Study on Strength of Friction Stir Welded Plate in Corner Joint Configuration

By

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CERTIFICATION OF APPROVAL

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

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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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD NUR FARHAN BIN MOHD YASIN

ABSTRACT

This report is a representation of the project background regarding on Fiction Stir Welding (FSW) in Corner Joint Configuration. Nowadays, there are many process involving the FSW butt joint but very rare involve in corner joint configuration. FSW process has a lot of advantages to the materials especially for aluminum alloy 6061 Series. The objective of the project is to study the strength of the corner joint friction stir welded plate. Furthermore, there is no one did the research about the strength of the corner joint FS welded plate. Thus, to study the strength, there are several tests can be done such as ballistic shock test, basic destructive test, fillet-welded test, peel-off test and microhardness test. This research is focusing on corner joint configuration that has 90 degree in position. Furthermore, FSW in corner joint has been conducted and the result was discussed in the result section about the surface roughness and the parameter of the FSW. In addition, strength value and hardness value has been analyzed and discussed briefly to meet the objective of this project.

ACKNOWLEDGEMENT

Alhamdulillah, praises to Allah that I was able to complete my final year project. In preparing this project, I was in contact with many people who have contributed towards my understanding and thought. In particular, I would like to express my sincere appreciation to my supervisor, Dr. Mokhtar Awang for encouragements, guidances and critics.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Friction Stir Welding (FSW) is one of the latest welding process that involve in joining and critical application for the joining of structural components made of Aluminum Alloy 6061 Series. Several researches have been forward on FSW butt joint configuration such as ' Study the strength and microstructure Friction Stir Welded plate in butt joint', 'Study the effect of rotating speed of tool in FSW butt joint' and so on. Previous studies focusing more on butt join configuration.

According to the A. Ogur *etal.*2007 [1] friction stir welding is a relatively simple process as shown in Figure 1.0 and a specially shaped cylindrical tool with a screw thread probe, made from material that have a hard and wear resistant relative to the material being welded, is rotated and plunged into the abutting edges of the aluminum parts to be joined. After entry of the screw thread probe to almost the thickness of the material and to allow the tool shoulder to just penetrate into the aluminum plate, the rotating tool is transitioned along the joint line.

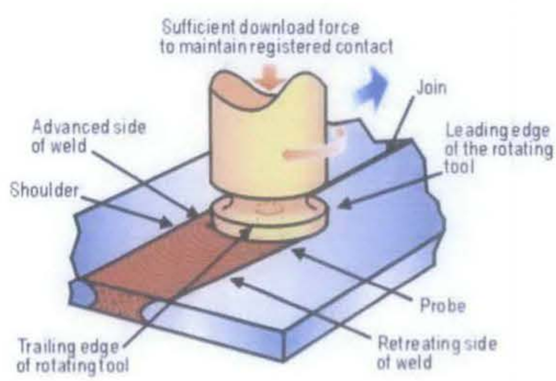


Figure 1.0- Friction stir welding process[1]

The process proves predominance for welding non-heat treatable or powder metallurgy aluminum alloys, to which the fusion welding can not be applied. Thus fundamental studies both on the weld mechanism and on the relation between microstructure, properties and process parameters, have recently been started especially in butt joint rather than corner joint configuration. Basically, there are two designs for corner joint configuration. The two type designs are butt corner design and rabbet corner design. These two types are for friction stir welding and also can be used in conventional arc welding. Figure 1.1 shows a schematic of two differences in corner joint design.

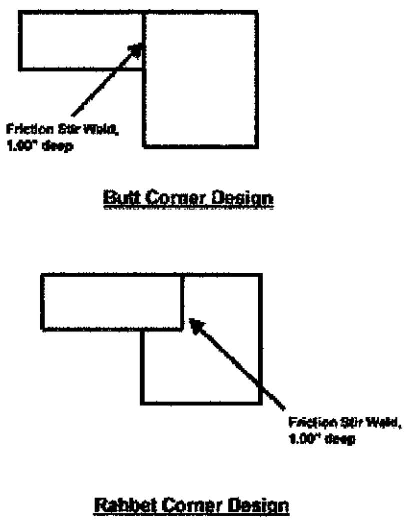


Figure1.1 – Corner joint designs [2]

These two types of designs must be considered in order to achieve the objective. Butt corner design can be done with a low energy density welder if the parts are small enough, but is usually done with a high energy density beam. This allows deep penetration and can form a weld that is as strong as the base material. This advantage of strength is countered by the joints increased proneness to deformation, as well as the increased difficulty and equipment cost of the weld.

On the other hand, rabbet corner design commonly used in conventional arc welding, fixturing is less challenging but a segment between the horizontal and vertical members is left un-welded. To obtain load transfer between the horizontal and vertical members in this region, it is a common arc welding practice to deposit a fillet weld along the inner edge.

1.2 Problem Statement

Not many party or person did research about FSW in corner joint configuration. Furthermore, there is no one did the research about the strength of the corner joint FS welded plate. Thus, to study the strength, there are several tests for instance ballistic shock test, peel-off test and basic destructive test. In order to achieve the objective of the project, there are several works that must be done which are design the jig that can hold the plate to be machined and design the special tool to weld the 90 degree plates.

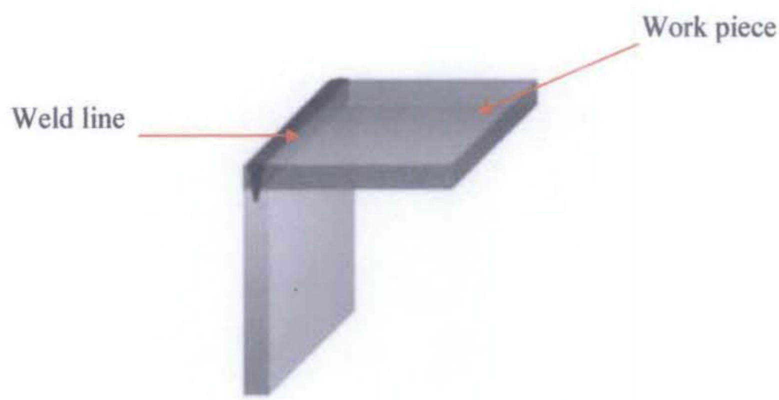


Figure 1.2 - 90 degree corner joint configuration.

1.3 Objective and Scope of Study

1.3.1 Objective

The objective of this research is to study the strength of the corner joint friction stir welded plate.

1.3.2 Scope of Work

This research is focusing on corner joint configuration that has 90 degree in position. The plate that will be used is Aluminum Alloy 6061. Welding samples have been prepared using CNC machine (Bridgeport Machine) with special design of jig and tool.

CHAPTER 2

LITERATURE REVIEW

A method of solid phase welding, which permits a wide range of parts and geometries to be welded and called friction stir welding (FSW), was invented by W. Thomas and his colleagues of The Welding Institute (TWI), UK, in 1991. Friction stir welding can be used for joining many types of material and metal combinations, if tool material and designs can be found which operate at the forging temperature of the workpieces. The process has been used for manufacture of butt welds, overlap welds, T-sections and corner welds. For each of these joint geometries specific tool designs are required which are being further developed and optimized.

In 2005, Jamie Florence [3] found that FSW in corner joint configuration was successful in Ballistic Shock Testing. The goal of the test is to measure the ability of the weld to resist cracking under ballistic shock load. The test evaluates the performance of welds under high strain rate loading by firing a 75-mm-diameter by 150-mm-long soft aluminum slug into the joint at a specified velocity. To pass, the length of any cracks produced in the joint must total less than 12 in. The ballistic shock test was done according to the standard of MIL-STD-662F [4]. Figure 2.0 shows that how the ballistic shock test be conducted.

Figure 2.0 - Ballistic Shock Testing Panel [3]

PAUL J. KONKOL etal.[5] compared between butt corner joint design and rabbet corner joint design and were tested in Ballistic Shock Testing. The two 90-deg corner butt-joint weld panels passed the test on both the 1- and 2-in. faces. Acceptable performance of the butt corner joints is significant because use of the butt corner presumably reduces production costs by eliminating the machining of the rabbet in the sidewall. Note that the butt corner joint design places the point of maximum shear loading on the center of the weld, but the superior deformation and fracture properties of the FSW stir zone, created by the fine-grained microstructure, enable it to pass the test. The rabbet corner weld panels failed the test due to excessive cracking. Figure 2.1 shows designs involve in the test.

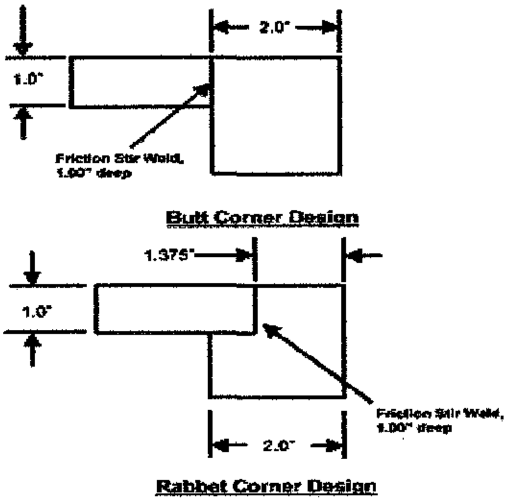


Figure 2.1 – Corner joint design [6]

M. Grujicic etal.[6] stated that each of the two aforementioned corner joints possess certain advantages and shortcomings, e.g., while the butted corner joint requires less pre-weld preparation (less or no machining is required for preparation of the weld surfaces), it entails special tooling in-order to support the horizontal weld plate. On the other hand, in the case of the rabbet corner weld joint which is commonly used in conventional arc welding, fixturing is less challenging but a segment between the horizontal and vertical members is left un-welded. To obtain load transfer between the horizontal and vertical members in this region, it is a common arc welding practice to deposit a fillet weld along the inner edge.

Steve Linder [7] demonstrated ballistic performance advantages on the AAAV corner joint FSW application compared to conventional gas metal arc welding (GMAW). The rabbet corner design was used the result shown that corner joint ballistic were virtually distortion free after welding. The low distortion of the FSW is another productivity advantage of the process. FSW procedures are currently being developed to eliminate the need for a seal weld by forming an integral fillet along the root of the corner joint. Figure below show the effect of adding the fillet in corner joint design.

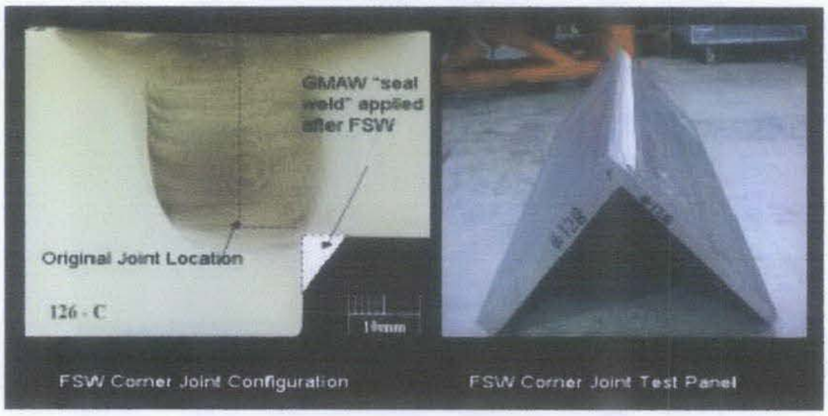


Figure 2.2 – Additional of fillet in rabbet corner design [7]

Subramanian *etal.* [8] stated that corner joint must be hammered until it is flat in basic destructive test as shown in figures 2.3 and 2.4. The corner joint must be able perform bend without fracture. Weld is to be as strong and ductile as base metal.

