The Effect of Welding Different Plate Thickness on Heat Affected Zone Microstructure and Hardness

by

Muhammad Amsyar bin Faizi

Dissertation Submitted in Partial Fulfillment of
the Requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JULY 2010

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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in partial fulfilment of the requirement for the
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(MECHANICAL ENGINEERING)

Approved by,

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(Assoc. Prof. Dr. Patthi bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD AMSYAR BIN FAIZI

ABSTRACT

The main purpose for this project is to research the effect of welding thickness with regard to heat affected zone (HAZ) microstructure and hardness. Welding cause heat that generates heat affected zone (HAZ) which change the properties of material. This generates the residual stresses cause failure to material performance in future. HAZ sizes are influence by several factors such as heat input, welding traveling and metal thicknesses. This research focus on welding thickness as parameters whilst the other parameters are keeps constant. Thickness parameter is chosen to observe the relationship between thermal diffusivity for different thickness. Theoretically, thicker material has high diffusivity. For this project, the material use is low carbon steel and equipment involved is welding machine, optical microscope, hardness testing tools and other suitable apparatus that needed to complete the task. The material were welded by using shielded metal arc welding and then sectioning, mounting, grinding, polishing and etching for metallographic examination. The different types of microstructure appear in comparison between affected and unaffected zone. The project further carried out by conducting hardness testing for different thickness. From the data acquired, one can know the information of welding parameters performing which affect the materials condition. The outcomes for different thickness plate towards HAZ size were influenced by thermal diffusivity of the material. Thicker material has higher thermal diffusivity and vise versa, hence less HAZ region due to fast rate cooling. For metallurgical region, the HAZ which adjacent to fusion boundary has lowest hardness compare to other region. Coarse pearlite microstructures were found in the area with small amount of ferrite. The hardness is increasing as distance from fusion boundary increased. For the conclusion, dissimilar parameters (different thickness) give different thermal diffusivity towards material which gives variety sizes of heat affected zone (HAZ) and hardness for HAZ is also increasing as the thickness of the material increased.

ACKNOWLEDGEMENT

Praise to Him the Almighty that in His will and given strength, author managed to complete the two semesters Final Year Project in Universiti Teknologi PETRONAS. A lot has emerged during this period of time and author was indebted to each and everyone who has made this project an enlightening and inspiring one. The author wishes to take the opportunity to express his utmost gratitude to the individual that have taken the time and effort to assist the author in completing the project. Without the cooperation of these individuals, no doubt the author would have faced some minor complications through out the course.

First and foremost the author’s utmost gratitude goes to the author’s supervisor, Assoc. Prof. Dr. Patthi bin Hussain. Without his guidance and patience, the author would not be succeeded to complete the project. To the Final Year Research Project Coordinator, Dr. Saravanan for provide him with all the initial information required to begin the project. To the entire technician in Mechanical Engineering, thank you for assisting the author in completing his project. To all individuals that has helped the author in any way, but whose name is not mentioned here, the author thank you all.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Welding process is widely used for many industries such as oil and gas, marine, outer space and others. This process is to joint two pieces metal together by melting the material and merge prior to solidifying as a uniform metal joint. This process may be caused by heat, pressure or a combination of both. The process of using heat alone is called fusion welding. There are a large number of welding and allied processes including arc welding, gas welding, brazing, soldering, resistance welding and solid state welding.

Some welded structures show poor mechanical properties at the weld and the adjacent zones. This has led to the collapse of structures when subjected to various torque [1]. Welding process affects the material in term of mechanical properties. The effects of welding on the material surrounding the weld can be damaging depending on the materials used and the heat input of the welding process used and the heat affected zone (HAZ) can be of varying size and strength.

Welders use various parameters in the welding of structural steel. Some failures have been unexplained by regular investigation. Different parameters used during welding process can give dissimilar effect on the material. The parameters involved such as welding speed, heat input, thickness and others can cause the material properties to change. This project focus on welding thickness parameter that affects the heat affected zone.

