# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND

Welding is the process of joining two or more pieces of material together by bringing the atoms of each piece into such close contact that an atomic bond takes place. To strengthen this statement, as stated by American Welding Society in 9$^{th}$ edition of Welding Science and Technology [1], the physics of welding deals with the phenomena associated with welding processes and the formation of weld bonds. Fusion welds are created by coalescence of molten base metals mixed with molten filler metals. Metals must be heated to the melting point for fusion welds to be produced. Heat for melting is either developed at the intended weld joint or applied to the intended joint from an external source.

Heat Affected Zone (HAZ) as being mentioned by Ivan Hrivnak [2] is a part of weld joint whose microstructure is influenced by heat while the weld joint is being formed. To simplify this statement, HAZ actually is an area of adjacent to the weld metal zone which is affected by the heat lost to the surroundings by conduction. Figure 1.1 illustrates HAZ occurred in welded joint process [2]:

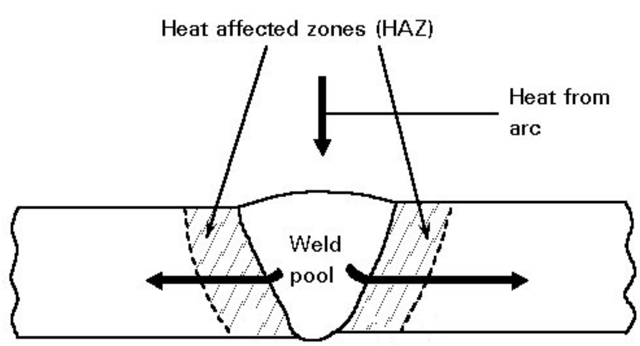



Figure 1.1: HAZ regions in welded joint process [2].

## 1.2 PROBLEM STATEMENT

To understand and predict the mechanical properties of a weldment, the microstructure and properties of the welded joint were studied by having some specimens made from the real welded joint process. These specimens will be exposed to different range of temperatures started with 300$^{o}$C until 800$^{o}$C in an electrical furnace. An analysis of welded joint metals can be carried out in term of mechanical properties of the specimens itself since thermal of the heat-affected zone has a substantial influence on its structure and properties.

## 1.3 OBJECTIVES

The objectives of this study are:

i. To study the effect of different temperature applied on the welded joint.
ii. To determine the mechanical properties of welded joints upon increasing of temperatures.

## 1.4 SCOPE OF STUDY

Implementation of welding method using Shielded Metal Arc Welding (SMAW) process will be carried out to mild steel plate. To evaluate its mechanical properties, type of mechanical testing had been identified in order to study the properties of the specimen. Test that will be carried out are Vickers hardness test and Charpy V notch test.

# CHAPTER 2

## LITERATURE REVIEW

The weldability of a metal is usually defined as its capacity to be welded into a specific structure that has certain properties and characteristics. The structural integrity of welded components operated at elevated temperatures is of key importance in any structural welded joint applications. Noted by Ivan Hrivnak [2], weld metal is often formed through heating of the material above the solidus temperature, but becomes extruded from the zone when the weldments are pressed together.

The area adjacent to the weld is termed as Heat Affected Zone (HAZ). The author have the same opinion with Ivan Hrivnak [2], whereby he claimed that HAZ region is the portion of the weld joint which has experienced peak temperatures high enough to produce solid state micro structural changes but too low to cause any melting. General speaking, the surrounding section of the materials is also affected by strain. In such a case, the affected zone is given by a superposition of the action of heat and strain.

The welded joint undergoes important metallurgical and physical changes which have a major effect on the properties and performance of the welded component or structure. Mechanical properties of metals can be determine via the range of usefulness of the metal and establish the service that can be expected. Mechanical properties are also used to help specify and identify metals. The most common properties considered are hardness and ductility of the materials itself.

## 2.1 METALLURGY OF WELD METAL

Although a weldment formed by the fusion welding result in the information of monolithic structure but such a joint varies in a metallurgical structure from point to point variation in mechanical properties. Basically in welding process, as the heat source interacts with the material, the severity of thermal excursions experienced by the material varies from region to region, resulting in three distinct regions in the weldment. These are:

i. The fusion zone (FZ) also known as the weld metal.
ii. The heat affected zone (HAZ).
iii. The unaffected base metal (BM).

Weld metal zone constitute the weld bead and is a cast structure. The HAZ in a way is the heat treated portion of the weldment while the unaffected base metal is originally work material. Different microstructure may be expected from different zones of weldment formed by the fusion welding.

### 2.1.1 Weld Metal Zone

The weld metal zone is formed by the solidification of weld pool which itself is formed by the melting of a part of parent material plus the additional material solidification of molten metal in the weld pool start as soon as it reaches the liquidus temperature for that material composition it require no under cooling and as the partially grain provide the nuclei where from the growth of the grain start in to the solidifying weld pool such a mode of solidification is referred to as epitaxial solidifications.

### 2.1.2 Heat Affected Zone

HAZ is a part of welded joint which has been heated up to a temperature unto the solidus of parent material resulting in varying degree of influence of microstructure on a consequences of heating and cooling cycle depending upon the pack temperature. As being mentioned by Samsiah Sulaiman [5], HAZ is the portion of the weld joint which has experienced peak temperatures high enough to produce solid state micro structural changes but too low to cause any melting. Almost material properties in an HAZ are degraded compared to the base material Microstructure changes in the HAZ depend on the chemical composition of steel and also on its original microstructure. In the actual weld joint, HAZ is only a few millimeters wide and the structures and properties of the HAZ cannot be readily determined from an actual weld joint. The HAZ in the steel can be subdivided into the following zones starting from the weld metal site:

i. Under bead zone: The part of HAZ which is heated to beyond critical temperature of grain growth and extend up to the fusion boundary zone.
ii. Grain growth zone beyond 1250$^{o}$C peritectic temperature.
iii. Grain refined zone: 950$^{o}$C to 1150$^{o}$C up to grain refined temperature.
iv. Partially transform zone: 750$^{o}$C to 950$^{o}$C.
v. Zone of sophisticated carbide: 550$^{o}$C to 750$^{o}$C.
vi. Zone of unchanged base material: up to 550$^{o}$C.

The material microstructure in the HAZ varied based on its polymorphous transformations. Steels destined for any type of construction must be suitable for welding. Significant structural changes take place in HAZ of steels that have an impact on the properties of weld joints. The solidified weld metal has a cast structure and has properties characteristic of cast steel. The composition of the electrode is usually chosen so that the resultant weld metal is stronger than the connected elements. Occasionally, specific conditions may override this choice. When the weld pool is cooling and solidifying, the majority of the heat flows through the parent metal alongside the joint. The steel is thus subjected to heating and cooling cycles similar to those experienced in heat treatment practice.

A characteristic feature of structural change in the area of weld joints is that they take place in the presence of gradients, Ivan Hrivnak [2]. A temperature gradient results from heat flow from its source right up to the unaffected material. Temperature gradient emphasizes that no two adjacent sites have the same temperature at a given moment. Knowledge and prediction of the shape or parameters of the thermal cycle is of essential significance for estimating steels weldability. The final microstructure of a section HAZ depends on several factors including composition, grain size, peak temperature attained, heating and cooling rates.

## 2.2 WELDING

The term welding is applied to a process yielding an inseparable joining of materials. A metallurgical joining of metal section can be achieved in welding with the aid of a weld metal. Citation by Ivan Hrivnak [2], the weld metal is formed with the aid of molten filler materials. The weld metal may generally be said to be that part of the weld joint which is heated above the solidus temperature of the matrix metal, formed from the fused base material mixing with the deposited filler material. Welding processes are divided into three basic categories which are:

i. Fusion welding.
ii. Solid- state welding.
iii. Brazing and soldering.

Most fusion welding processes apply heat from an external source to the weld joint to produce the weld bond. Heat is transported from the heat source to the joint by conduction, convection and radiation. Sources of externally developed heat include electron beams, laser beams, exothermic chemical reactions and electric arcs. Fusion welding processes that apply heat from external sources are usually identified according to the type of heat source employed, American Welding Society (AWS) [3].

This external heat source is applied to the prepared edges to be joined and moved along the intended joint. The welded joint is formed over period of time required for the heat source to transverse the length of the joint. The energy density of the heat source must be sufficient to accomplish local melting. Filler metal may be added, in which case the heat source must also melt the filler metal as it is delivered to the joint. The transferred power of a heat source is the rate at which energy is delivered per unit time from the heat source to the workpiece, typically expressed in joules per second or watts. The heat produced by a welding heat source occurs in 2 stages. First, heat is transferred from the source to the surface of the workpiece. Then heat is transferred within the workpiece from the contact area to colder regions of the materials to be joined.

The term arc welding applies to a large, diversified group of welding processes that use an electric arc as the source of heat. Electric arcs, the most widely used heat source are the basis for the various arc welding processes. It is widely used because the heat of the arc can be effectively concentrated and controlled. An electric arc consists of a relatively high current discharge sustained through a thermally ionized gaseous channel termed as a plasma column. The arc is established between a welding electrode and the workpiece.