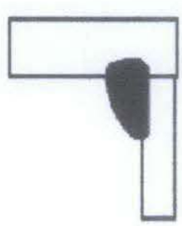


Figure 2.3 – Corner joint before bend test [8]

Figure 2.4 – Corner joint after bend test [8]

Rene J. Van Caneghem [9] did the Ballistic Shock Testing on aluminum alloy welded 90 degree corner joints to evaluate the ballistic shock absorption and welded strength in different striking velocities as shown in figure 2.5.

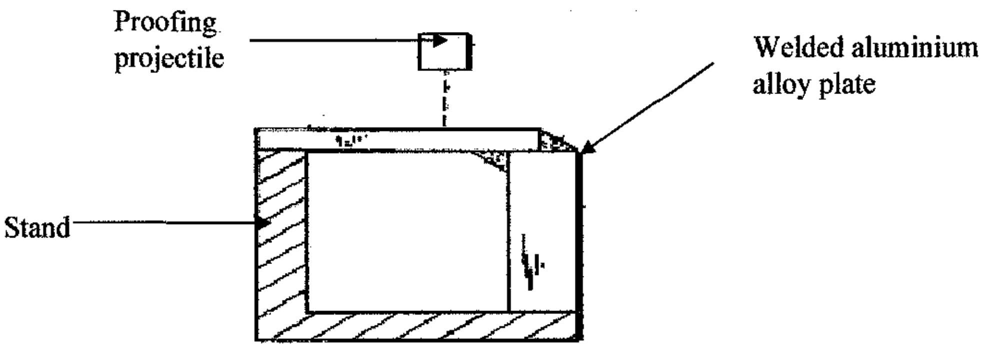


Figure 2.5 – Ballistic shock test [9]

Thus, Ballistic Shock Testing is the only test that had been researched in welded corner joint.

Basically, ballistic shock is a high-level generally single pulse shock that results from the reaction loads of the firing of projectiles and ordnance. The test provides confidence that material can structurally and functionally withstand the shock effects caused by the high reaction loads on a structural configuration to which the material is mounted. In order to do this test, some limitation must be considered which [10] are;

a. This method does not include special provisions for performing ballistic shock tests at high or low temperatures. Perform tests at room ambient temperature unless otherwise specified or if there is reason to believe either operational high temperature or low temperature may enhance the ballistic shock environment.

b. This method does not address secondary effects such as blast, EMI, and thermal.

In ballistic shock test, there are five procedures that need to be selected according to the material specification that will be used in the experiment. According to the standard procedure 5 is the suitable procedure to do the ballistic shock test. Procedure 5 stated that Procedure V - Drop Table. Light weight components (typically less than 18 kg (40 lbs)) which are shock mounted can often be evaluated for ballistic shock sensitivity at frequencies up to 500 Hz using a drop table. This technique often results in overtest at the low frequencies. The vast majority of components that need shock protection on an armored vehicle can be readily shock mounted. The commonly available drop test machine is the least expensive and most accessible test technique. The shock table produces a half-sine acceleration pulse that differs significantly from ballistic shock. The response of materiel on shock mounts can be enveloped quite well with a half-sine acceleration pulse if an overtest at low frequencies and an undertest at high frequencies is acceptable. Historically, these shortcomings have been acceptable for the majority of ballistic shock qualification testing [10].

Ballistic shock is simulated by the impact resulting from a drop. The test item is mounted on the table of a commercial drop machine using the test item's tactical mounts. The table and test item are dropped from a calculated height. The table receives the direct blow at the impact surface, which approximates the lower frequencies of general threat to a hull or turret. This procedure is used for 'partial spectrum' testing of shock mounted components that can withstand an overtest at low frequencies.

The projectile used was the 75mm, M1002A aluminum plate proofing projectile which is generally cylindrical shape approximately 75mm in diameter and 20cm long. The firing procedure was the normal up and down firing method commonly used in ballistic limit determinations. For example, if the first round fired caused little cracking, the next round was fired at a higher striking velocity. If this round caused excessive cracking the velocity of the next round was adjusted downward to cause less cracking. This procedure was followed until an equal number of impacts causing little damage (i.e. no cracks or crack less than 12 inches long) and equal number of impacts excessive damage (i.e. crack more than 12 inches long or catastrophic failure) were attained within a velocity spread of 125ft/sec. four or six round were used to assure reproducibility of results. Propellant charges were adjusted upward or downward by an amount estimated to produce a velocity change of about 50ft/sec. the average of all these striking velocities represent the critical striking velocity. This velocity normally not causes long cracks, whereas velocity above this figure likely will cause such damage [8].

The acid etch provides a clear visual appearance of the internal structure of the weld. Particular interest is often shown at the fusion line, this being the transition between the weld and the base material. Such items as depth of penetration, lack of fusion, inadequate root penetration, internal porosity, cracking and inclusions can be detected during inspection of the etched sample. This type of inspection is obviously a snapshot of the overall weld length quality when used for sampling inspection of production welds. This type of testing is often used extremely successfully to pinpoint welding problems such as crack initiation, when used for failure analyses.

After some literature survey has been conducted, there are two tests that can be considered to be done in corner joint configuration which are Fillet-Welded Joint Test and Peel-Off Test. Taking into consideration that there are no standards concerning the tests of the FSW joints, the quality assessment of test joints were conducted in accordance with the Polish standard like for the resistance welds [11].

The use of Fillet-Welded Joint Test is to check the soundness of a fillet weld. *Soundness* refers to the degree of freedom a weld has from defects found by visual inspection of any exposed welding surface. These defects include penetrations, gas pockets, and inclusions. Prepare the test specimen, as shown in figure 2.6. Now apply force until a break occurs in the joint. This force may be applied by hydraulics or hammer blows. In addition to checking the fractured weld for soundness, now is a good time to etch the weld to check for cracks [12].

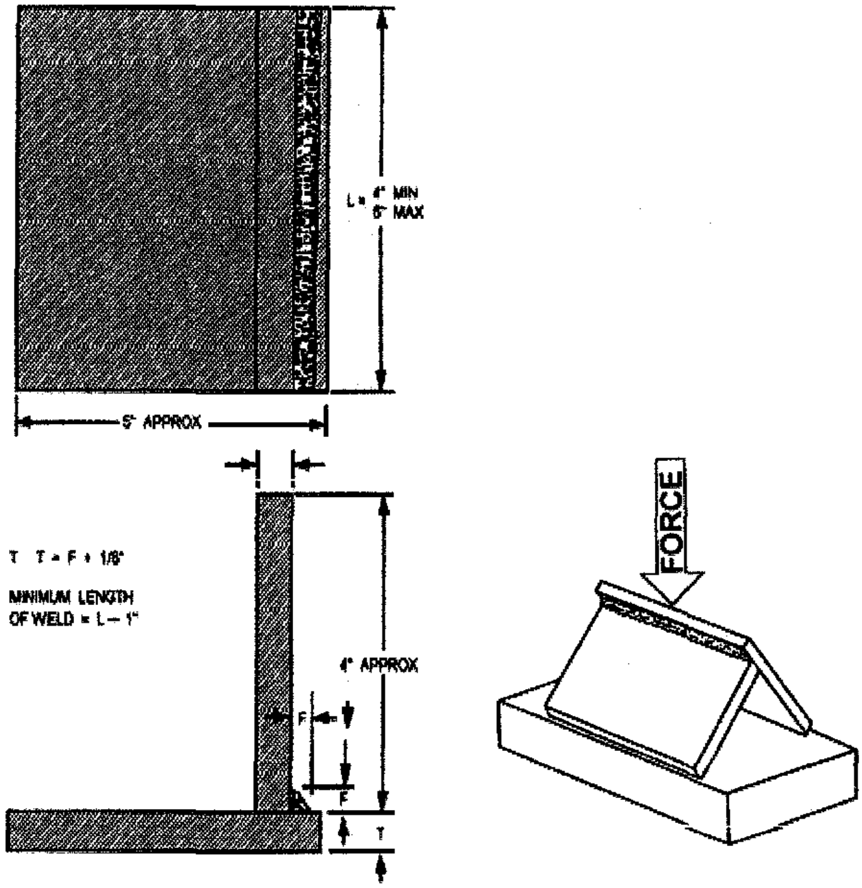


Figure 2.6 – Fillet-Welded Joint Test [12]

Peel-Off Test Peel testing applies force to a plate of weld contact area shows in Figure 2.7. As peeling proceeds, this plate breaks away, resulting in the peel force being applied to the next plate of contact area.

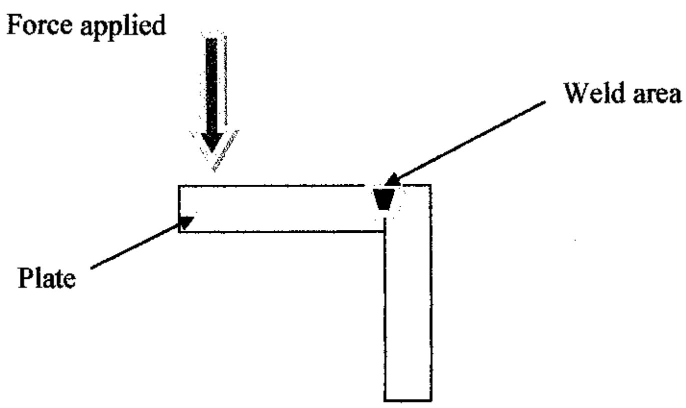


Figure 2.7 – Peel-off Test

This test will be considered as the main test for this project. This is because it will give the values of strength of the welded plate. This test will be done by using Universal testing Machine and special jig required in order to run the test.

In addition, Hardness is the resistance of a material to localized deformation. The term can apply to deformation from indentation, scratching, cutting or bending. In metals, ceramics and most polymers, the deformation considered is plastic deformation of the surface. For elastomers and some polymers, hardness is defined at the resistance to elastic deformation of the surface. The lack of a fundamental definition indicates that hardness is not be a basic property of a material, but rather a composite one with contributions from the yield strength, work hardening, true tensile strength, modulus, and others factors. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be nondestructive tests when the marks or indentations produced by the test are in low stress areas [13].

Microhardness testing per ASTM E-384 gives an allowable range of loads for testing with a diamond indenter; the resulting indentation is measured and converted to a hardness value. The actual indenters used are Vickers (more common; a square base diamond pyramid with an apical angle of 136°) or Knoop (a narrow rhombus shaped indenter). The result for either Vickers or Knoop microhardness is reported in HV and is proportional to the load divided by the square of the diagonal of the indentation measured from the test [14].

According to Somasekharan, E. Murr [13], microhardness samples were prepared in exactly the same way as the optical metallography samples. The Vickers microhardness measurements were taken using aShimadzu digital microhardness tester, using a load of 100 gf (1N) applied for 15 seconds. At least 46 microhardness readings were taken through the mid-thickness for all the weld samples. For obtaining a better profiling of microhardness values in the weld zone from the FSW of Mg alloys to 6061-T6 Al, two more sections of testing (~0.5 mm above and below the mid-thickness) were performed from one side of the FSW zone to another.

CHAPTER 3
METHODOLOGY

3.1 Milestones Year 2010/2011

Table 3.0 – Milestone

MILESTONE FYP 2010

NO	DETAIL/WEEK	6	7	8	9	10	11	12
1	TO COMPLETE DESIGN JIG	3-Aug-10						
2	TO COMPLETE DESIGN TOOL			27-Sep-10				
3	TO COMPLETE FABRICATE JIG						18-Oct-10	
4	TO COMPLETE FABRICATE TOOL							25-Oct-10

The proposed date at certain work had been stated in order to achieve the goal of this research as shows in Table 3.0. It will start with to complete the design of the jig that uses to hold the 90 degree welded plate. The propose material for the jig design is mild steel that is less in cost budget if compare with the other type of steel.