1.2 Problem Statement

1.2.1 Problem Identification

Metals are joined together by using welding technique which generate heat affected zone (HAZ) around the weld joint area. Different metal thickness gives variation of HAZ sizes which mean the larger the HAZ area, residual stress is high and lead to failure. Basically the problem is that normally, it is hard to predict the HAZ effect on material's hardness for different thickness. This is because the diffusivity or cooling rate of metals is varying with its thickness. Therefore, large thickness has low diffusivity and bigger HAZ area. Since welders used various parameters, welding process gives different heat input towards material. Therefore, it is expected that the HAZ vary with dissimilar factors.

1.2.2 Significant of Project

In the future, this project can be refer as a benchmark for further research on welding thickness effect on HAZ area with the data that is established in this project. Companies as well as universities would be able to use this research to update the uncertainties and design for practical used when dealing with HAZ

1.3 Objectives

The objectives of the project are as follows:

1. Investigates the grain structure of the fusion zone of structural steel to identify the mode of growth and grain transition of the zone and adjacent weld.
2. Study the relationship of different welding thickness to the resultant structure of welded structures.
3. To analyze the hardness of material's HAZ area with different thickness

1.3.1 Scope of Study

The scope of study will be on low carbon steel which different thickness is used to perform the hardness testing. This project stress on experimental. The work initially is to research and analyze the HAZ regarding the weld thickness. The parameters involved during welding; heat input, welding speed, geometry, thickness. From there, the experiment can be done to weld different thickness metal and perform hardness testing to verified

1.4 Relevancy of The Project

1. Give general knowledge for welding scenario which is HAZ that altered microstructure of the metal.
2. To give awareness for welders that different parameters use on welding process gives different effects to the material.
3. As a guideline to study about welding process, microstructure and mechanical testing.

1.5 Feasibility of Project Within

The project is feasible as it make use of carbon steel pipeline which can be obtained from the UTP workshop and hardware shop. This project is low in cost for analysis and brings huge benefits for the future. The time frame for the project is about two semesters because of the preparation of material and equipment involved.

CHAPTER 2
LITERATURE REVIEW

2.1 Carbon Steel

Carbon steel is a mixture of Iron and Carbon with other small amounts of elements such as silicon, sulfur, phosphorous, and manganese. Other elements may be added to impart a specific quality in enhancing its usefulness.

Hardening or strengthening the steel can be done by addition varying amount of carbon. The hardness and tensile strength increases as carbon content increases while the ductility, plasticity, and malleability will decrease. The reason for the carbon content addition is to produce a variety of steels that present the preferred characteristics for certain application.

Most of the steel produced is plain carbon steel which is classified into the following types [2]:

1. Low carbon steel (up to 0.15% carbon) or mild steel (0.16–0.29% carbon)
2. Medium carbon steel (0.30–0.59% carbon)
3. High carbon steel (0.6–0.99% carbon)
4. Ultra High carbon steel (1.0–2.0% carbon)

2.1.1 Low Carbon Steel

For this paperwork, it focuses on low carbon steel. Low carbon steel has carbon content of 0.15% to 0.45%. Low carbon steel is the most common type of steel as its price is relatively low while it provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its low carbon content. It has lower tensile strength and malleable [2].

Figure 2.1: Low carbon steel

2.2 Heat Affected Zone

Heat Affected Zone is the section of the base metal where not melted during brazing, cutting, or welding, but the microstructure and mechanical properties were altered by the heat. The thermal diffusivity of the base material plays a large role. If the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Conversely, a low diffusivity leads to slower cooling and a larger HAZ. Schematic diagram of HAZ is shown in Figure 2.2 below.

The HAZ in low carbon steel of normal structure welded in one run with coated electrodes or by submerged arc process comprises three metallurgical distinguished regions [3].