The creation of weld between metals using these processes does not usually involve pressure but may utilize a filler metal. The arc is struck between the workpiece and the tip of the electrode. The intense heat produced by the arc quickly melts a portion of the base metal resulting in the formation of a weld. The arc welding processes may be moved along the joint to produce the weld or held stationary while the workpiece is moved under the process. Shield Metal Arc Welding (SMAW) is one of the common used processes that operate with external heat sources. The electrode may be consumable to SMAW which provide filler metal where the heat input to the electrode is carried to the weld in the form of thermal energy of the liquid filler metal.

### 2.2.1 Shielded Metal Arc Welding (SMAW)

Arc welding operations are performed by conducting the welding current through consumable electrodes, which take the form of a wire or rod, or non consumable electrodes consisting of carbon or tungsten rods. Metal arc processes utilize consumable electrodes that combine electrode filler metal with the molten base metal to create the weld. They may also produce a slag covering to protect the molten metal from oxidation. The non consumable arc processes can generate a weld by melting the base metal only, resulting in what is termed an autogenously weld. If filler metal is required in a non consumable process, it may be fed either manually or mechanically into the molten weld pool. In this case, the non consumable electrode serves only to sustain the arc.

SMAW is a basic, versatile process used to weld ferrous and some nonferrous metals. The most widely known of the arc processes is sometimes referred to colloquially as stick welding or simply arc welding, G.A Kennedy [3]. Detailed by AWS [1], this process which is applied without pressure incorporates the use of a metal arc, which is formed between a covered electrode and the weld pool. The electrode consists of a wire core around which a concentric mixture of silicate binders and powdered materials such as fluorides carbonates, oxides, metal alloys and cellulose is extruded. This covering serves as a source of arc stabilizers and vapors to displace air as well as metal and slag to protect, support and insulate the hot weld metal.

The bare section of the electrode is clamped into an electrode holder, which in turn is connected to the power source by a cable. The workpiece is connected to the other power source terminal. The arc is initiated by touching the tip of the electrode on the workpiece and then withdrawing it slightly. The heat of the arc melts the base metal in the immediate area along with the electrodes metal core and covering. The equipment used in shielded metal arc welding is the simplest and least expensive of that used for the electric welding processes.

This kind of welding may be devised to meet various needs such as to:

i. Minimized costs.
ii. Control distortion.
iii. Avoid defects or achieve good impact properties.

Figure 2.1 below illustrated the connection of SMAW process:

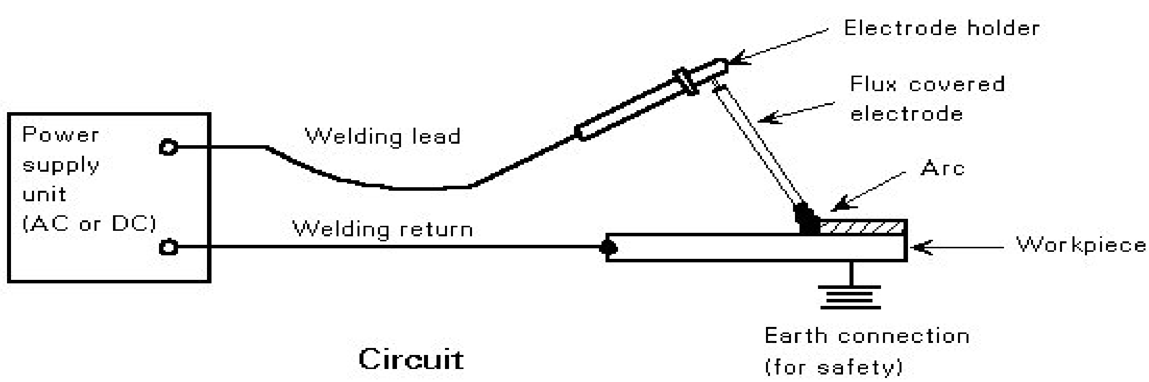



Figure 2.1: SMAW process.

As stated in Figure 2.1, the necessary components for SMAW are a power source of adequate current rating and duty cycle, suitably sized electrical cables, an electrode holder, and a workpiece lead clamp. Utility duty, single phase alternating current (AC) welding machines are the least expensive and can be used with small electrodes designed for ac current. Industrial duty alternating current/direct current or dc power source can be used with the greatest variety of electrodes.

The current controls heat input. The minimum value is fixed by the need to fuse the plate and to keep the arc stable; the specified minimum, however, may be higher to avoid HAZ cracks. The maximum current depends on operating conditions. Usually, as high a current as possible is used to achieve faster welding, and hence lower costs. The most commonly used heat source, in structural work, is a low voltage 15V to 35V, and high current of 50 amps to 1000 amp arc. The use of maximum current may be restricted by position. High currents usually give low impact properties.

The electrode consists of a steel core wire and a covering flux containing alloying elements, such as manganese and silicon. The arc melts the parent metal and the electrode. As metal is transferred from the end of the core wire to the weld pool, the welder moves the electrode to keep the arc length constant. This is essential as the width of the weld run is largely governed by the arc length. The flux melts with the core wire and flows over the surface of the pool to form a slag, which must be removed after solidification.

The operating characteristics of the electrode are controlled by the composition of the flux covering. A variety of electrodes are available to suit different applications. The current used is chosen to match the diameter of wire being used. When low hydrogen contents in the weld pool are necessary to avoid cracks in the heat-affected zone (HAZ) on cooling, SMAW electrodes must be baked and stored at temperatures and times recommended by the manufacturer. These procedures ensure that the electrodes deposit weld metal with appropriate low levels of diffusible hydrogen.

The advantageous of this SMAW process classified by G. A. Kennedy [1] are as below:

i. Low capital cost.
ii. Freedom of movement; it can be used up to 20m from the power supply.
iii. It can be used in all positions.
iv. It is suitable for structural and stainless steels.

With respect to PPE, operators that used this machine must wear sturdy dry clothing and leather gloves for protection against spatter and electric shock. A helmet equipped with a dark lens shields the eyes from the brilliance of the arc, electromagnetic radiation and flying slag particles. This guideline was stated by A.C Davies [4].

## 2.3 PROPERTIES AND TESTING METHOD

Welded joints are expected to possess certain service related capabilities. Weld testing specifically refers to the physical performance of operations to determine quantitative measure of certain properties. In other words, this process aims to determine quality.

The behavior of welded components is depends on the properties of its welded joint with BM, HAZ and FZ. BM is a structural steel itself, with uniform microstructure and mechanical properties, corresponding to its chemical composition and manufacturing procedure while FZ is obtained by crystallization of base metal and electrode material mixture by heat introduced during welding. As for the HAZ, temperature gradient occurred during welding from melting point to the level at which no more transformation. From this process, it’s possible the microstructure is continuously changed. The structural and sub structural transformations in HAZ result in mechanical, electrochemical and physical properties. The properties of HAZ in metals with polymorphous transformation are principally affected by the product of that transformation.

Destructive tests are carried out on test specimens made. These kinds of tests are of greatest value in determining the ultimate strength of a weld and afford a check on the quality of weld metal. Eventually, this test has been divided as follow:

i. Test capable of being performed in the workshop.
ii. Laboratory test, which may be divided into;
    a. Microscopic and macroscopic.
    b. Chemical, analytical and corrosive.
    c. Mechanical.

As for this project, the main intention of the author was to study the mechanical properties of HAZ by doing some mechanical test upon weldment.

### 2.3.1 Mechanical Test

Mechanical test in welding structure is regarded as the most reliable and least expensive to determine strength and other properties. This kind of destructive testing are carried out to the specimen's failure, in order to understand a specimen's structural performance or material behavior under different loads. Destructive testing is most suitable, and economic, for objects which will be mass produced, as the cost of destroying a small number of specimens is negligible. These tests are generally much easier to carry out, yield more information, and are easier to interpret than nondestructive testing. Types of testing are as below:

i. Hardness test.
ii. Impact test.

#### 2.3.1.1 Hardness Test

The Metals Handbook defines hardness as "Resistance of metal to plastic deformation, usually by indentation". The dictionary of Metallurgy defines the indentation hardness as the resistance of a material to indentation. This is the usual type of hardness test, in which a pointed or rounded indenter is pressed into a surface under a substantially static load.

Hardness testing of welds provides an indication of two parameters significant to the determination of a successful weld joint:

i. Strength.
ii. Microstructure of a known material.