3.1.1 Milestone FYP 2011

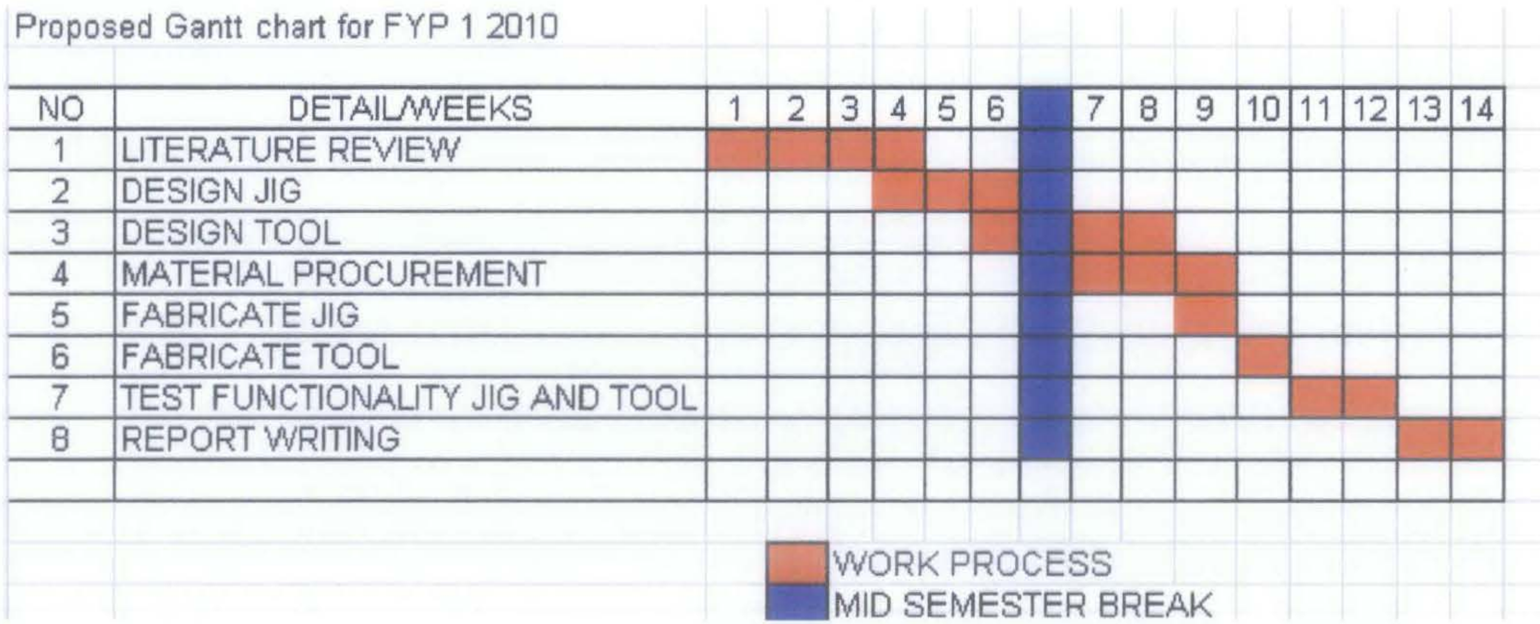
Table 3.1 – Milestone FYP 2

NO	DETAIL/WEEK	4	6	14
1	TO COMPLETE ANALYSE WELDING PLATE	14-Jun		
2	TO PRODUCED NEW WELDING PLATES		29-Jun	
3	TO COMPLETE STRENGTH ANALYSIS			30-Aug

Table 3.1 shows that, there are three key milestones to be completed in year 2011. After the welding plate has been produced, the welding plate will be analyzed the defect that presence in the FSW. In addition, new welding plates should be made with new welding parameter and tool. So that, comparison between the samples can be done which one is better in FSW.

3.2 Specific Gantt chart for FYP 1 2010

Table 3.2- Gantt chart for FYP 1



Literature Review in some project is very important to get the gab between the other projects. The objective and the problem statement of the project can come out from the literature review when the gab has been found. In order to analyze the strength of corner joint friction stir welded plate, there are some work must be done first which are fabricating the special jig and tool as shown in Table 3.2.

3.2.1 Specific Gantt chart for FYP 2 2011

Table 3.3 - Gantt chart for FYP 2

NO	DETAIL/WEEKS	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	UPDATE LITERATURE REVIEW															
2	REPRODUCE FSW PLATES															
3	ANALYSE THE STRENGTH OF FSW															
4	SUBMIT PROGRESS REPORT															
5	ANALYSE MECHANICAL PROPERTIES															
6	PRE-EDX															
7	COMPLETE FINAL WORK															
8	SUBMIT DISSERTATION FINAL															
9	ORAL PRESENTATION															

DOCUMENTATION PROCESS
WORK PROCESS
MID SEMESTER BRAKE

Strength Test which consists of Peel-off Test and Microhardness Test are the most common test for welded corner joint. These type of tests will determine the strength of the welded plate either it is pass the test or not. Last but not least, the final year project will ends up with writing the dissertation report and oral presentation as shown in Table 3.3.

3.3 Methodology of the Project

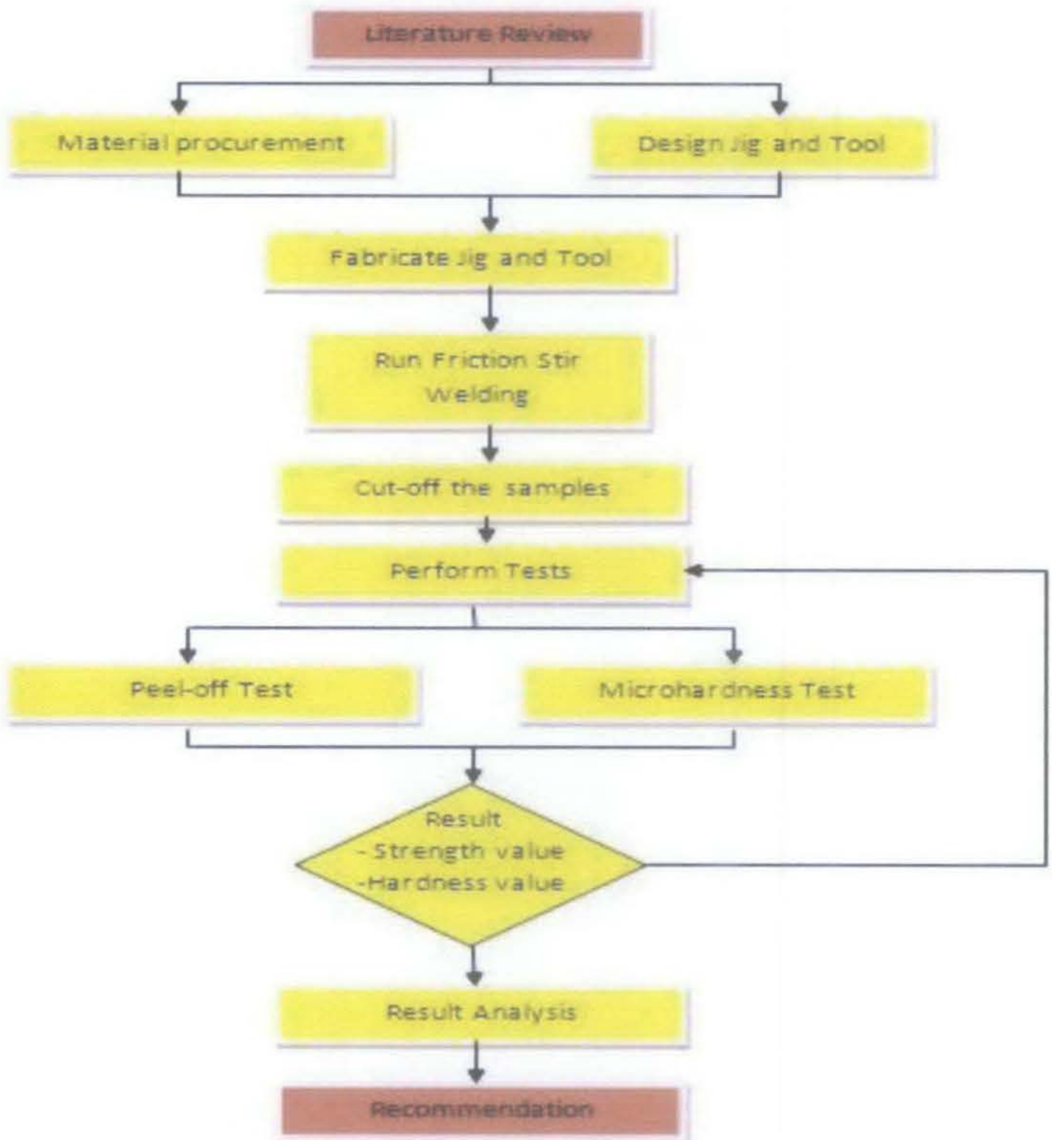


Figure 3.0 -Methodology

The first important thing before start implementing the project is do the research and literature review of the project. Figure 3.0 and 3.1 shows that the steps involve in this project. The project will start with Literature Review and will end with result analysis and recommendation. This will take several weeks to search for the literature review. After the research has been done, there are few stages to achieve the objective which are;

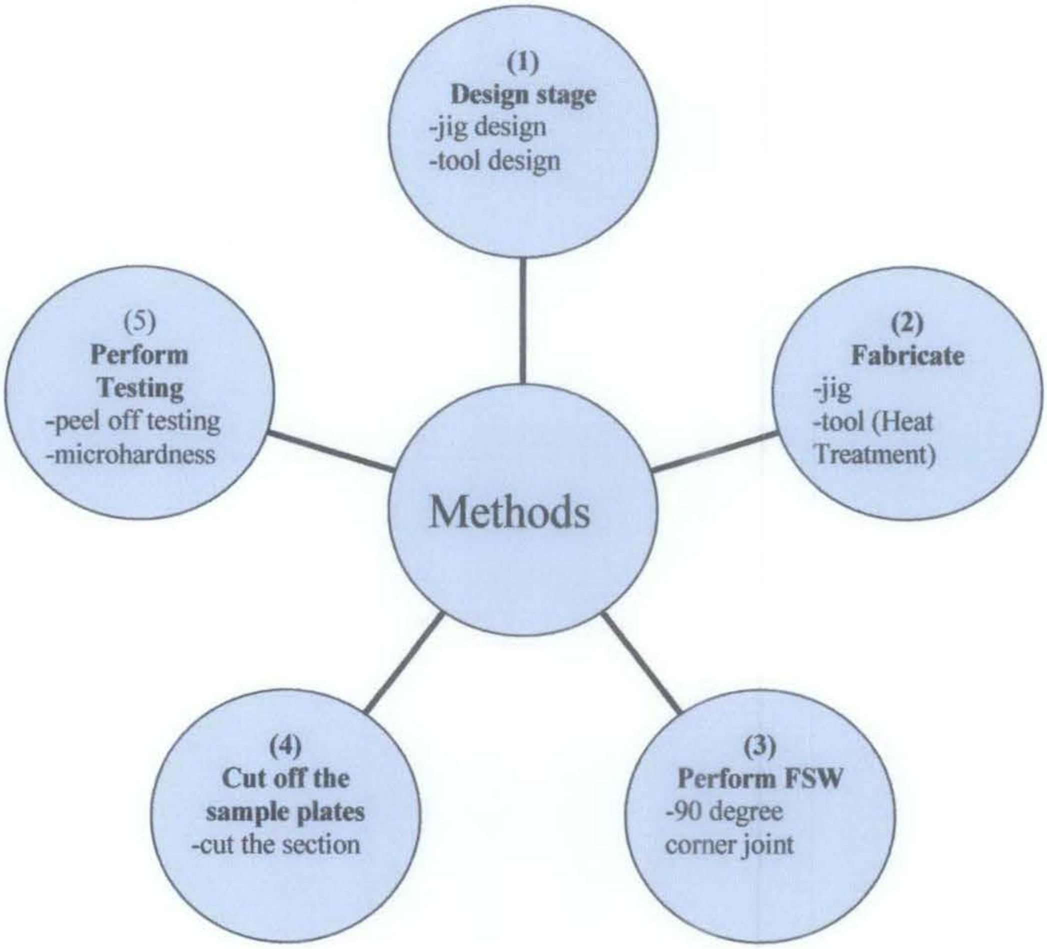


Figure 3.1 – Steps taken

1) Design the jig and tool

- Design jig and tool by using AutoCAD Software. The good design will determine the accuracy of the jig and tool in the fabrication process.