1. The grain growth region.
2. The grain refined region.
3. The transition region.

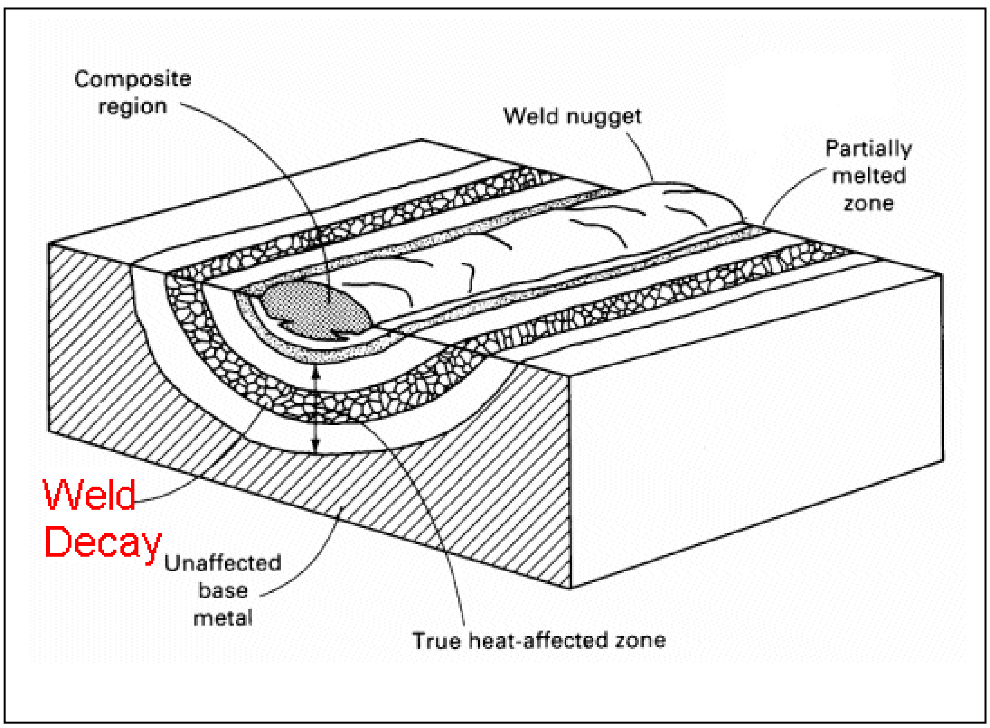

Figure 2.2: Schematic Diagram of Heat Affected Zone (HAZ)

a. Grain growth region

Grain growth region is adjacent to the weld metal zone (fusion boundary). In this zone, parent metal has been heated to a temperature well above the upper critical (A_3) temperature. The condition resulting in grain growth or coarsening of the structure. The maximum grain size and the extent of this grain growth region increase as the cooling rate decreases. The large regions of pearlite and smaller grains of ferrite come into view in this area. *(Iron-Carbon Diagram can be seen in Appendix A)*

b. Grain refined region

Next to the grain growth region is the grain refined zone. The refined zone indicates that in this region, the parent metal has been heated to just above the A_3 temperature where grain refinement is completed and the finest grain structure exists. Complete recrystallization is shown in which the ferrite (white) and pearlite (dark) areas are both much finer.

c. Transition zone

In the transition zone, a temperature range exists between the A_1 and A_3 transformation temperatures where partial allotropic recrystallization takes place. The structure of the transition zone of the low carbon steel in which the ferrite grains have not been altered but the pearlite regions have been made much finer.
This change was produced by heating into the critical range which transformed the pearlite into austenite and by subsequent cooling reformed the pearlite.

d. Unaffected parent metal

Outside the heat affected zone is the parent metal that was not heated sufficiently to change its microstructure. The typical grain structure of the parent metal is ferrite (white) and pearlite (dark) which not exposed to high temperature.

2.2.1 Structural Change in The Heat Affected Zone (HAZ)

Welding is often described as being a small casting in a metal mould. The properties of the casting and the adjacent metal are directly related to the thermal condition and alloying element (Lindberg and Braton, 1976) [1]. It will be realized that there is a zone adjacent to the weld where the material is affected structurally by the heating and cooling associated with the welding cycle. This is termed the Heat Affected Zone (HAZ).