Schematic diagram of each area with its hardness traverses outcome was represented by Figure 2.2:

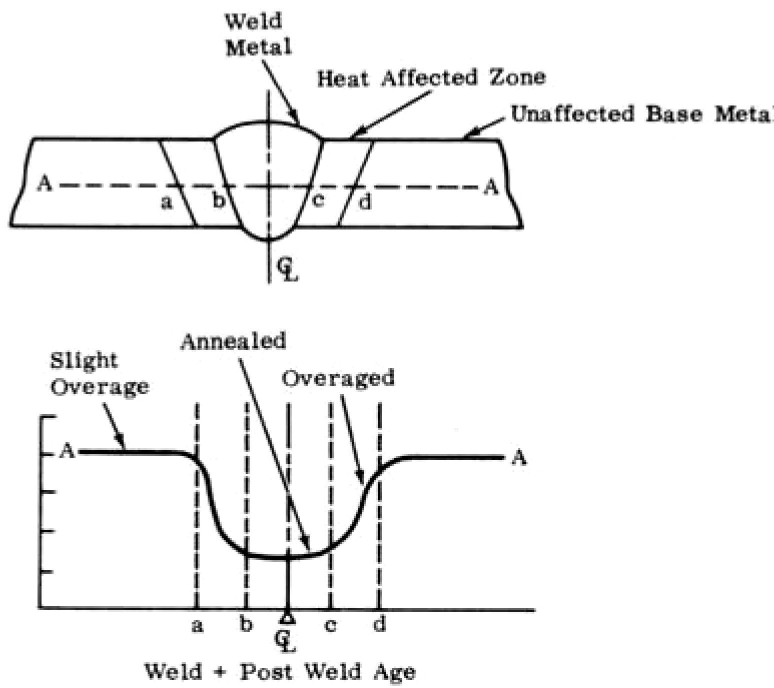



Figure 2.2: Schematic diagram of hardness traverses of welds in each area.

Indentation tests use an indenter that is pressed against the surface of a material in order to leave an indentation on that surface. The type and material of the indenter, the load applied to the indenter, and the length of time that the load is applied are all controlled so that the dimensions of the indentation that results give a direct and accurate value of the hardness of the material at that point.

There are four types of indentation hardness tests which are Brinell, Vickers, Knoop, and Rockwell. Hardness testing of welds and their HAZ usually requires testing on a microscopic scale using a diamond indenter. The Vickers Hardness test is the predominant test method with Knoop testing being applied to HAZ testing in some instances.

Hardness measurement can be defined as macro, micro or nano scale according to the forces applied and displacements obtained. Measurement of the macro-hardness of materials is a quick and simple method of obtaining mechanical property data for the bulk material from a small sample. It is also widely used for the quality control of surface treatments processes. For materials that have a fine microstructure, are multi-phase, non-homogeneous or prone to cracking, macro-hardness measurements will be highly variable. Micro hardness is the hardness of a material as determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of the material. Micro indenters works by pressing a tip into a sample and continuously measuring: applied load, penetration depth and cycle time.

The micro hardness test method is used frequently throughout the world to obtain test results for small test samples of a variety of materials including steels. The test method requires a square pyramid indenter made of diamond to be pressed into the test sample at a specified load. Then the indentation is measured from tip to tip in both axes. The average measurement is converted to a Vickers hardness value according to a formula or a chart based on the formula. Higher loads create larger indentations which are more accurately measured. Higher loads provide more indentation resolution and more measurement resolution so the result is generally more reliable.

Generally, the main requirement for the test sample in Vickers hardness testing is a level, polished finish test surface and loads applied for 10 to 15 seconds. Samples also need to be securely mounted perpendicular to the indenter to prevent any rocking during the test. Figure 2.3 shows the schematic diagram of Vickers indentation;

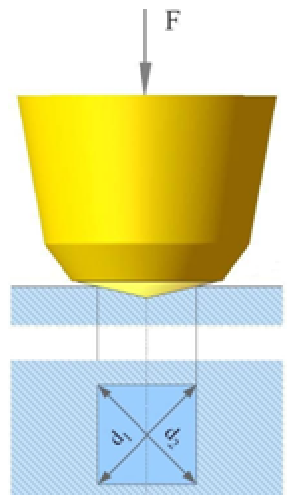



Figure 2.3: Vickers indentation [3].

The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º. The diamond is pressed into the surface of the material at loads ranging up to approximately 120 kilograms-force, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated using the following formula:

$$HV = 1.854(F/D2) \text{ ............... (Equation 1)}$$

F is the applied load which is measured in kilograms-force and D is the area of the indentation measured in square millimetres. The applied load is usually specified when HV is cited. The diamond material of the indenter has an advantage over other indenters because it does not deform over time and use. The impression left by the Vickers penetrator is a dark square on a light background. The Vickers impression is more easily "read" for area size. The Vickers number is determined by dividing the load by the surface area of the indentation using the following formula;

$$H = P/A \text{ .................. (Equation 2)}$$

The load varies from 1 to 120 kilograms. To perform the Vickers test, the specimen is placed on an anvil that has a screw threaded base. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments.

#### 2.3.1.2 Impact Test

Impact tests are designed to measure the resistance to failure of a material to a suddenly applied force. The test measures the impact energy, or the energy absorbed prior to fracture. In welded joint, this impact test is common to check the ability of a weld to absorb energy under impact without fracturing. This is a dynamic test in which a test specimen is broken by a single blow, and the energy used in breaking the piece is measured. This test compares the toughness of the weld metal with the base metal. It is useful in finding if any of the mechanical properties of the base metal were destroyed by the welding process.

There are 2 common method of impact testing which are known as Charpy and Izod test. The Charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch while the Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise.

The Charpy test is a three point bend impact test. It requires a specimen containing a machined notch in the center of the face facing away from the impacting device and a sturdy machine that can impart a sudden load to the specimen. The Charpy tester consists of a heavy pendulum which is allowed to strike the specimen at the bottom of its arch as shows in Figure 2.4:

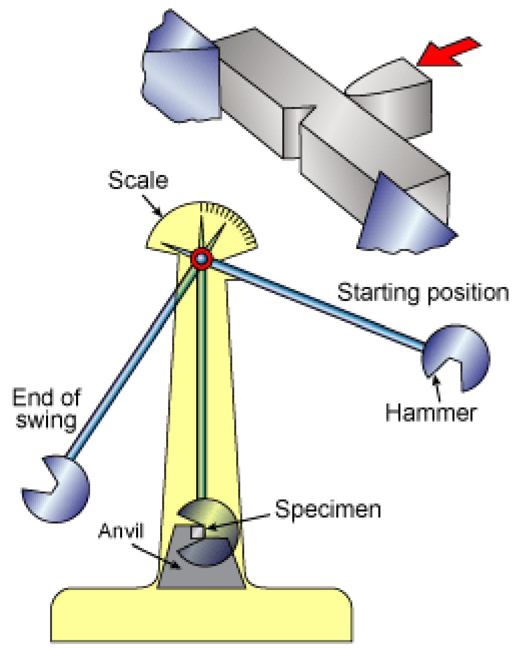


Figure 2.4: Schematic of Charpy test [3].

As the specimen deforms and fractures, a portion of the kinetic energy of the pendulum is transferred to the specimen. The specimen is broken and the two pieces of the fractured specimen are knocked clear of the testing machine while the pendulum continues its swing to a somewhat lower position than it was released from. The differences in these heights and the mass of the pendulum determine how much energy was absorbed by the specimen.

The results of the Charpy tests are useful indications of how the material might behave in service.It is a relatively simple, quick and inexpensive method for testing the dynamic fracture behavior of materials. ASTM E23 describes the Charpy test in detail. The most common type of Charpy test used a V-notched specimen.

# CHAPTER 3

## METHODOLOGY

### 3.1 SPECIFIC PROJECT ACTIVITIES

Project activities performed is shown in Figure 3.1 below:

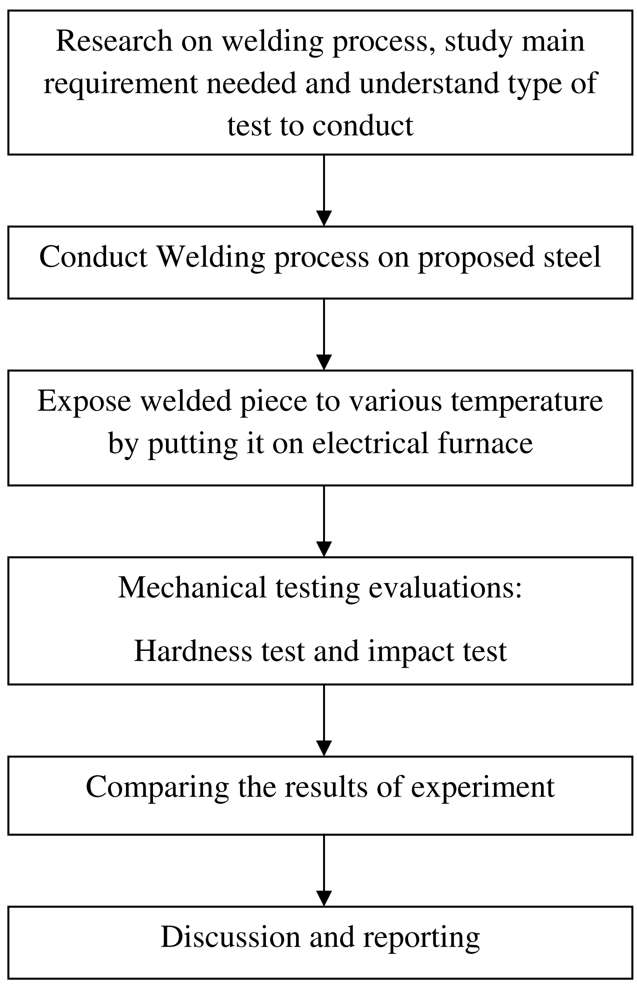
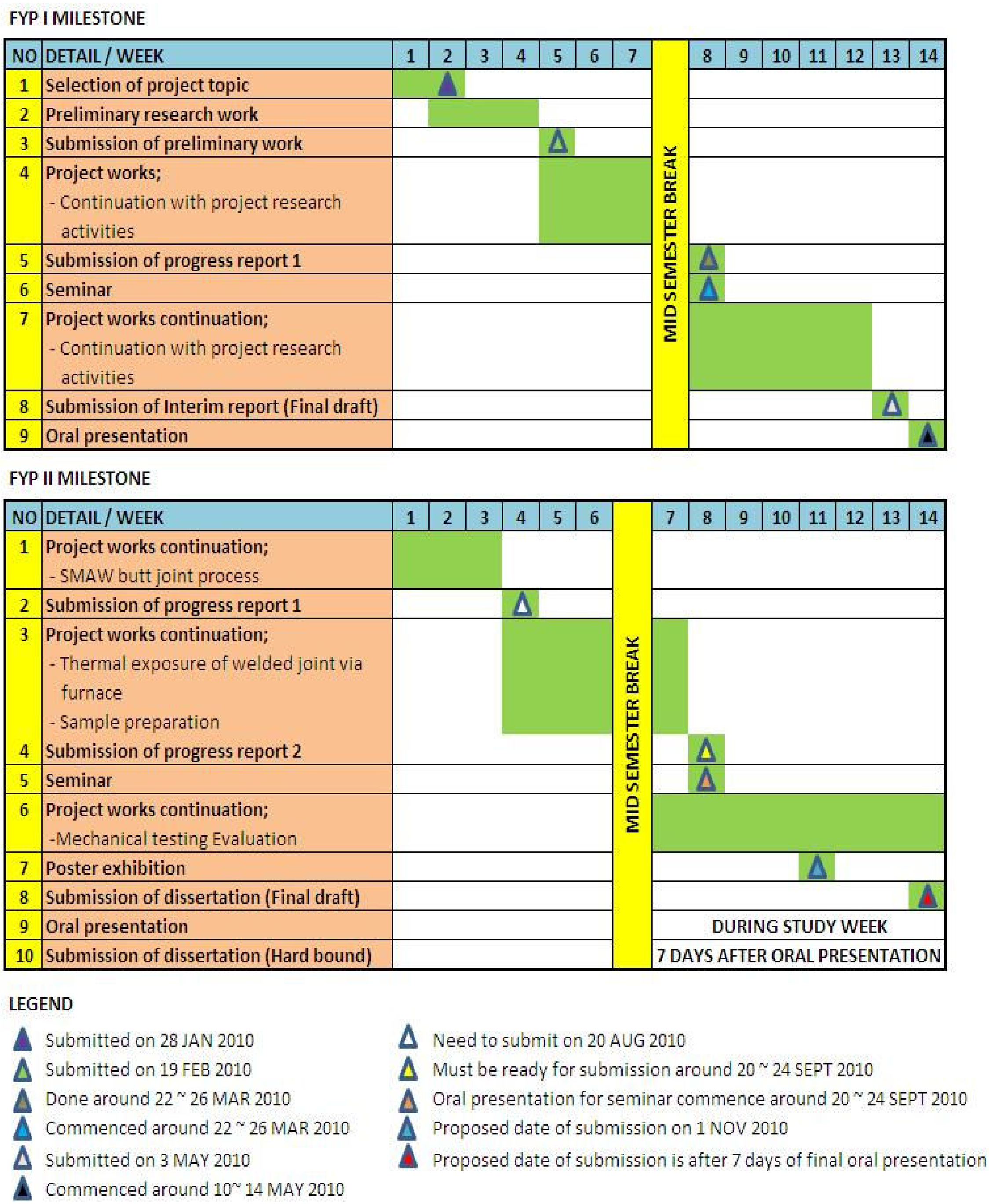



Figure 3.1: Project process flow.

## 3.2 MILESTONES

FYP I and FYP II milestones are stated as Table 3.1 below:

Table 3.1: FYP I and FYP II milestones.



### 3.3 SAMPLE PREPARATIONS

Basically, test equipment used for development of this study can be classified as Figure 3.2 below:

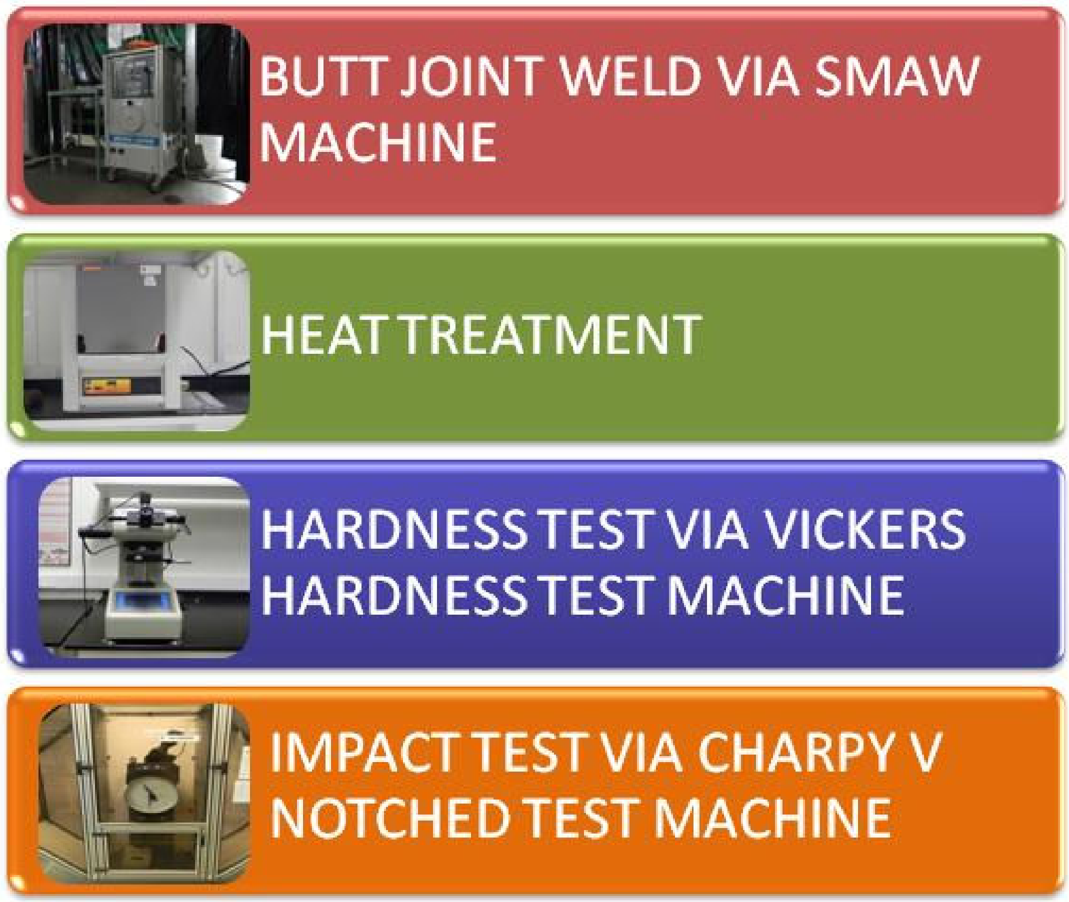



Figure 3.2: Test equipment used in this study.

From Figure 3.2, a lot of samples are needed in order to complete this study. Various methodologies that were used for these sample preparations comprised of:

i. Welding process.
ii. Cutting process.
iii. Heat treatment process.
iv. Grinding and polishing process.
v. Hardness measurement.
vi. Impact testing.

### 3.3.1 Welding Process

A welded joint was produced by the SMAW process using AWS E 6013 (RB 26) electrode. This kind of electrode is a low carbon steel electrode with high tatania-potassium type coating and suitable for both AC and DC. Main reasons for the usage of this kind of electrode are stated below:

i. Its ability to provide excellent welding technological performance because the arc is extra stable.
ii. Spatter loss is negligible.
iii. The slag is easy to remove.

In general, this welding electrode are being mostly used in structural steels, as for this project a mild steel has been used. Figure 3.3 show the AWS E 6013 (RB 26):


Figure 3.3: KOBELCO welding electrodes AWS E 6013 (RB 26).

As being stated earlier, the material used for welding procedures is a joining of 2 pieces of mild steel. The actual figure of this proposed mild steel has been stated in Figure 3.4 and Figure 3.5 for the outcome from this joining process while Figure 3.6 was the actual welding machine used for this study:

Figure 3.4: Raw mild steel.


Figure 3.5: Single V butt joint weld.


Figure 3.6: Nichia arc welding machine, ND – 300.

For this study, the welding parameters used are as follows:

i. Mild steel plate with 12-mm thickness, Welding current: 55 Amp, and electrode type: AWS E 6013 (RB 26).
ii. Root pass parameters: electrode diameter: nominal 2 mm, positive electrode polarity and welding voltage: 60 V.
iii. Filling pass parameters: 4 mm electrode diameter, welding current: 120 Amp, DC, positive electrode polarity and welding voltage: 60 V.
iv. Position: flat.
v. Joint type: single V joint with 60°.
vi. Root gap: 2 mm.