2) Fabricate jig and tool

- Fabricate jig and tool will be done in-house.

a. Jig

-The material of the jig is mild steel

-Conventional arc welding process which is Gas Tungsten Arc Welding (GTAW) will use to fabricate the jig.

b. Tool

-The material of the tool is tool steel

-To fabricate the tool, CNC Turning Machine (Bridgeport) will be used to get better accuracy in dimension.

-After the tool being fabricated, the tool must through Heat Treatment Process (Hardening). Hardening is a process of increasing the metal hardness, strength, toughness, fatigue resistance[12].

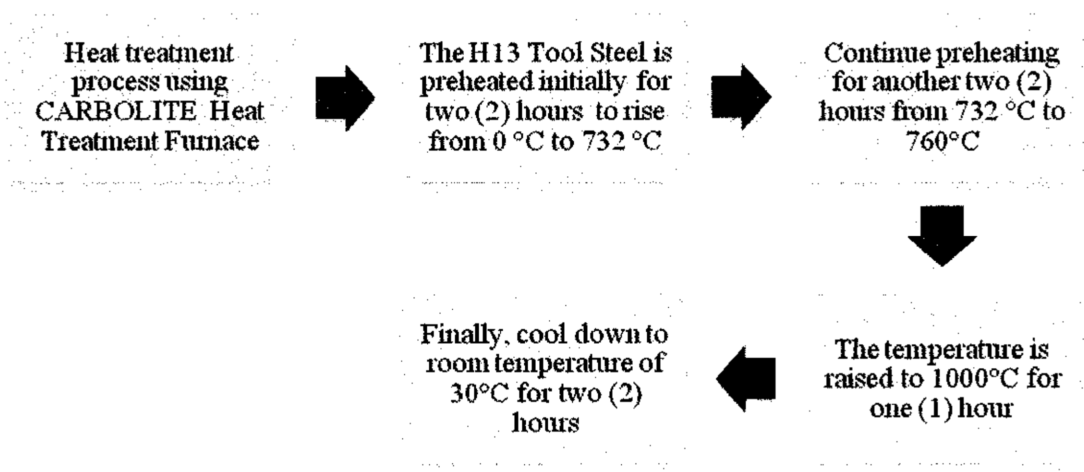


Figure 3.2 – Steps taken in Heat Treatment Process [15]

3) Complete the FSW in 90 degree corner joint plates

- Fabricate the FS welded plate in corner joint by using the CNC Milling machine which is Bridgeport Machine. The parameter of the welding will be varies as shown in Table 3.4 and 3.5.

a. Fixed Move Feed rate.

Table 3.4 - Fixed feed rate

Sample	Spindle speed, rpm	Plunge feed rate, mm/min	Move feed rate, mm/min	Penetration, mm
01	1000	10	8	8.1
02	1500	10	8	8.1
03	2000	10	8	8.1

b. Fixed Spindle Speed

Table 3.5 - Fixed spindle speed

Sample	Spindle speed, rpm	Plunge feed rate, mm/min	Move feed rate, mm/min	Penetration, mm
01	1000	10	8	8.1
04	1000	10	10	8.1
05	1000	10	15	8.1

4) Cut-off the sample plates

- Some important process parameters that should be taken into account and control the quality of the weld are the tool spindle speed (rpm), transverse speed (mm/min), plunging speed (mm/min), dwell time and depth of penetration (mm). All of these process parameters were optimized to obtain defect free friction stir welded joints.

- The plates that had been produced must be cut at the section where the FSW is performed. This is because two tests are required to be done which are peel-off test and microhardness test.

- Peel-off test will be done by using Universal Testing Machine (UTM) and special jig must be used to run the test. Thus, the jig for testing will be design and fabricate properly.

5) Perform Testing

- Peel-off test must be done by using Universal Testing Machine (UTM). The stroke velocity is set to be 1.0 mm/s. this is to get the accurate data and graph.
- The test can be considered success until the plate is failed to sustain the load.
- Microhardness Test is the second test that should be done to the samples by using Vickers Microhardness Test.
- Before the test is started, several preparation of the sample should be done first for example, mounting, grinding and polishing.
- All of the equipment use in surface preparation is shown in Appendix 4.0.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Jig Design

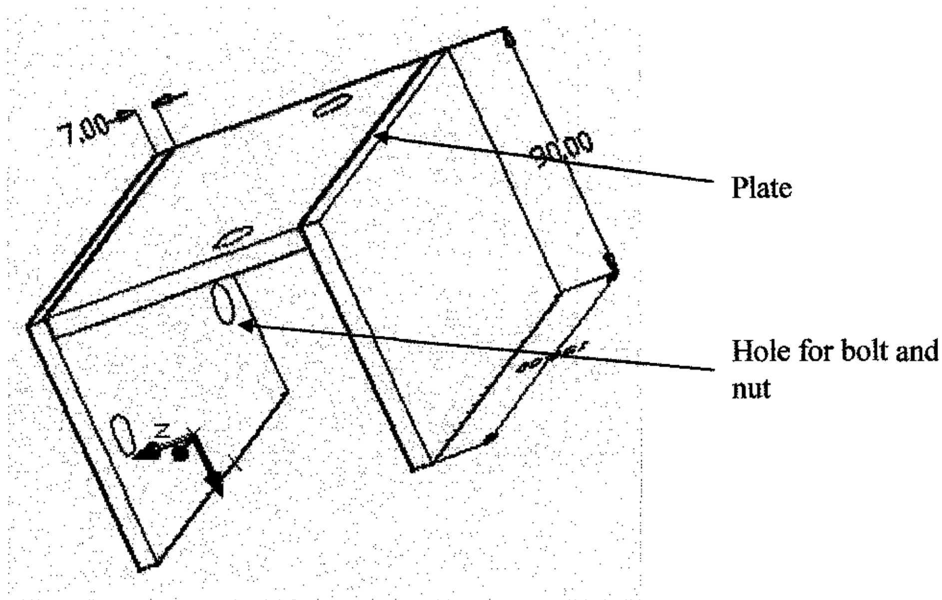


Figure 4.0 – Jig design

Design the jig for friction stir welding is necessary because there is no CNC machine that has the jig that can support 90 degree welded plates. The new jig as shown in Figure 4.0 will attached to the base of the workspace in the CNC machine. Figure 4.1 shows the drawing detail of the jig.

The equipments that used to fabricate the jig are;

i. Linear hack Saw Machine
ii. Drilling Machine
iii. Gas Tungsten Arc Welding (GTAW)
iv. Abrasive Cutter
v. Grinding Machine

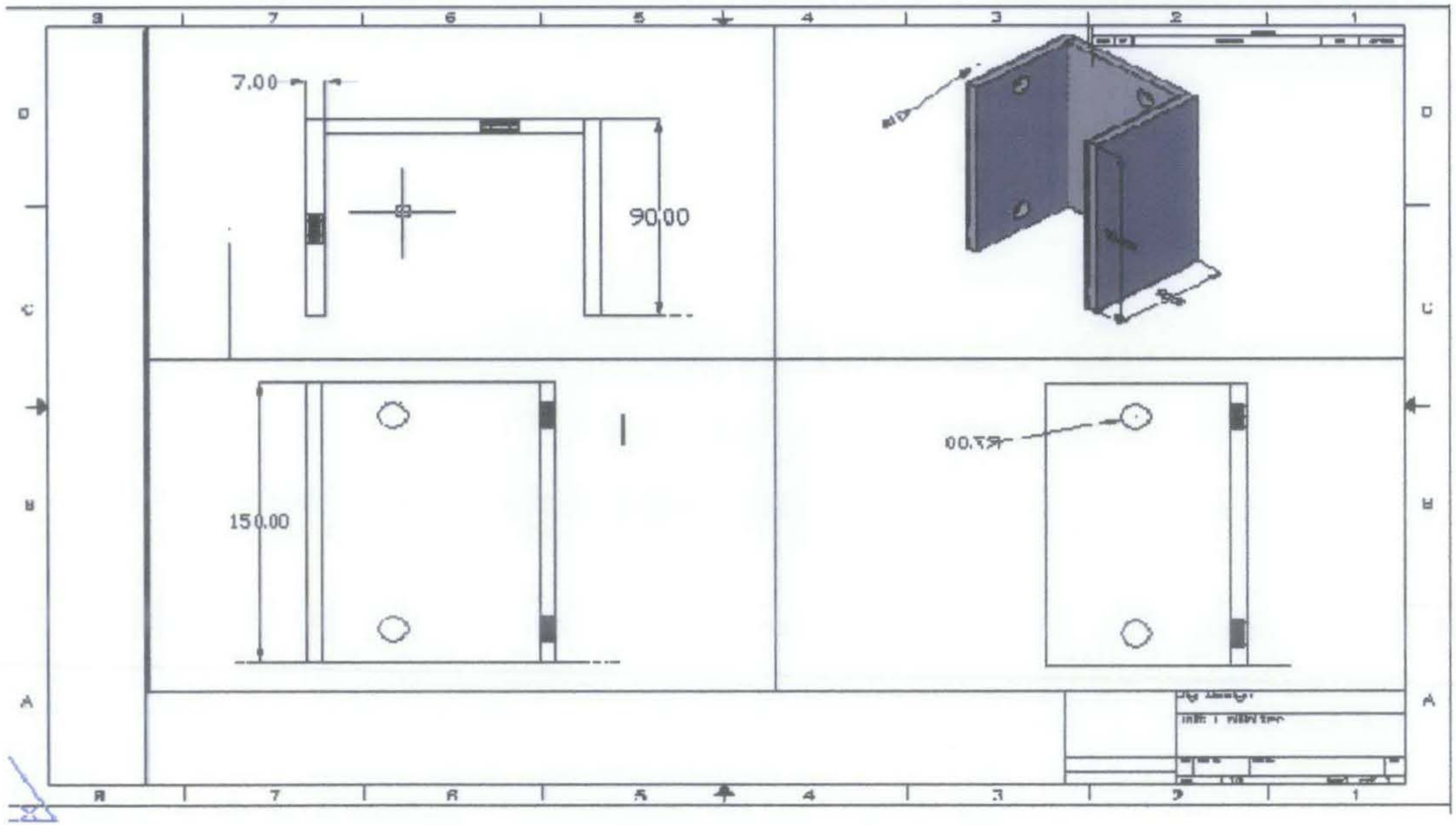


Figure 4.1 – Jig from varies view

Figure 4.2 – The jig for 90 degrees corner plate

The material of the jig is mild steel that has a thickness of 7mm. There are also four threaded hole for bolt and nut (M8X40) to tighten up the aluminum. The figure of mild steel plate is shown in Appendix 3.0 *Figure A-3.0.* Figure 4.3 shows that the equipment used to cut the mild steel to the specific dimension.