The fact that the material is heated to its melting point means that there is a temperature gradient in the material that is not melted and this clearly extends from its melting point down to the temperature of the material well away from the weld. The whole area of the weld will cool down as soon as the source of heat has been removed or has moved away from the point being considered, and the hottest material will cool most rapidly from the higher temperatures (Oyawale and Ibhadode, 2004) [1].

2.3 Heat Input

The amount of heat injected by the welding process plays an important role as well, as processes like oxyacetylene welding have an unconcentrated heat input and increase the size of the HAZ. Processes like laser beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ. Arc welding falls between these two extremes, with the individual processes varying somewhat in heat input. To calculate the heat input for arc welding procedures, the following formula can be used:

$$Q = \left(\frac{V \times I \times 60}{S \times 1000}\right) \times Efficiency \qquad . \qquad . \qquad \text{[Eqn. 1]}$$

where Q = heat input (kJ/mm), V = voltage (V), I = current (A), and S = welding speed (mm/min). The efficiency is dependent on the welding process used, with shielded metal arc welding having a value of 0.75, gas metal arc welding and submerged arc welding, 0.9, and gas tungsten arc welding, 0.8 [4].

Earlier chapter in this project stated that welding parameters play important roles towards HAZ result. Thus, these constraints need to be controlled in order to get similar heat input during welding process. For the project, only material thickness is variable (6, 9, and 12 mm). Other constraints were keeping as constant even though there is some inaccuracy due to human error. Table 2.1 show the heat input for three different plate thicknesses.

Heat input calculations:

Table 2.1: Heat Input used for various Thicknesses

Plate Thickness	**6 mm**	**9 mm**	**12 mm**
Voltage, V	405	405	405
Current, I	120	140	160
Speed, mm/min	70.83	86.17	111.7
Efficiency	0.75	0.75	0.75
Heat Input, Q	**308.8 KJ/mm**	**296.1 KJ/mm**	**261.1 KJ/mm**

2.3.1 Thermal Diffusivity

In heat transfer analysis, thermal diffusivity is the ratio of thermal conductivity to volumetric heat capacity. It has the SI unit of m²/s.

$$\alpha = \frac{k}{\rho c_p} \quad . \quad . \quad . \quad . \qquad \text{[Eqn. 2]}$$

Where k is thermal conductivity (SI units: W/(m·K)), ρ is density (kg/m³) and c_p is specific heat capacity (J/(kg·K)). The denominator of the thermal diffusivity expression above, ρc_p, can be identified as the volumetric heat capacity with the SI unit of J/(m³·K).

Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings, because they conduct heat quickly in comparison to their volumetric heat capacity or 'thermal bulk' [5].

2.4 Factors Affecting Weld Metal Cooling Rate

Many factors affect the rate at which the weld deposit and the HAZ cool. Among these are the energy input, plate thickness, geometry, and thermal characteristics of the base metal (Kou, 1987) [1]. The term energy input is used to describe the amount of heat or energy used for each inch of weld.

The time a plate will remain at an elevated temperature tends to decrease with an increase in thickness and the thermal characteristics of a material and this is referred to as its diffusivity or thermal conductivity (Quigley, 1977) [1]. The lower the thermal diffusivity of the material, the steeper the distribution of peak temperature; the higher the thermal diffusivity, the shorter the time at elevated temperature for a thermal cycle with a given peak temperature.

Part of the heat affected zone becomes heated to the austenitic condition and transforms to martensite on being cooled rapidly. Cooling is by conduction into the surrounding metal and it is very rapid in welds which have not been preheated, particularly where heavy sections are involved. The extent of the change in the grain structure depends upon the maximum temperature to which the metal is subjected, the length of time this temperature exists, the composition of the steel, and the rate of cooling (Savage, 1980) [1]. The cooling rate will not only affect grain size but it will also affect physical properties. As a rule, faster cooling rates produce slightly harder, less ductile, and stronger steel.