### 3.3.2 Cutting Process

To locate the area of interest, sectioning or cutting is the most common technique for obtaining this area of interest. In cutting the specimen from the main body of the material, proper care has been taken in order to minimize altering the structure of the metal. Via referring to ASTM E3 – 95, section 6 clause 6.1 for cutting of metallographic specimens, the author of this report choose to use sawing by machine with lubrication as sectioning method. The length of the specimens has been decided to be 15 mm each. Equipment used was linear hack saw machine and the process can be described in Figure 3.7 and 3.8 as for the outcome from this process are stated in Figure 3.9:


Figure 3.7: Linear hacksaw machine.

Figure 3.8: Material sectioning process.

Figure 3.9: Actual specimen 15 mm $\pm$ 5 mm.

Proper sectioning should have the following characteristics:

i. Flat and cut close to the area of interest.
ii. Minimal microstructure damage.
iii. Smeared metal.
iv. HAZ.
v. Excessive subsurface damage.
vi. Damage to secondary phases.

### 3.3.3 Heat Treatment Process

Heat treatment is defined as an operation or combination of operations, involving heating and cooling of a metal, alloy or for this case involving the mild steel in its solid state with the object of changing the characteristic of the material. The changing of the characteristic can be explored through the microstructure test with applying the microscope that was form various characteristic as pearlite, martensite, temper martensite and so on. Heat treatment is generally employed for following purposes such as to improve mach inability, to change or refine the grain size of the material structure, to improve mechanical properties such as tensile strength, hardness, ductility and so on. Equipment used in this process was CARBOLITE RHF 1400 as shown in Figure 3.10. The heat treatment involved was carried out as stated in Table 3.2 of process parameter for 45 min and air cooling to room temperature (normalized condition). Specimens were prepared as per AWS D1.1standard with heat treatment welded joints.

Figure 3.10: Carbolite RHF 1400 used for heat treatment process.

Table 3.2: Heat treatment parameter.

| SAMPLE NO | QUANTITY | TEMPERATURE SET UP |
|---|---|---|
| 1 | 5 | $300^0C$ |
| 2 | 5 | $400^0C$ |
| 3 | 5 | $500^0C$ |
| 4 | 5 | $600^0C$ |
| 5 | 5 | $700^0C$ |
| 6 | 5 | $800^0C$ |

### 3.3.4 Grinding and Polishing Process

For this process, equipment used was Buehler Metaserv 2000 dual polisher grinder as stated in Figure 3.11. The sample is ground on progressively finer Silica Carbide (SiC) waterproof paper from 120 to 1000 grit, to produce a reasonably flat surface and it is lubricated with water to keep it cool and to remove the grinding products. The sample should be moved forward and backward on the paper until the whole surface is covered with unidirectional scratches. It is then washed with running water to remove debris associated with the grade of paper used. It is then ground on the next finer paper such that the scratches produced are at right angles to those formed by the previous paper. This procedure is repeated through the range off papers available.

Figure 3.11: Buehler Metaserv 2000 dual polisher grinder.

When the specimen has been ground on the final paper, it is generally worthwhile rotating it through and grinding again with less pressure than before. This technique can decrease the time required for the next stage, which is polishing. Polishing is the final step in production a surface that is flat, scratch free and mirror like in appearance. This is done using rotating wheels covered with a cloth impregnated with a very fine abrasive compound. Before polishing, the specimen must be washed and dried to remove any SiC particles. Usually, rough polishing is done with the laps rotating at 500 and 600 rpm. Cloths with a medium or high nap are ordinary used on slow rotating laps for intermediate and final polishing.

As for the polishing technique, it should not introduce extraneous structure such as disturbed metal, pitting, dragging out of inclusions, comet tails and staining. Polishing usually involves the use one or more of abrasives:

i. Aluminum oxide ($Al_2O_3$).
ii. Magnesium oxide (MgO).
iii. Iron oxide ($Fe_2O_3$).
iv. Diamond compound.

The common compounds used are diamond and alumina. The polishing was done by the following grades of emery papers:

i. 400.
ii. 600.
iii. 800.
iv. 1000.
v. 1200.

The requirement of any good polishing cloth include the ability to hold an abrasive, long life, absence of any foreign material that may cause scratches, and absence of any processing chemicals that may react with the specimen. The cloth most frequently used is canvas, low nap, cotton, nylon, silk and pylon. Figure 3.12 below was an outcome from this process:

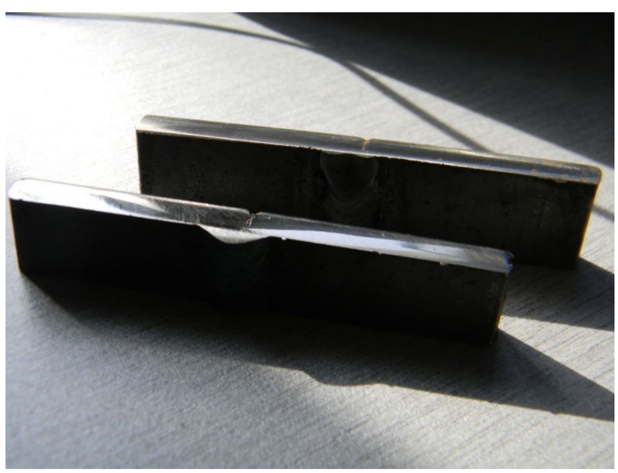


Figure 3.12: Smooth and mirror surface finish of samples.

### 3.3.6 Hardness Measurement

Hardness testing of welds and their Heat Affected Zones (HAZ) usually requires testing on a microscopic scale using a diamond indentor. The Vickers Hardness test is the predominant test method that being applied to HAZ. A hardness value was referred in terms of the Vickers Number, “HV”. This test is obtained by dividing the load applied to indent the pyramidal diamond into the test piece by the area of indentation thus created. Hardness characterizations were carried out in the polished and etched condition taking special care to eliminate the possible deformed layers on each specimen by repeated polishing and etching. The heat-treated specimens were subjected to Vickers hardness test. Thus the micro hardness testing was been carried out with loads in the 0.5 to 2 kg range. Figure 3.13 below show the Vickers hardness test equipment:

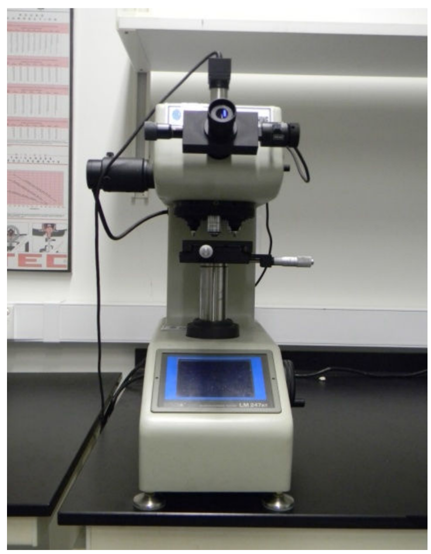


Figure 3.13: Vickers hardness test equipment.

The hardness profile was drawn through the unaffected base metal, heat affected zones and as well as welds metal zones. The applied load is 300mg and the indentation time is 30 according to ASTM E92-72. The arithmetic mean, the maximum and minimum values of the hardness number of each specimen are determined. The outcome of the results will be compared with Figure 2.2.

### 3.3.7 Impact Testing

Charpy impact tests are a type of dynamic fracture test that probes the ability of steels to absorb energy before fracturing. In the Charpy test, the energy used to break a notched specimen is measured as a function of temperature. It is conducted in order to study the behavior of welded structure under shock or impact loads. The test analysis indicates resistance offered by the material to rapid buildup stresses. In this way, the toughness of the material was analyzed. A charpy specimen of cross section measuring 10x10mm, length 55 mm with 45 degree notch of 2mm depth and 0.25 mm root radius from heat treated HAZ selected region will be hit by a pendulum at the opposite end of the notch.

To perform the test, the pendulum is raised to a specific position and impact the specimen at the opposite end of the notch to produce a fractured sample. The potential energy equal to approximately 300J is stored. This potential energy is converted into the kinetic energy after releasing the pendulum. The absorbed energy required to produce two fresh fracture surfaces will be recorded in the unit of Joule. Predicted outcomes that can be made from this test was the greater of the high of the pendulum swings to the other side of the machine, the less energy absorbed during the fracture surface. This means the material fractures in a brittle manner. On the other hand, if the absorbed energy is high, ductile fracture will result and the specimen has high toughness. This test was carried out on a polished and etched condition eliminating possible deformed layers on each specimen. Equipment used is shown in Figure 3.14 below:


Figure 3.14: Amsler RKP 450 impact testing machine.