Figure 4.3 – Linear Hack Saw Machine

The fabrication process to make the jig is by using conventional arc welding which is Gas Tungsten Arc Welding (GTAW) at manufacturing lab Block 21.

4.2 Tool Design

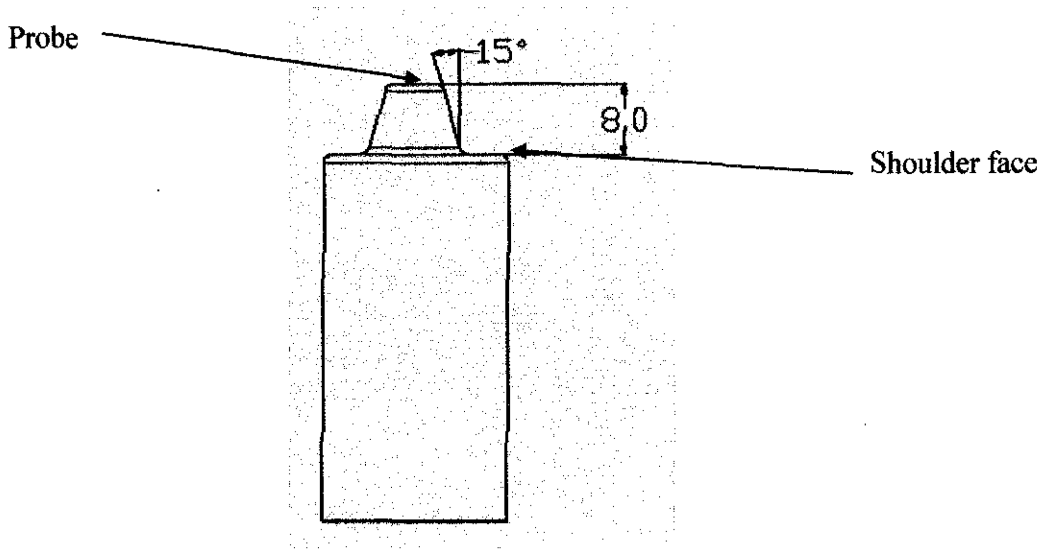


Figure 4.4 – Tool design

Figure 4.4 above shows the comprise cylinder with a first end for attachment to a rotating drive for rotation about longitudinal axis and a shoulder face opposite first end. A probe project downward at a substantially right angle to the shoulder face and it's integral with cylinder. Probe has a longitudinal axis that is co-extensive with the cylinder axis. The material for friction stir welding tool is tool steel. Basically, the height of the probe is 80% from the thickness of the plate. Figure 4.5 shows the detail drawing of the tool.

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be 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 temperatures (red-hardness). Tool steel is generally used in a heat-treated state [16]. The figure of tool steel is shown in Appendix 3.0 *Figure A-3.1*

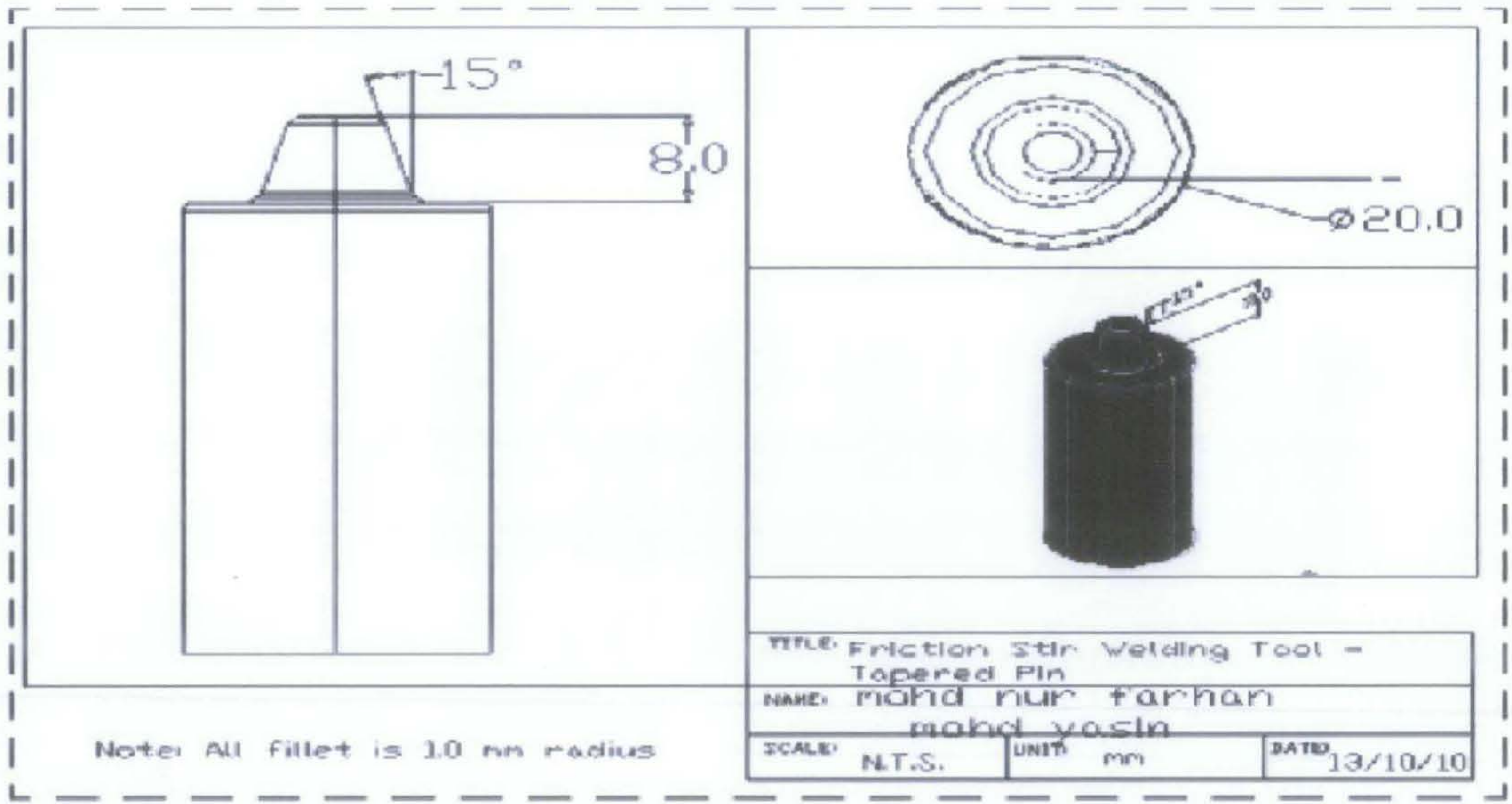


Figure 4.5 – Tool views

4.2.1 Coding for CNC Machine (Bridgeport)

CNC Machine was used to fabricate the tool. Figure 4.6 below is the coding system that was used in the CNC machine Bridgeport.

```
01515;
T1212;
G92 S1600 M08;
G96 S200 M03;
G00 X35.0 Z0.1;
G01 X1.0 F0.25;
G00 X25.0 Z2.0;
G71 U0.3 R0.5;
G71 P1 Q10 U0.1 W0.0 F0.35;
N1 G00 X0;
G00 Z0;

N1 G00 X0
G00 Z0;
N2 G01 X3.0;
G03 X5.0 Z-1.0 R1.0;
N3 G01 X8.0 Z-7.0;
N4 G02 X10.0 Z-8.0 R1.0;
N8 X19.0;
N9 G03 X20.0 Z-9.5 R1.5;
N10 G01 Z-35.0;
G70 P1 Q10;
M09;

G70 P1 Q10;
M09;
U28 U0 W0;
M05;
M30;
%
```

Figure 4.6 – Coding tool design

4.3 Performed FSW 90 degrees Corner Joint

Friction Stir Welding in corner joint was conducted at Block N by using Bridgeport CNC Milling Machine. The tool is inserted in the machine to perform the FSW as well as the jig for 90 degrees corner joint plate. The arrangement of the jig and plate is shown in the Figure 4.7 below;

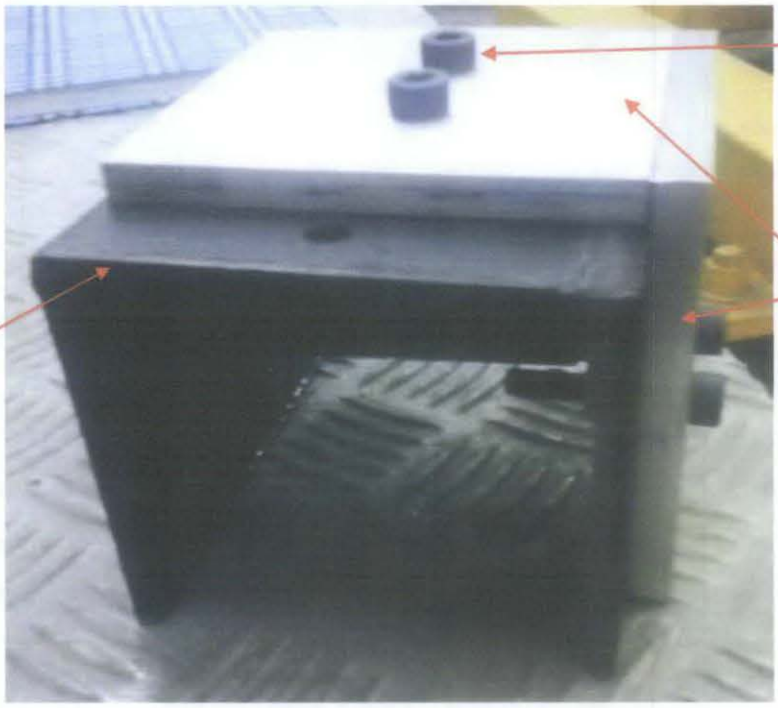


Figure 4.7 – The arrangement of jig and plate

Basically, there are 5 samples that had been produced by varying the parameter of the friction stir welding. However, the parameter of the FSW was divided into two categories which are fixed the move feed rate and fixed the spindle speed. The tables and figures below are basically the samples that had been produced.

a. Fixed Move Feed rate.

Table 4.0 - Fixed feed rate

Samples	Spindle speed, rpm	Plunge feed rate, mm/min	Move feed rate, mm/min	Penetration, mm	Result description
01	1000	10	8	8.1	High flash Smooth surface at start Rough surface at end
03	2000	10	8	8.1	Very high flash Rough surface

For the sample_01 which is the first sample as shows in Figure 4.8, the surface is smooth from the beginning and little rough surface at the end of the process. The flash is very high at the side of the plate. Flash is the material expelled along the weld toe during FSW. The good sample has very minimal of flash and smooth surface. Table 4.0 shows that the parameter and the result when FSW is conducted by fixed the feed rate.

