet of copper-aluminium with 4000 rpm tool rotational speed

Figure 24: Close-up top view of spot friction weld on the upper sheet of copper alloy-copper alloy with 4000 rpm tool rotational speed



. Figure 25: (a) Spot weld joint of copper alloy to copper alloy with 2000 rpm (b) Spot weld joint of copper alloy to copper alloy with 3000 rpm (c) Spot weld joint of copper alloy to copper alloy with 4000 rpm

Figure 26(a) below shows the cross-sectional view of weld region formed by Friction Stir Spot Welding of Aluminum alloy-Aluminum alloy. The regions affected by the process are divided into three sections. Region I is the base metal, region II is the thermo-mechanically affected zone and Region III is the stir zone region which is caused by the tool tip stirring process during plunging. Figure 26(b) shows close-up views of region I as marked in Figure 26(a). Region I is the base metal while mark II is the region affected by the tool shoulder (TMAZ). Mark III is the region affected by tool pin which is the stir zone area where the upper and lower sheets are bonded is represented in the Figure 26(c).



(a)

(b) (c) (d)

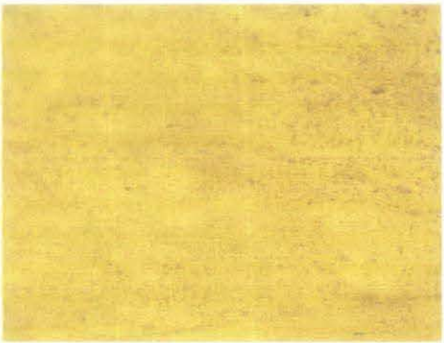
Figure 26: (a) Cross-sectional of FSSW on Aluminum alloy-Aluminum alloy (b) Micrograph view of base metal region at region I (c) Micrograph view of base TMAZ at region II (d) Micrograph view of stir Zone at region III

Figure 26(b) is the base metal which is not affected by the friction stir spot welding. The micrograph view of base metal shows very coarse grain with lots of small pores. The porosity may because of the oxide stringers that may be interrupted during the manufacturing process of Aluminum alloy 6061 T6.

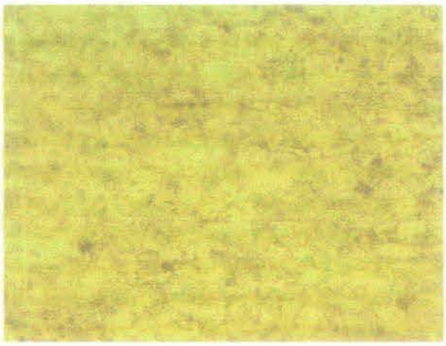
For figure 26(C), it is taken at the whereby the alloy affected by the tool shoulder; thermo-mechanically affected zone. The micrograph view of this region shows coarse grains with small pores but less than the base metal. This may happen due to force from the tool shoulder. The micrograph view of this region shows finer grains. These may happen because the higher force from the stirring tool pin gives more compaction to the grains. Figure 26(d) shows the affected area by tool pin. This region shows a very fine grain region full of metallurgical bond. The equiaxed grains in the stir zone are formed due to stirring and recrystallization process.

Figure 27(a) is the cross-sectional view of weld region formed by Friction Stir Spot Welding of Copper alloy-Aluminum alloy. The pressure given by the tool tip during the plunging process reduced the 2 mm joint of thickness to 1 mm. The regions affected by the process also are divided into three sections same as the previous aluminum alloy to aluminum alloy spot weld joint. Region I is the base metal. Figure 27(b) illustrates the micrograph of copper alloy base metal which is not affected by the stir process. Figure 27(c) with mark II is the micrograph of region affected by the tool shoulder (TMAZ). For figure 27(d) with mark III is the region affected by tool pin which is the stir zone area where the upper and lower sheets are bonded. The surface of the joined sheets after gone through the grinding and polishing process is not smooth because wrong tool were used during cutting the workpiece.

(a)



(b) (c)



(d)

Figure 27: (a) Cross-sectional view of weld region formed by Friction Stir Spot Welding of Copper Alloy-Aluminum 6061-T6 (b) Micrograph view of base metal region at region I (c) Micrograph view of base TMAZ at region II (d) Micrograph view of stir Zone at region III

However, the study on microstructural view of the welded joint area cannot be done properly because of the view. To get a good view of microstructure, a few procedure of preparing the sample need to be done. Grinding, polishing, and etching need to be repeated several times. Due to constraint of time, the microstructural study is very limited. A few ways to solve this problem are being discussed in the recommendation.