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 HARDNESS TEST

The sample for the hardness measurement of real HAZ was cut from a welded joint obtained by shielded metal arc welding (SMAW) method. As been stated earlier in the literature review, the test was carried out for the weld joint at the BM, HAZ and FZ. The experimental values of the Vickers hardness number which has been proposed in Figure 2.2 were tabulated and presented from tables 4.1 until 4.5 and from figures 4.1 until 4.5 with regards of each area:

Table 4.1: Microhardness values for A-a area.

| TEMPERATURE (°C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) | TEMPERATURE (°C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) |
|---|---|---|---|---|---|
| 300 | 221 | 220 | 600 | 220.3 | 220 |
| | 219.8 | | | 220 | |
| | 220 | | | 220.1 | |
| | 219.9 | | | 220 | |
| | 220 | | | 220 | |
| 400 | 219.4 | 220 | 700 | 220 | 220 |
| | 220.2 | | | 220 | |
| | 220.5 | | | 220.3 | |
| | 218.3 | | | 220 | |
| | 221.2 | | | 220 | |
| 500 | 220.1 | 220 | 800 | 220 | 220 |
| | 220 | | | 220.1 | |
| | 220.2 | | | 221 | |
| | 220.1 | | | 220 | |
| | 220.2 | | | 221.3 | |

Table 4.2: Microhardness values for a-b area.

| TEMPERATURE ($^{o}$C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) | TEMPERATURE ($^{o}$C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) |
|---|---|---|---|---|---|
| 300 | 216.9 | 218 | 600 | 200.5 | 202 |
| | 213.3 | | | 201.1 | |
| | 217.4 | | | 200.4 | |
| | 221.7 | | | 202.6 | |
| | 220.6 | | | 203.9 | |
| 400 | 215.7 | 214 | 700 | 199.7 | 198 |
| | 214.3 | | | 195.9 | |
| | 211.6 | | | 198.9 | |
| | 218.5 | | | 199.3 | |
| | 210.2 | | | 198.4 | |
| 500 | 210.6 | 210 | 800 | 192.1 | 195 |
| | 207.3 | | | 194.3 | |
| | 210.8 | | | 196.1 | |
| | 213.7 | | | 197.6 | |
| | 205.9 | | | 195.9 | |

Table 4.3: Microhardness values for b-c area.

| TEMPERATURE ($^{o}$C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) | TEMPERATURE ($^{o}$C) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) |
|---|---|---|---|---|---|
| 300 | 193.2 | 195 | 600 | 195.2 | 195 |
| | 194.5 | | | 195.1 | |
| | 194.4 | | | 195.5 | |
| | 195.2 | | | 195 | |
| | 196 | | | 194.4 | |
| 400 | 195 | 195 | 700 | 195.1 | 195 |
| | 195.7 | | | 195.4 | |
| | 195.2 | | | 195.3 | |
| | 194.5 | | | 196.4 | |
| | 195.3 | | | 195.2 | |
| 500 | 192.1 | 195 | 800 | 197.1 | 195 |
| | 193.2 | | | 193.2 | |
| | 196.3 | | | 195.5 | |
| | 195.6 | | | 196.3 | |
| | 194.4 | | | 194.9 | |

Table 4.4: Microhardness values for c-d area.

| TEMPERATURE ($^{o}C$) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) | TEMPERATURE ($^{o}C$) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) |
|---|---|---|---|---|---|
| 300 | 197.3 | 195 | 600 | 209.7 | 212 |
| | 195.9 | | | 214.5 | |
| | 194.8 | | | 213.8 | |
| | 195.6 | | | 212.2 | |
| | 192.5 | | | 211.1 | |
| 400 | 196.3 | 196 | 700 | 213.7 | 214 |
| | 195.9 | | | 217.4 | |
| | 198.1 | | | 213.3 | |
| | 195.4 | | | 210 | |
| | 196.5 | | | 215.4 | |
| 500 | 199.2 | 201 | 800 | 219.4 | 220 |
| | 200.4 | | | 220.2 | |
| | 204.7 | | | 220.5 | |
| | 199.3 | | | 218.3 | |
| | 203.1 | | | 221.2 | |

Table 4.5: Microhardness values for d-A area.

| TEMPERATURE ($^{o}C$) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) | TEMPERATURE ($^{o}C$) | VICKERS HARDNESS VALUE (HV) | AVERAGE (HV) |
|---|---|---|---|---|---|
| 300 | 220.3 | 220 | 600 | 221.1 | 221 |
| | 220 | | | 220 | |
| | 220.4 | | | 220 | |
| | 220.1 | | | 220.4 | |
| | 220.3 | | | 221 | |
| 400 | 220.2 | 220 | 700 | 221.2 | 221 |
| | 220 | | | 220 | |
| | 220.2 | | | 220.4 | |
| | 220.1 | | | 221.1 | |
| | 220.5 | | | 220 | |
| 500 | 220 | 220 | 800 | 221.2 | 221 |
| | 220 | | | 221.5 | |
| | 220 | | | 220.8 | |
| | 220.4 | | | 220.5 | |
| | 220 | | | 221 | |

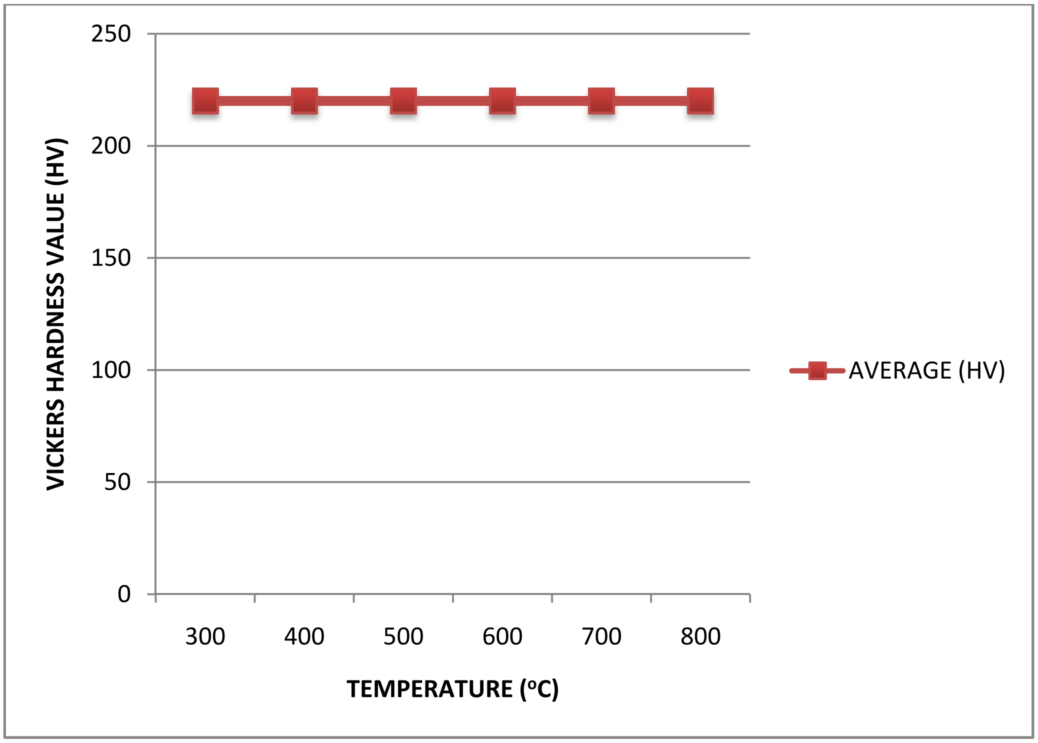



Figure 4.1: Microhardness profile of the weld joints at the position of A-a area.

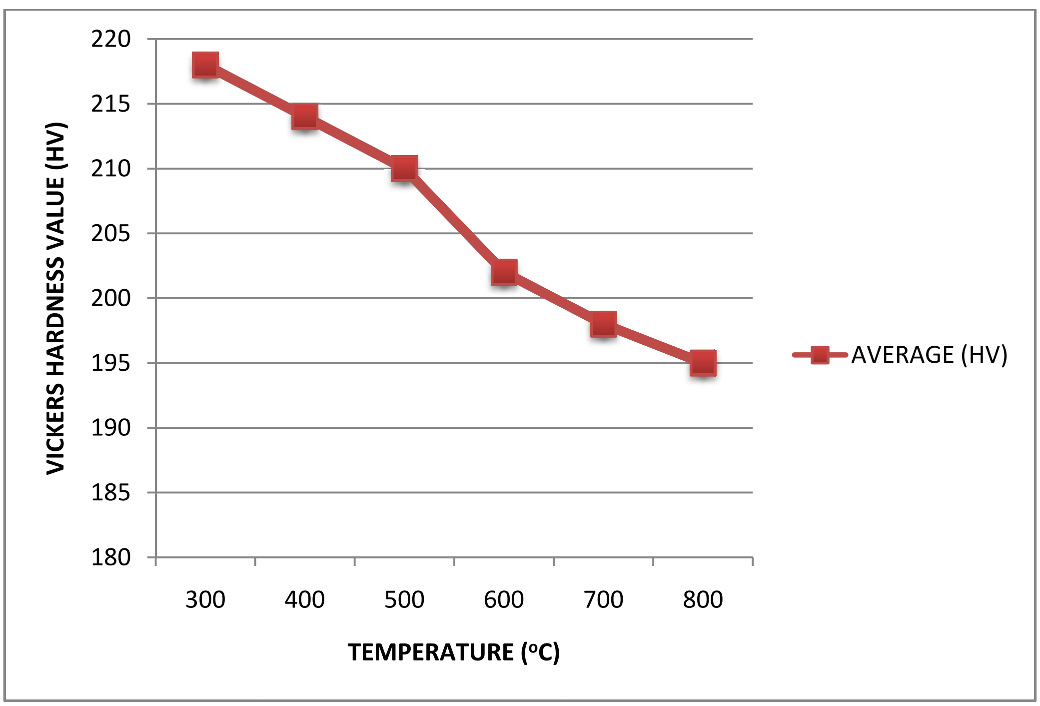



Figure 4.2: Microhardness profile of the weld joints at the position of a-b area.