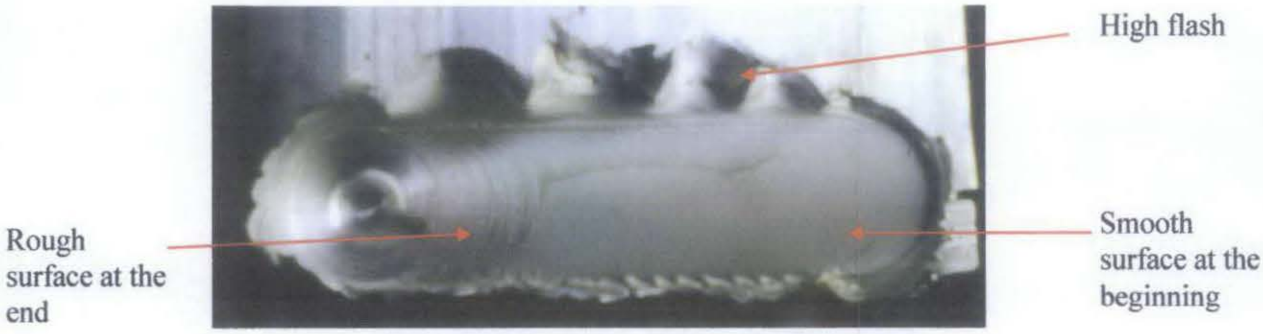


Figure 4.8 – Sample (1000 rpm, 8mm/min)

For the sample_03, surface roughness is very high as well as high flash occur at the side of the plate. This shows that, the sample is not too good compared to the first sample. The figure of the second sample is shown in the Appendix 4.0 *Figure A-4.0*.

b. Fixed Spindle Speed

Table 4.1- Fixed spindle speed

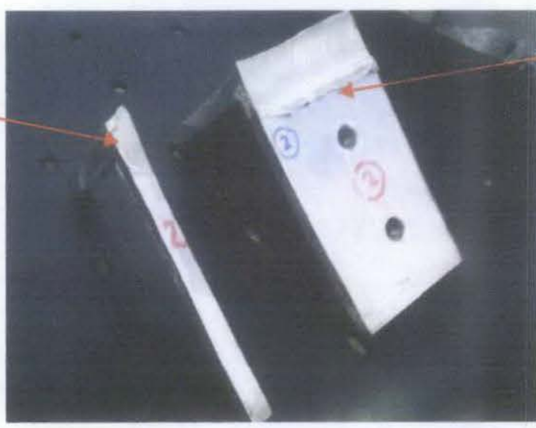
Sample	Spindle speed, rpm	Plunge feed rate, mm/min	Move feed rate, mm/min	Penetration, mm	Result description
05	1000	10	15	8.1	Minimal flash Smooth surface at start Rough surface at end

Sample_05 (1000rpm, 15mm/min) as shows in Table 4.1, the surface is the same like the first sample which are smooth at the beginning and little rough at the end of the process. The flash produce also minimal compared to the first sample. The figure of the sample_05 and the other samples are shown in the Appendix 4.0 *Figure A-4.1.*

4.4 Cut off the sample plates

All samples that had been produce were cut into two sections. The first section is to use for Peel-off Testing and the second section is use for Microhardness Testing. The abrasive cutting tool was used to cut the samples. The samples that had been cut are shown below.

Sample for Microhardness Test



Sample for Peel-off Test

Figure 4.9 – Sample had been cut off.

4.5 Perform Testing

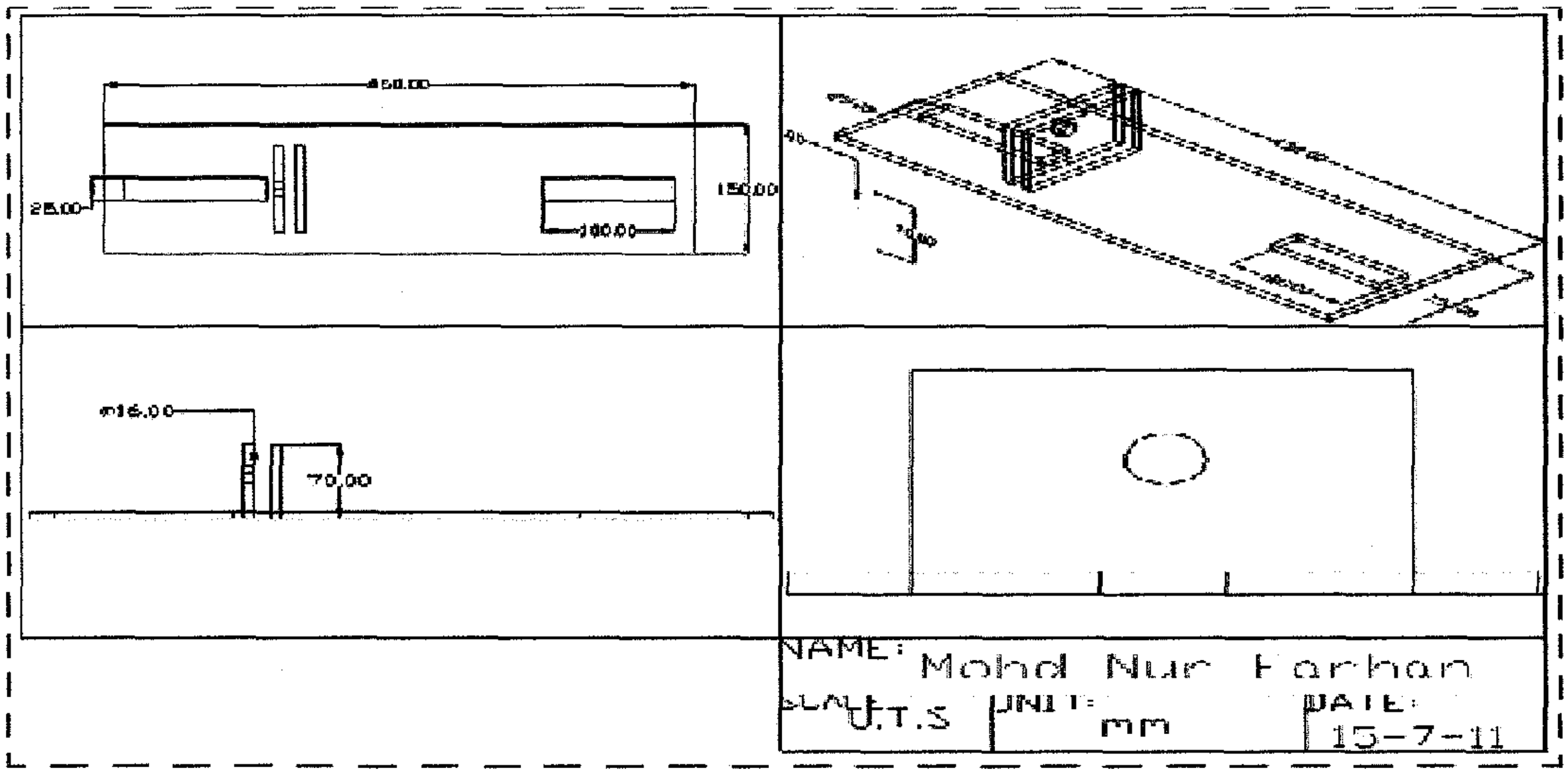


Figure 4.10 – Jig design.

Peel-off Test will be done by using Universal Testing Machine (UTM). In order to run the peel-off test, special jig should be design properly to fit with the UTM. Figure 4.10 shows the detail drawing of the jig.

The Peel-off Test is successfully done with the stroke load 1.0 mm/s. The test was set up as shown in Figure 4.11 below.

Figure 4.11 – Peel-Off Test setup

The peel-off test is started with sample_01 as the first sample to be tested. This is following by sample_02 until sample_05. Figure 4.12 and Figure 4.13 below shows the result before and after the test.

Figure 4.12 – Before Test

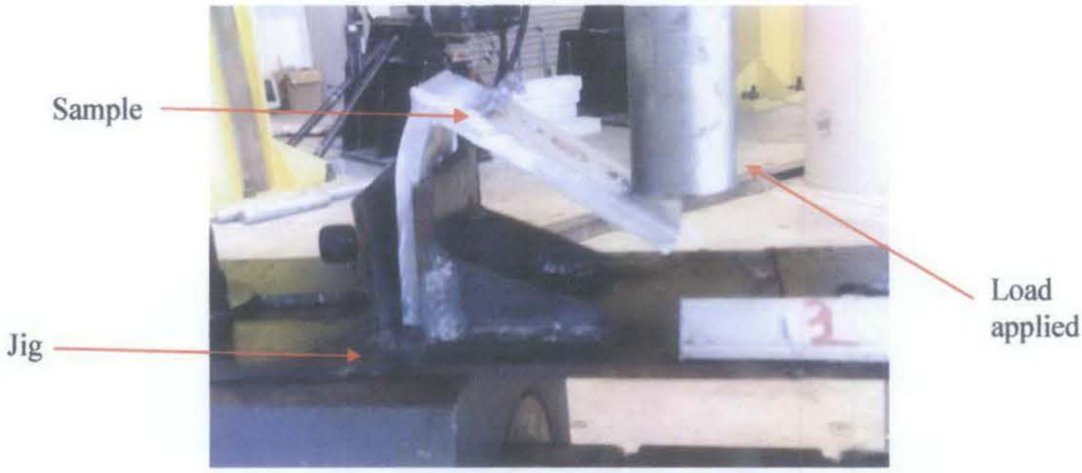


Figure 4.13 – After Test

Figure 4.14 – Plate after test

Figure 4.13 shows that, the plate bend after the test is done. The first hypothesis is the sample plate will broke after the test at the weld zone. Unfortunately, the weld zone is still the same no crack found. But, the change in the plate is bending after the test. This shows that, the FSW is strong enough to weld the two plates.

All data has been collected and was converted into the graph to know which sample has the best quality in term of strength value. The graph Load (kN) versus Stroke (mm) is done to each sample. The highest and the lowest value of strength has been determined as shown in Figure 4.14 and 4.15 and strength comparison between each sample has been compute as shown in Figure 4.16.