A few samples with different tool rotational speed were used to study the effect of each parameter on properties of welded joints. However, due to some problem while conducting the testing, only one sample from each combination of workpiece. The results for the tensile strength test were recorded in the Table 10 below:

Table 11 Results of tensile strength test of FSSW

Sample	Tool rotational speed (rpm)	Tensile Shear Force (N)
Copper alloy-copper alloy	4000	554
Copper alloy-Aluminum alloy	2000	2386
Aluminum alloy-Aluminum alloy	2000	2628

From the result of tensile strength test, only three samples were able to be tested. It is shown that FSSW with high tool rotational speed of copper alloy to copper alloy resulted to low tensile strength. The tensile shear force can be related to the tensile strength of the FSSW sample. The higher the tensile shear force, the higher tensile strength will be. The tensile strength test for copper alloy to copper alloy with tool rotational speed of 2000 rpm may result to higher than the sample of 4000 rpm tool rotational speed. Compared to copper alloy to aluminium alloy, the tensile shear force is almost the same with aluminium alloy to aluminium alloy. The graph of maximum tensile shear force of the testing can be referred to appendix 2.

The relationship between tool rotational speed cannot be done successfully with the limited results from the test. However, from the table above, higher tool rotational speed onto the Copper alloy Copper alloy welding resulted to the low tensile shear force. However, with the low tool rotational speed on the Aluminium alloy to Aluminium alloy experiment; it is proven from the result that the tensile shear force is higher than the other combinations of materials. From this result, it can be seen that, aluminium alloy to aluminium alloy sample has higher tensile strength compared to copper alloy to aluminium alloy.

Nevertheless, the difference in term of metal sheet also has effect on the properties of weld joint. Based on two specimen; one is copper alloy sheet to aluminium alloy sheet weld joint and second is aluminium alloy to aluminium alloy sheet with the tool rotational speed of 2000 rpm. In comparison of copper alloy sheet to aluminium sheet to aluminium alloy to aluminium alloy, the higher tensile force of spot weld joint is the combination of aluminium alloy material to aluminium alloy. It illustrates that aluminium alloy to aluminium alloy sheet after the process of friction stir spot welding has a better weld bond. However, to see whether the copper alloy spot weld joint has higher tensile force or not compared to aluminium alloy cannot be done because the available specimen to be tested is different in term of tool rotational speed.

Prediction on the tensile force of copper alloy spot weld joint is that with the outcome of 4000 rpm of tool rotational speed; it will be less strong than aluminium alloy spot weld joint. To be more certain in this matter, a follow up study should be done comprehensively onto the copper alloy sheet of friction stir spot welding strength with few proposed recommendation discussed in the recommendation.

CHAPTER 5

CONCLUSION

From the experiment of the microstructure view of Friction Stir Spot Weld, it can be concluded that there are three areas formed by Friction Stir Spot Welding which are region which is not affected by the process (base metal), thermo-mechanically affected zone and stir zone. However, no specific conclusion regarding the microstructure could be done because of the failure occurred at the specimen. Even though, this experiment is not a success in analyzing the microstructure, but it is proven that friction stir spot weld can be applied on the Copper alloy by using the fabricated Tool Steel H13. Furthermore, the weld joint of the process resulted to a high tensile strength for combination of Copper alloy sheet and Aluminum alloy sheet if compared to copper alloy-Copper alloy sheets. Based on the tensile strength test result, Aluminum alloy-Aluminum alloy sample has the highest tensile strength.

As conclusion, Friction Stir Spot Welding is a widely used process nowadays that is implemented in automotive industries. FSSW is a process of joining metal alloys such as Aluminum alloy and it has shown a potential practical application for welding process. Bridgeport Machine is very helpful to produce the spot weld. A mobile machine with the same function of Bridge Port CNC machine is recommended as it can reach difficult angle and area and can be implemented in the industry rather the fixed horizontal workpiece only. Further to that, more study should be done on the alternative material of Aluminum alloy as the main workpiece material for FSSW so that a better quality of product can be achieved.

CHAPTER 6

RECOMMENDATIONS

Because of this project has not been done fully successful, there are a lot of improvement that can be done to get a better result in the future. This project should be continued with proper planning according to the timeframe. This is important so that the process flow will run smoothly thus the result will be better. Further to that, a deep study on the copper alloy also should be done especially on the parameters of Friction Stir Spot Welding plunge test.