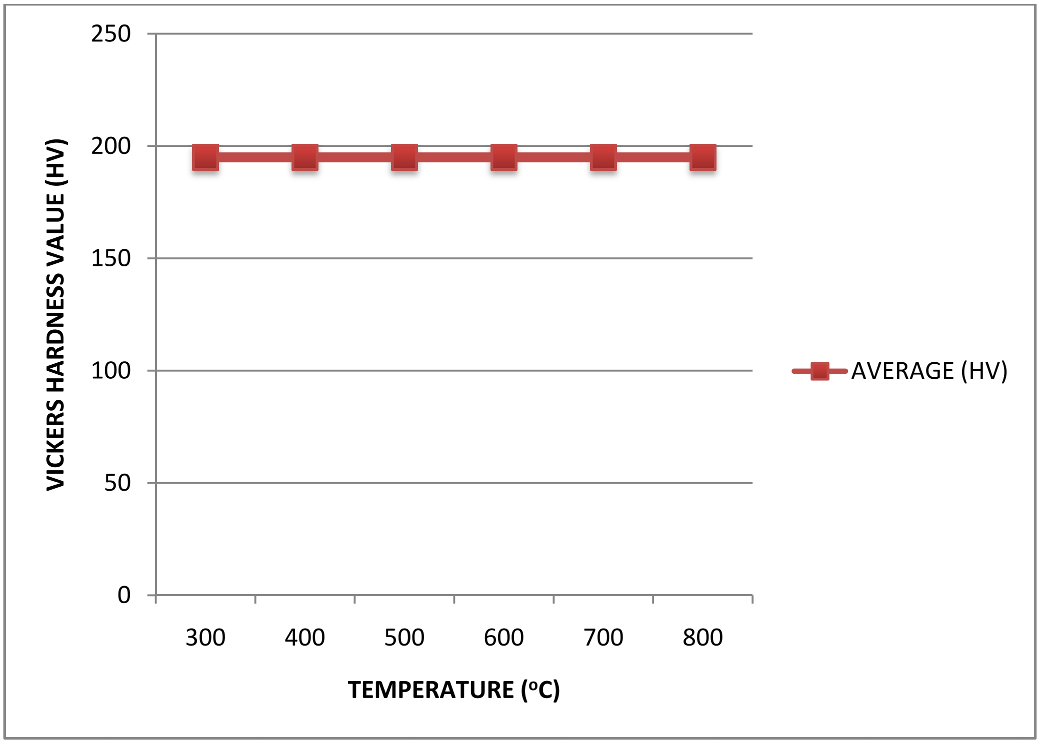



Figure 4.3: Microhardness profile of the weld joints at the position of b-c area.

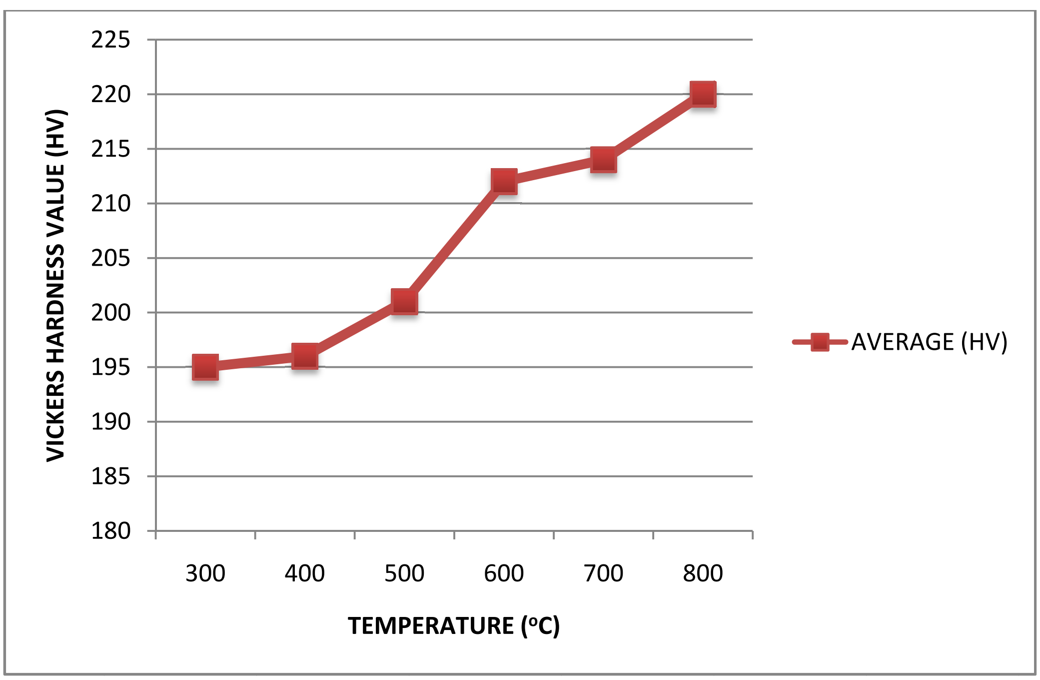



Figure 4.4: Microhardness profile of the weld joints at the position of c-d area.

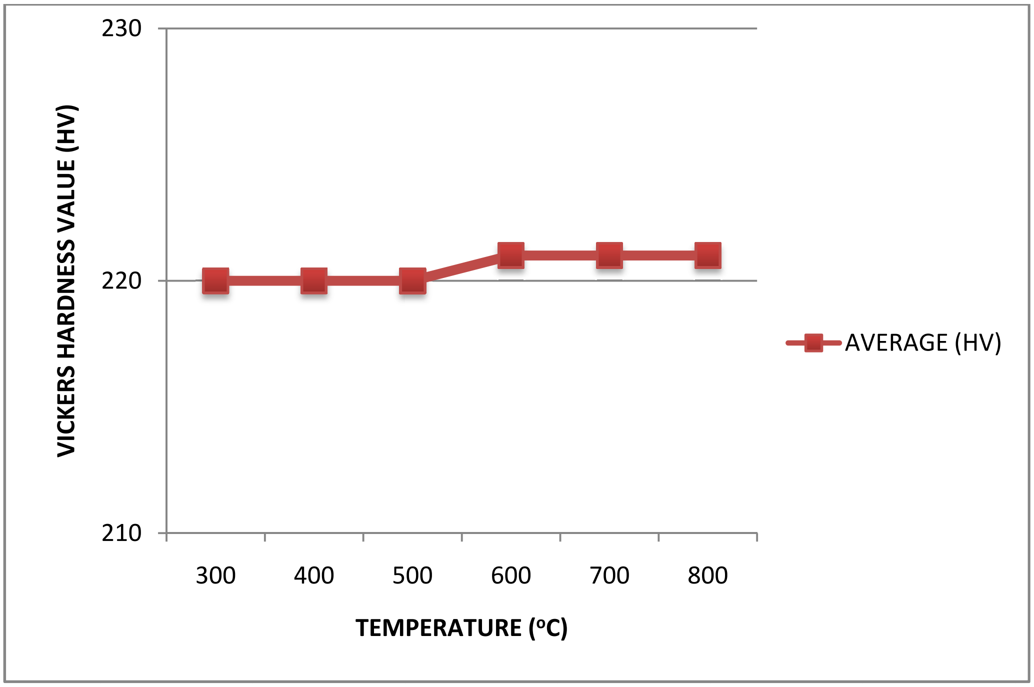



Figure 4.5: Microhardness profile of the weld joints at the position of d-A area.

Based on the result obtained, hardness testing conducted on the weldment cross sections revealed hardnesses in the FZ ranging from b-c area, the HAZ which occurs at 2 side which at a-b and c-d area and the BM resulting from a-A and d-A area.