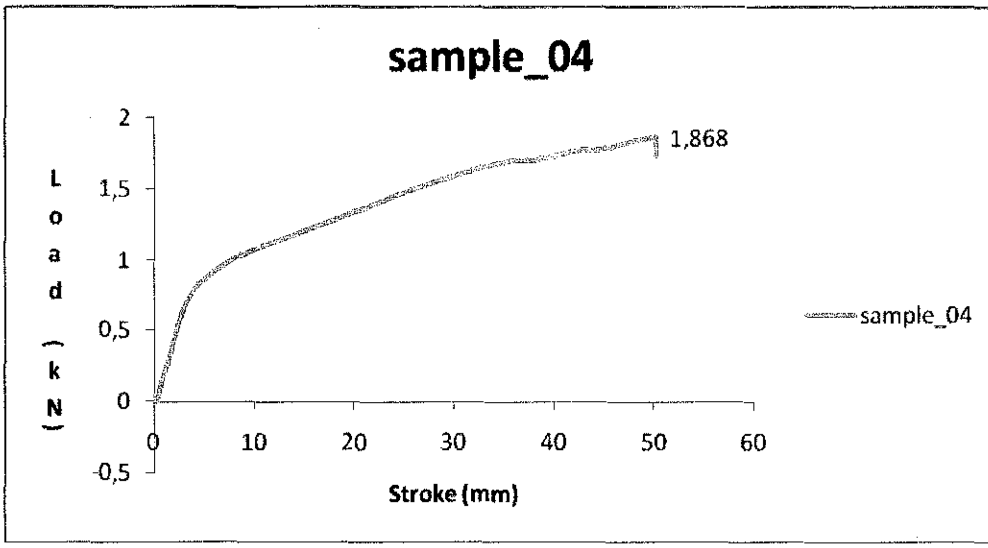


Figure 4.15 – The Highest Strength

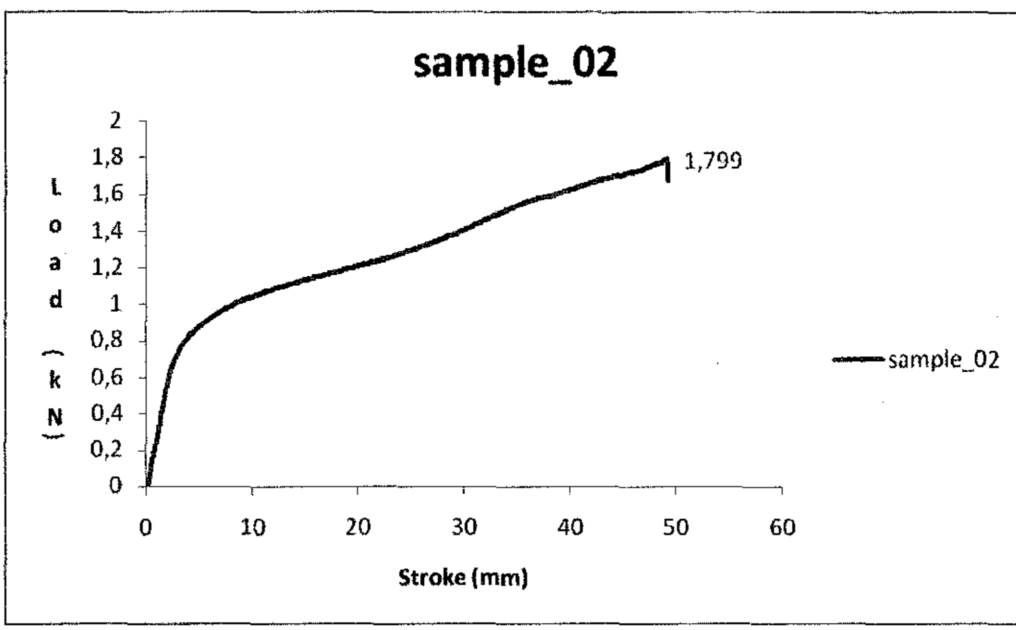


Figure 4.16 – The Lowest Strength

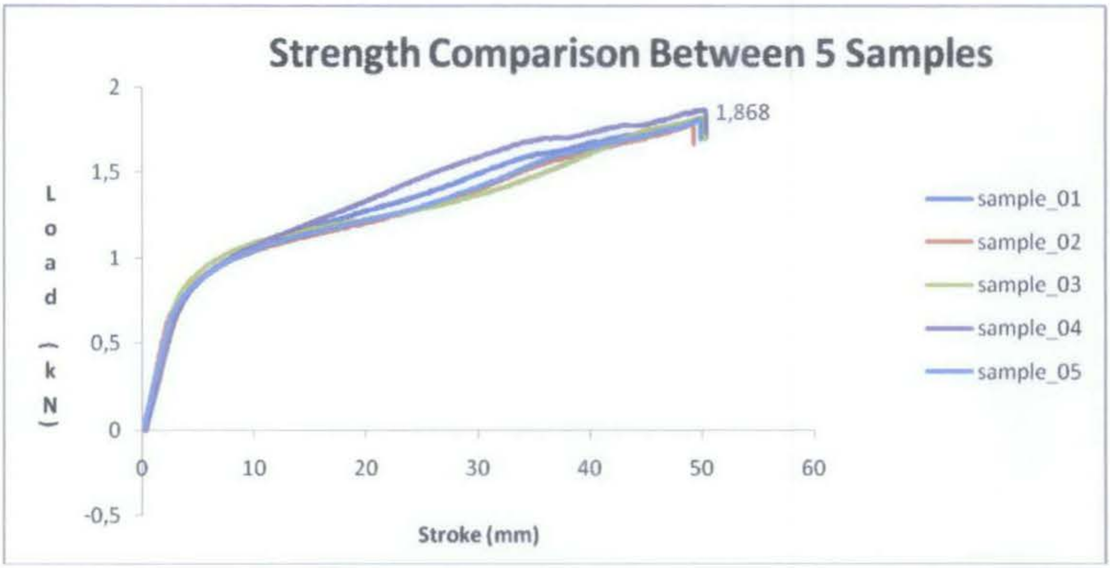


Figure 4.17 – Strength comparison

After has been analyzed, sample_04 (spindle speed, 1000rpm and move feed rate, 10 mm/min) gives the best value of strength, slip at approximately 52mm. The lowest value of strength is sample_02 (spindle speed, 1500rpm and move feed rate, 8 mm/min), slip at approximately 48mm.

Hardness is resistance of a material to deformation, indentation, or penetration by means such as abrasion, drilling, impact, scratching, and or wear, measured by hardness tests such as Brinell, Knoop, Rockwell, or Vickers. In the microhardness test, Vickers hardness test is use to determine the hardness of the welded plate as shown in Figure 4.16 below.

Figure 4.18 – Vickers Microhardness test

In addition, surface preparation for the five samples has been done in order to get the better accuracy of the hardness value. The samples has been mounted, grinded and polished to get flat surface and good diamond shape in microhardness test. The data has been recorded for each sample. The distance between the points of hardness is only 0.05inches. The least hardness value is shown in the Figure 4.17 below.

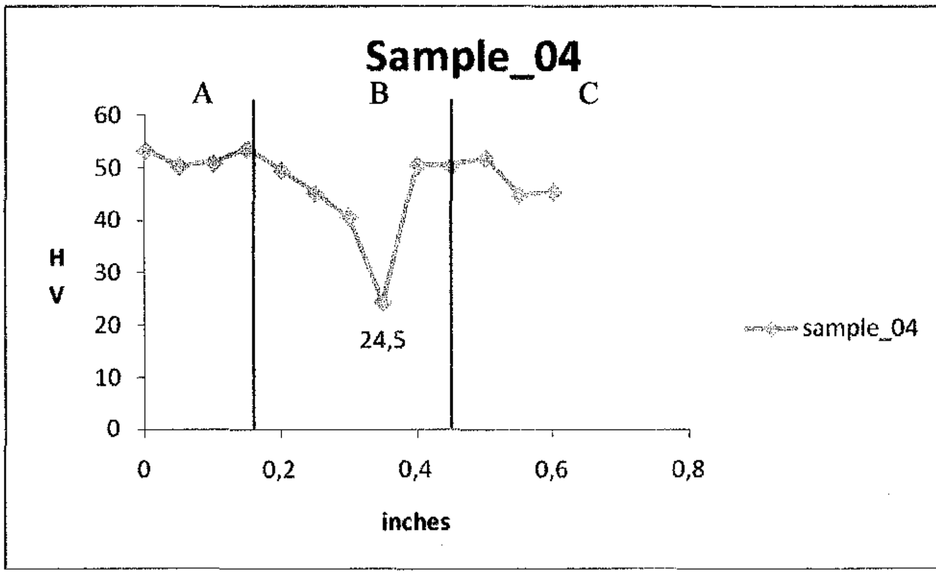


Figure 4.19 – The least Hardness value

Figure above shows the least of hardness value between five samples. Section A and C in the graph shows the hardness value of the plate before the weld area. The value of the plate is average. However, there is drop in hardness value in the section B, weld area until 24.5 HV. This is happened because the present of worm defect (worm tunnel) at the weld area. The size of the worm tunnel is relatively bigger than the other samples. Figure 4.20 shows the different in size of the worm defect (worm tunnel) at sample_04 and sample_02.

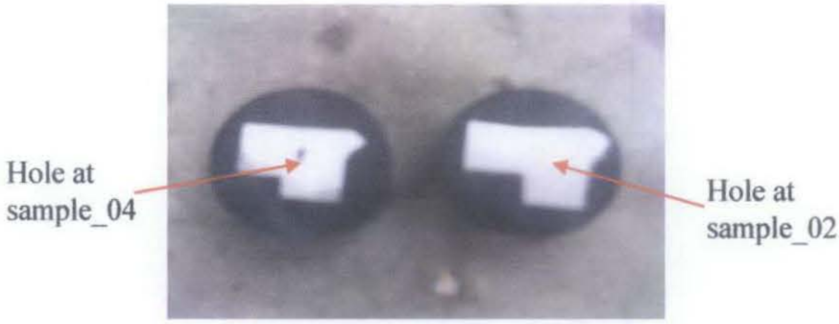


Figure 4.20 – Worm defect (worm tunnel)

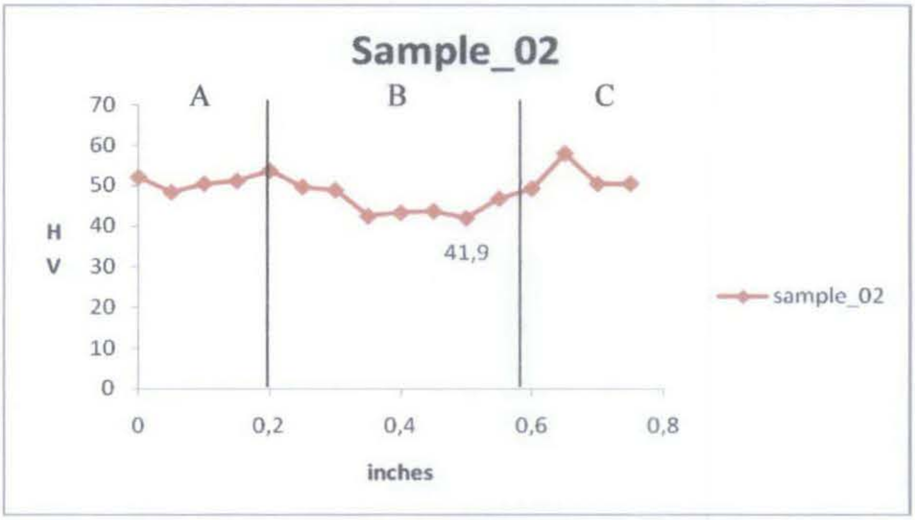


Figure 4.21 – The highest Hardness value

The above Figure 4.21 shows Samples_02 has the highest hardness value between five samples. The value of hardness of the plate at section A and C is average likely the same as the other samples. The drop also occurred when entered to the weld area until 41.9HV. The plate hardness average is about 51HV. The different between the weld area and non-welded area is about 10.9 HV.

Figure 4.22 – Comparison Hardness value

Figure 4.22 shows that, the comparison of hardness values between five samples that had been produced with different FSW parameter. Section A and C is the section of the aluminum plate while section B is the weld zone. The hardness of each sample dropped in the weld zone. Sample_04 shows the lowest hardness at the weld zone which is about 24.5HV. Among all the samples, sample_04 has the bigger worm tunnel which is defect to the aluminum. This gives affect to the hardness of the sample_04 compared to the others.

Thus, all data of each samples has been analyzed and found that sample_04 has the highest strength value which is 1868kN and the lowest hardness value at the weld zone at 24.5HV. While, sample_02 has the best hardness at the weld zone, 41.9HV and has the least strength which is about 1799kN.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

For the conclusion, there are a few points that can be concluded from this research which are:

1. All data has been analyzed and found that sample_04 (spindle speed, 1000rpm, feed rate, 10 mm/min) has the best strength in peel-off test, 1868kN.
2. While sample_02 (spindle speed 1500, feed rate 8m/min) has the least strength, 1799kN.
3. However, in the microhardness test, sample_02 (spindle speed 1500, feed rate 8m/min) has the highest hardness at the weld zone, 41.9HV.
4. While sample_04 (spindle speed, 1000rpm, feed rate, 10 mm/min) has the lowest hardness, 24.5HV because of bigger worm defect (worm tunnel).
5. Based on the result that has been analyzed, this project should be improved by how to reduce the worm defect that affects the strength and hardness of the weld area.