Other than that, several samples for each process with different parameter should be prepared. In case of any unpredictable problem occurred, there is still another sample to be tested. Through this project, a few unnecessary incidents had happened to the samples which finally affect the result of the experiment. For the grinding and polishing process, repetition on the procedure needs to be done in order to get a good view of microstructure. Scratches on the specimen can affect the result of the microstructure. The etchant suitable for Aluminum alloy to be used is Keller's reagent and for Copper alloy is aqueous ferric chloride.

Besides that, it is recommended to do several plunge testing to get the suitable welding key parameter that can produce a high strength of spot weld joints. A good result of spot weld joint is needed to obtain good microstructures samples.

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APPENDIX 1

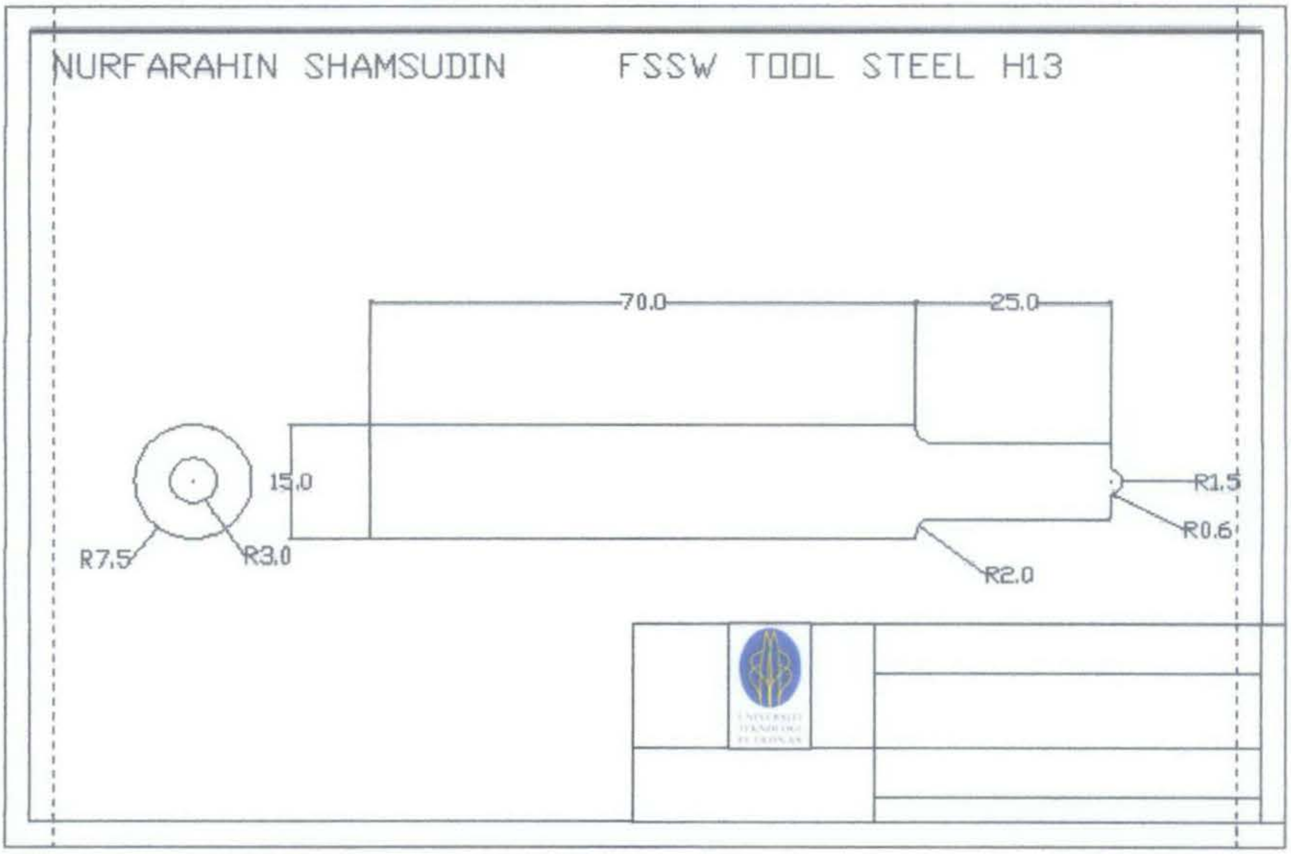

Figure 28: Detailed Design of FSSW tool steel

APPENDIX 2

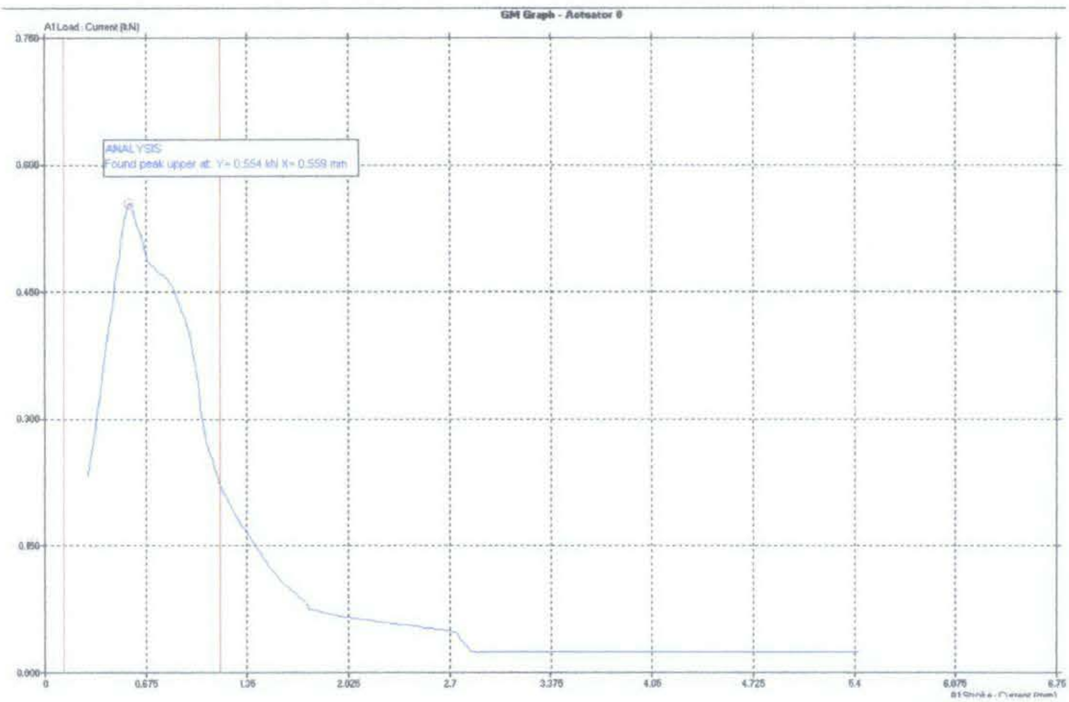

Figure 29: Graph of maximum tensile shear stress of copper alloy to copper alloy sheet