From the figure itself, the maximum average hardness value observed after 800°C of heat treatment for the three weld zones, (FZ, HAZ and BM) shows that the FZ has a constant value from 300°C to 800°C, which give 195HV. The toughness of the HAZ in a-b area presented decreasing values from 218HV to 195HV when the temperatures of the heat treatment were increase from 300°C to 800°C, while an expressive increase in hardness is observed at c-d area proportional with the increasing of heat treatment temperature. The value obtained was about 195HV to 220HV. The increase of hardness value at this area could be attributed to the effect of thermal cycle on the microstructure variation. As for A-a and d-A area, the hardness profile measure was around 220HV. To conclude this matter, Figure 4.6 show the combination result for each obtained area;

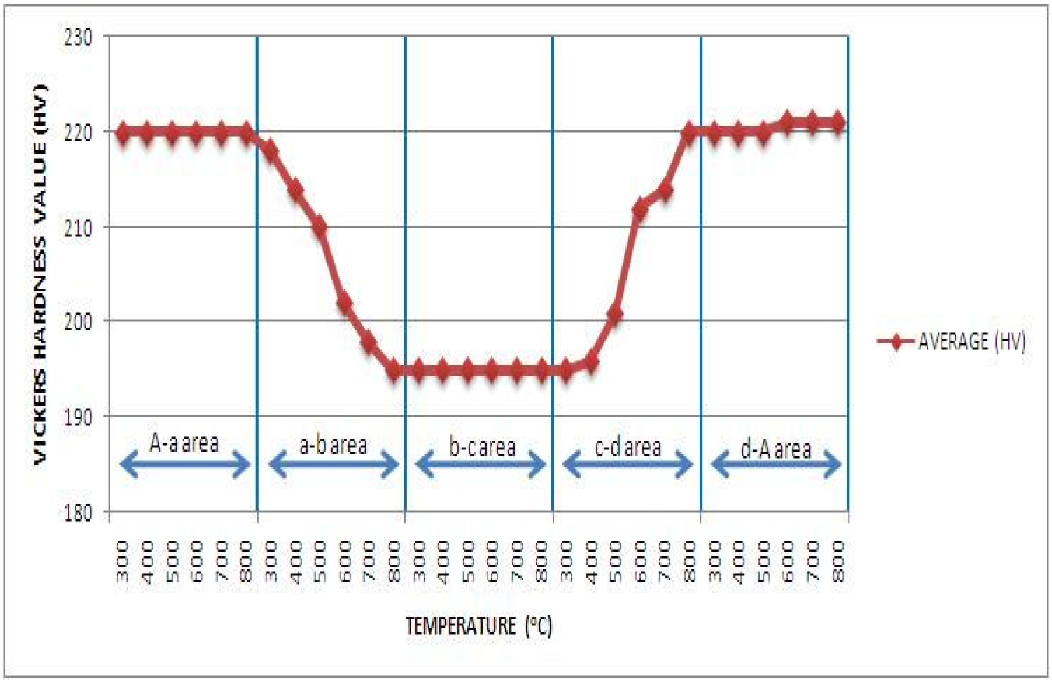



Figure 4.6: Microhardness profile of the weld joints for entire area.

It can be seen that the hardness profile for each inspected areas gave a quite similar curved with Figure 2.2. As from the result obtained, the author observed that the readings taken for each sample are not in a constant mode due to several factors. Most common problem that being encountered by the author was due to environment surroundings. Because of the light loads utilized in this test, vibration can be a contributor to loading accuracy. Even if the part is not impacted during loading, the oscillation of the indenter or the test specimen can cause the indenter to work its way deeper into the part, creating a softer result.

## 4.2 IMPACT TEST

A certain quantity of energy is required to produce a fracture in a material. This quantity of energy can be used as a measure of the toughness of the material, a higher absorption of energy indicating better toughness. The most common and simplest method of determining toughness is impact testing. Results were tabulated and presented in Table 4.6 and Figure 4.7:

Table 4.6: Charpy V impact test results at HAZ area.

| TEMPERATURE ($^oC$) | SAMPLE NO | IMPACT ENERGY (J) | AVERAGE (J) |
|---|---|---|---|
| 300 | 1 | 5.978 | 6.24 |
| | 2 | 6.637 | |
| | 3 | 6.094 | |
| 400 | 1 | 7.716 | 7.58 |
| | 2 | 6.994 | |
| | 3 | 8.019 | |
| 500 | 1 | 8.853 | 8.83 |
| | 2 | 8.619 | |
| | 3 | 9.004 | |
| 600 | 1 | 10.013 | 9.54 |
| | 2 | 9.541 | |
| | 3 | 9.067 | |
| 700 | 1 | 11.103 | 10.83 |
| | 2 | 10.954 | |
| | 3 | 10.442 | |
| 800 | 1 | 13.791 | 13.99 |
| | 2 | 14.016 | |
| | 3 | 14.129 | |

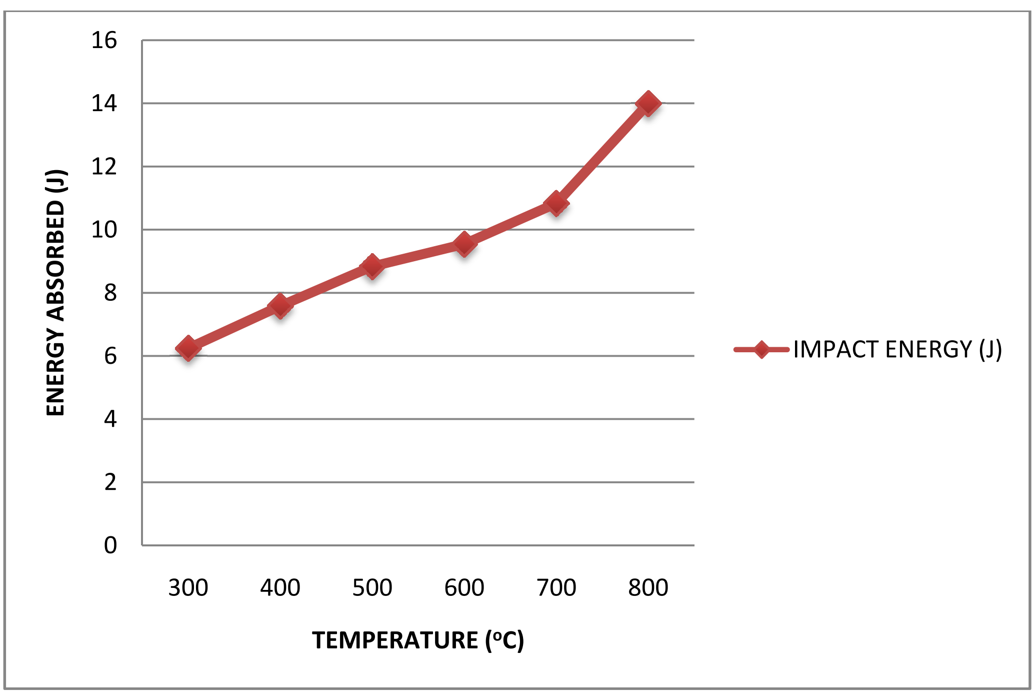



Figure 4.7: Impact energy of HAZ region in various heat temperatures.

Table 4.6 and Figure 4.7 depict impact test results at ambient temperature, 27$^{o}$C for HAZ which are the average of three samples values. The data in the table indicated that the average impact value of welded joint was increased from 6.24 to 13.99 joules when the temperature increases due to the heat treatment process.

According to the results, it indicates that samples exposed to different temperature parameter has an effect on it impact toughness. In other words, with the increasing of the temperature, the impact energy values of the HAZ are increased gradually. Higher impact value is deemed to be better, considering the desire of weldment to have longer life. It shows that the toughness of the HAZ area can be remarkably improved by the heat treated process. Figure 4.8 shown the actual test results:

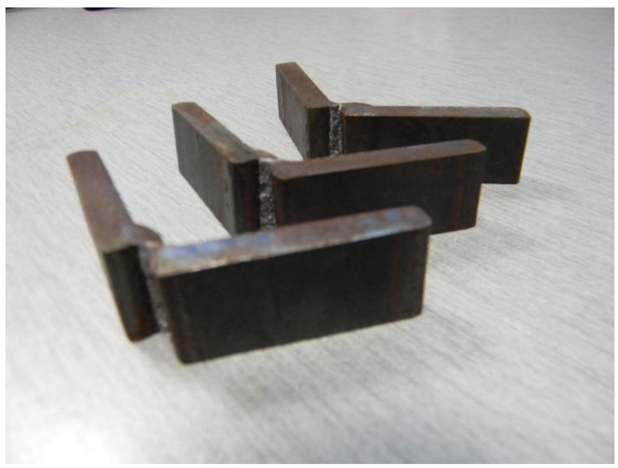


Figure 4.8: Samples structure after impact test.

From the results obtain from the experiment based on Figure 4.8 above, we can see that the mild steel fracture but did not broke completely and some part of the steel still attached. Therefore it is said to be in the ductile manner. From the way of sample cracks and the ‘grayish and fibrous’ broken surfaces of the mild steel, it shows that it undergoes plastic deformation and in the ductile manner. More energy is absorbed by mild steel shows that it is more suitable to be use in the structural construction that expose to high load.

# CHAPTER 5

## CONCLUSION AND RECOMMENDATION

### 5.1 CONCLUSION

Thermal analysis by heat treated parameter has been used to study the properties of joint metal parts. From what had been observed at stage a-b in HAZ area, the hardness change after the temperature is increased from 218HV until 195HV whereby the hardness begins to fall rapidly and continues to do so as the temperature increases. It was also found out that the hardness values were minimal at the FZ area compared to the HAZ area and the hardness remain constant around 220HV in BM region. Different with the result obtained while conducting Charpy V test, the value of the toughness itself were increase from 6.24J to 13.99J proportional to temperature.

### 5.2 RECOMMENDATION

Further experiment should be carried out to investigate other types of steel in the future with regards of its mechanical properties to be examined under different temperatures to see some variation results.

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