Below are a few recommendations that can be done:

1. This project is recommended to be proceeded with analysis of the worm defect that affected the hardness of the weld zone.
2. Linear Variable Differential Transformers (LVDT) also needs to be installed during testing in order to get the deflection of the samples.

CHAPTER 6

REFERENCES

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CHAPTER 7
APPENDICESS

Appendix 1.0

- 75-mm dia.
- 150-mm long aluminum slug
- Fired at specific velocity for thickness and alloy
- Weld must survive with less than 12"total cracking

FigureA-1.0- 1-inch 5083-H131 Corner Joint

Appendix 2.0

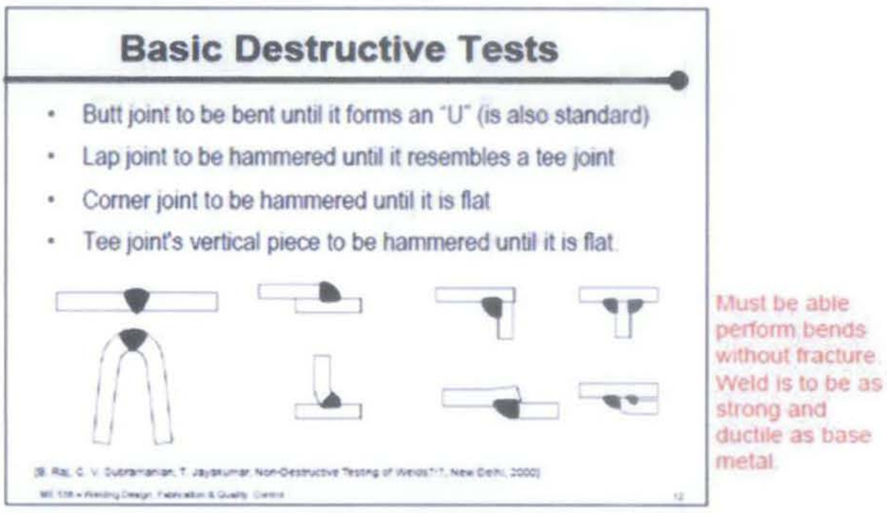

Figure A-2.0 – Basic destructive test

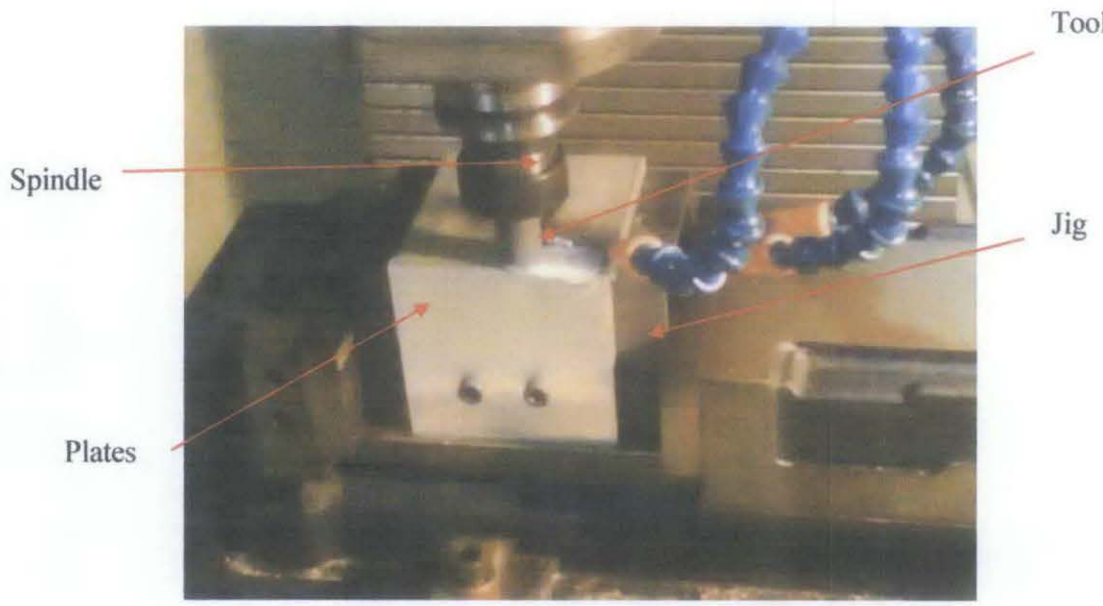

Figure A-3.2 – CNC Milling Machine

Figure A-3.3 – Grinding and polishing Machine

Figure A-3.4 – Hot Mounting Machine

Appendix 4.0

Result

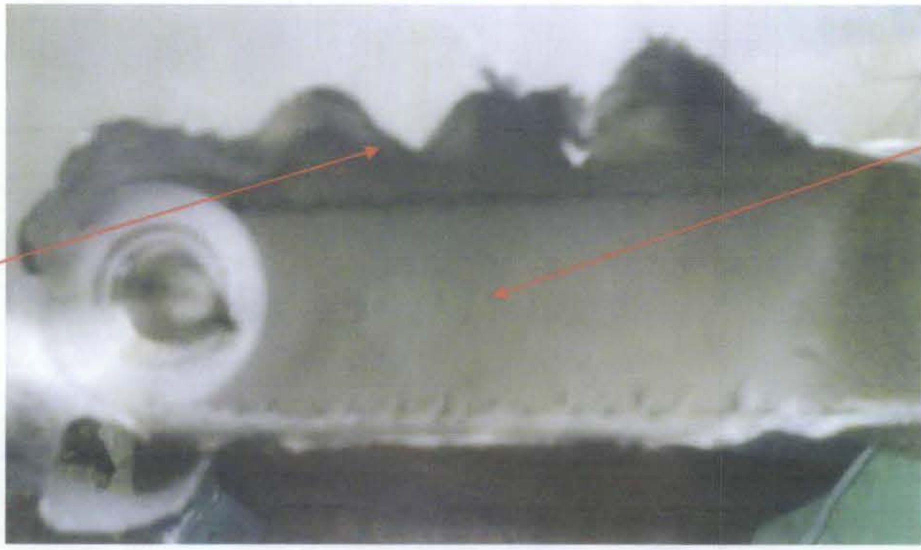

Figure A-4.0 – second sample (2000rpm, 8mm/min)

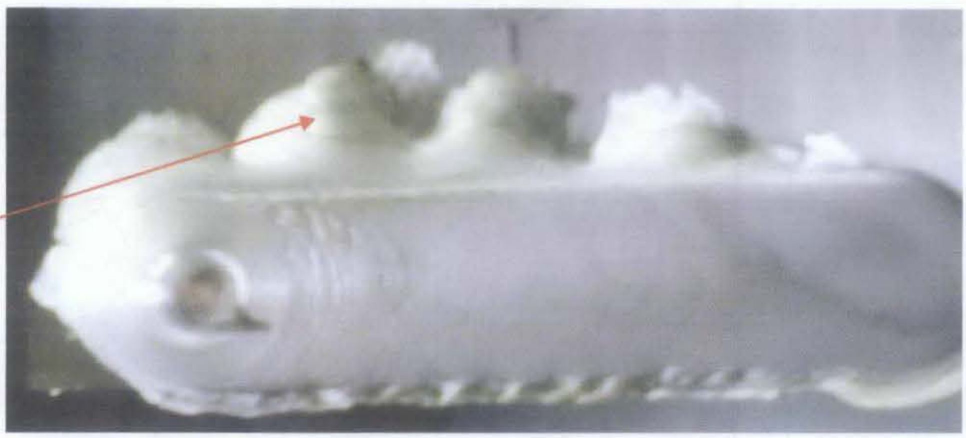

Figure A-4.1 – third sample (1000rpm, 15mm/min)

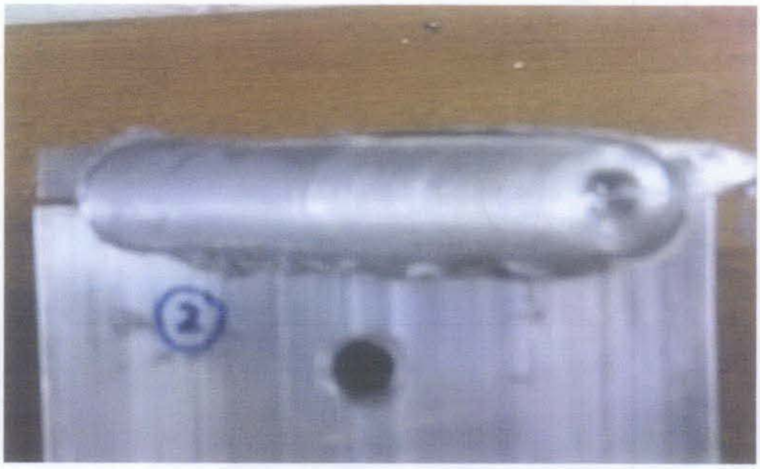

Figure A-4.2 – plate (1500rpm, 8mm/min)

Figure A-4.3 – plate (1000rpm, 10mm/min)

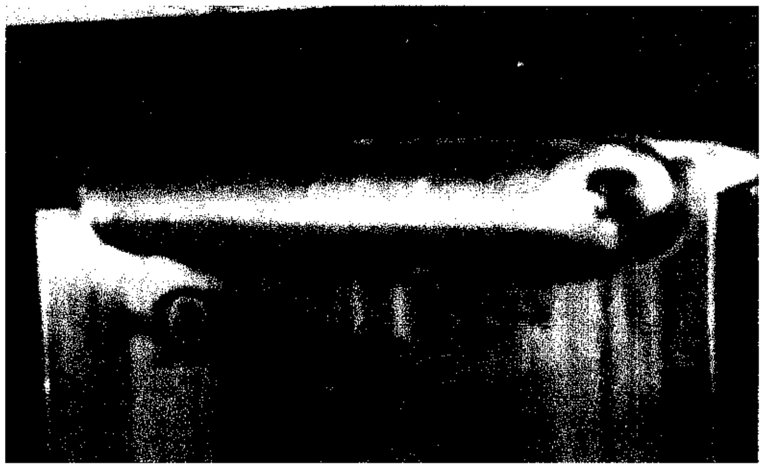

Figure A-4.2 – plate (1500rpm, 8mm/min)

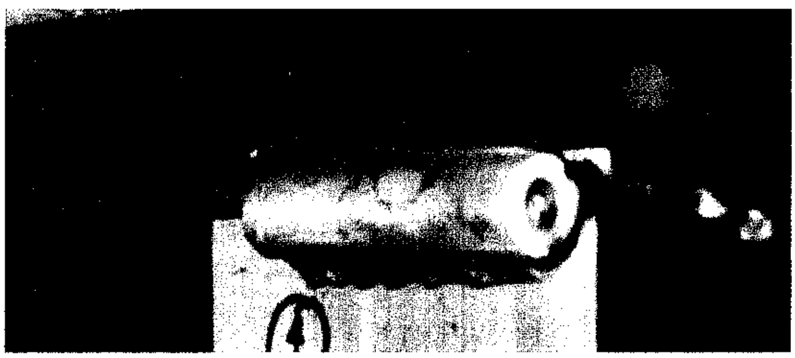

Figure A-4.3 – plate (1000rpm, 10mm/min)