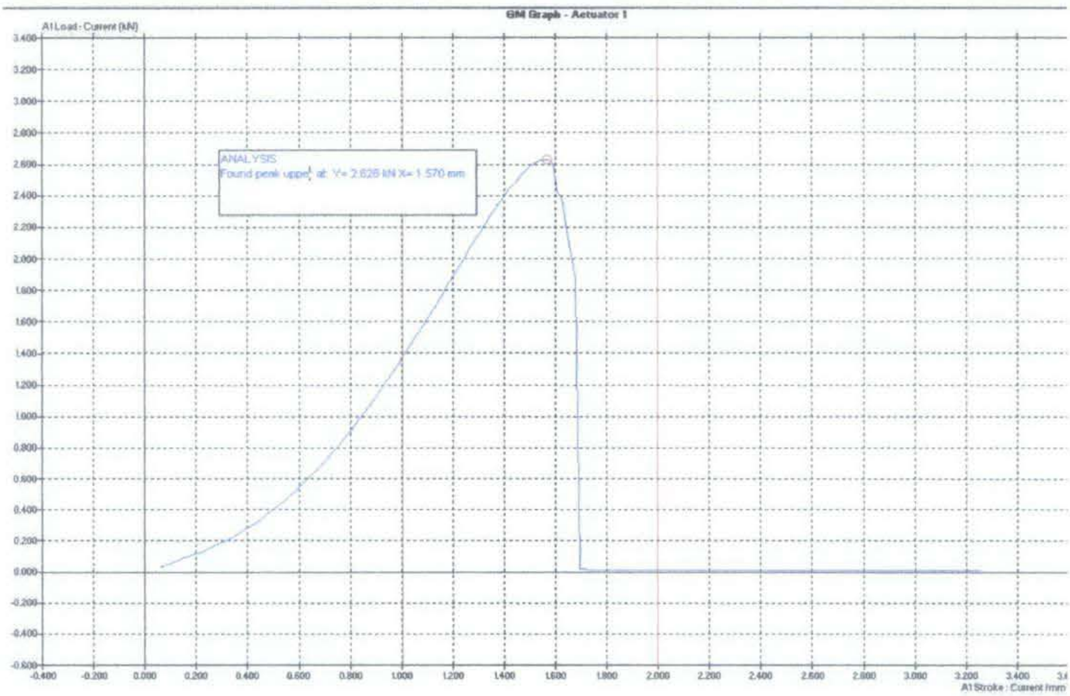

Figure 30: Graph of maximum tensile shear stress of aluminum alloy to aluminum alloy sheet

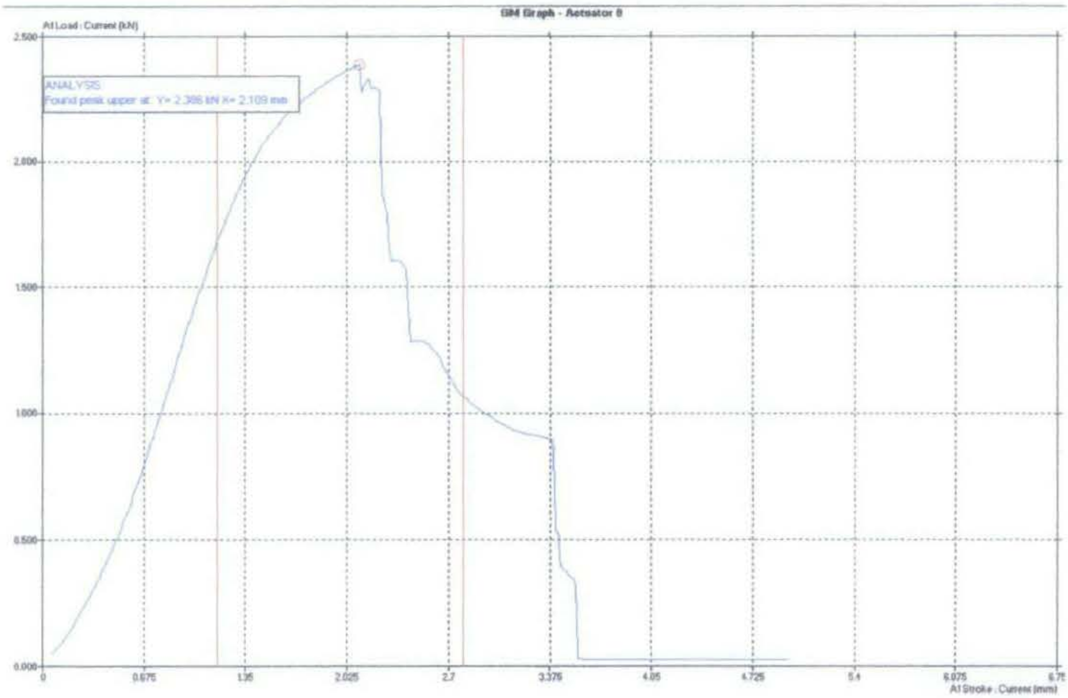

Figure 31: Graph of maximum tensile shear stress of copper alloy to aluminum alloy sheet

Suggested Milestone for the First Semester of Final Year Project

No.	Activities	Semester 1													
		Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topic														
2	preliminary research work														
3	Submission of preliminary report				●										
4	Project work														
	-Material selection														
	- Tool design														
	- Tool manufacturing														
5	Submission of progress report								●						
6	Seminar								●						
7	Project work														
	- Heat treatment														
8	Trial run on CNC machine														
9	Submission of interim report final draft														●
10	Oral presentation														●

●	Suggested milestone
	Process

Suggested Milestone for the Second Semester of Final Year Proje

No.	Activities	Semester II Week 1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project work																
	- Refurbish tool																
	- Heat treatment																
	- Trial run																
2	Submission of progress report									•							
3	Project work																
	- Analysis and discussion								Mid-sem break								
4	Pre-EDX												•				
5	Submission of draft report													•			
6	Submission of technical paper														•		
7	Submission of dissertation (soft bound)														•		
8	Oral presentation															•	
9	Submission of dissertation (hard bound)																•

•	Suggested milestone
	Process