2.5 Study of Mechanical Properties

As the objective of the project is to study the effect of welding different plate thickness on heat affected zone microstructure and hardness, the specimens will undergo hardness testing for different thickness to see the HAZ effect.

2.5.1 Hardness Testing

It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond. The diagonal of the resulting indention is measured under a microscope and the Vickers Hardness value read from a conversion table. Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter.

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:

$$HV = 1.854(F/D2) \quad . \quad . \quad . \quad . \quad \text{[Eqn. 3]}$$

with F being the applied load (measured in kilograms-force) and D2 the area of the indentation (measured in square millimeters). The applied load is usually specified when HV is cited [5].

CHAPTER 3
METHODOLOGY

3.1 Methodology

Methodology below shows the sequence activities for the project involving information gathering, material preparations, experiments, testing and analysis of data achieved.

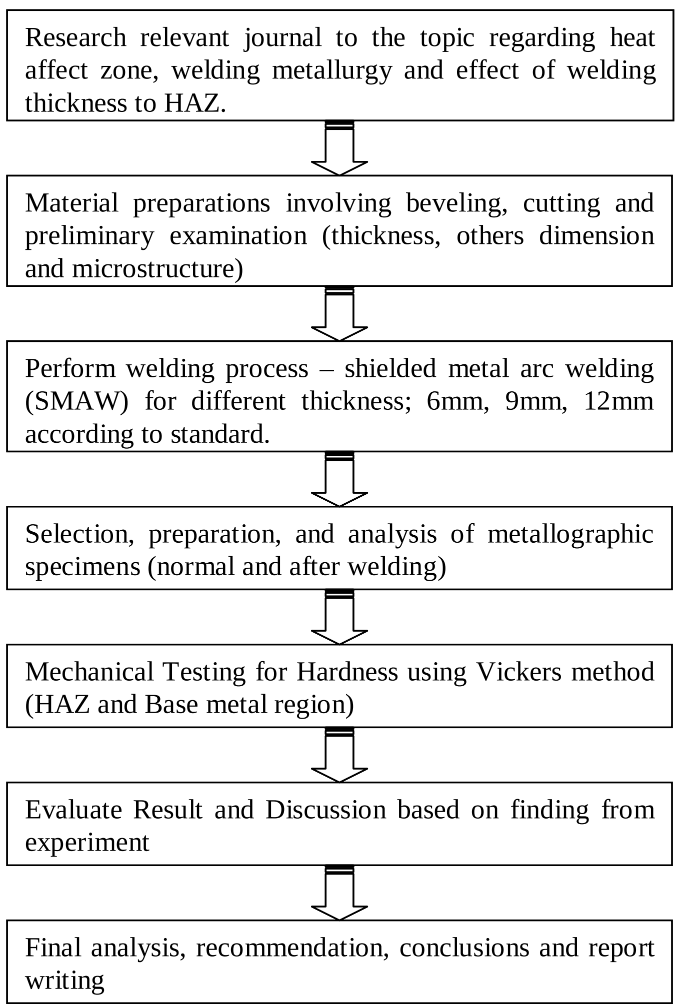

Figure 3.1: Research Methodology

3.1.1 Materials Preparations

Low carbon steel was collected from the mechanical workshop at block 21, UTP (6mm) and also ordered from TSA Engineering for thickness 9 and 12 mm. These were cut into plates 150mm x 40mm and in thickness of 6mm, 9mm, and 12 mm. Welding process Shielded metal arc welding is use to joint the two pieces of metals according to API 1104 – Welding of Pipeline and Related Facilities. A hacksaw was used to cut specimens which were mounted, grind, polished and etched for examination on the metallurgical microscope.

Before welding process is conducted, beveling was carried out to make ‘V joint’. The cutting process can be done by using Oxygen/Acetylene cutting and beveling machine. In this project, Vertical Turret Milling Machine, model 5VM was used to obtain the required bevel. The process and schematic diagram of bevel are shown in Figure 3.2:

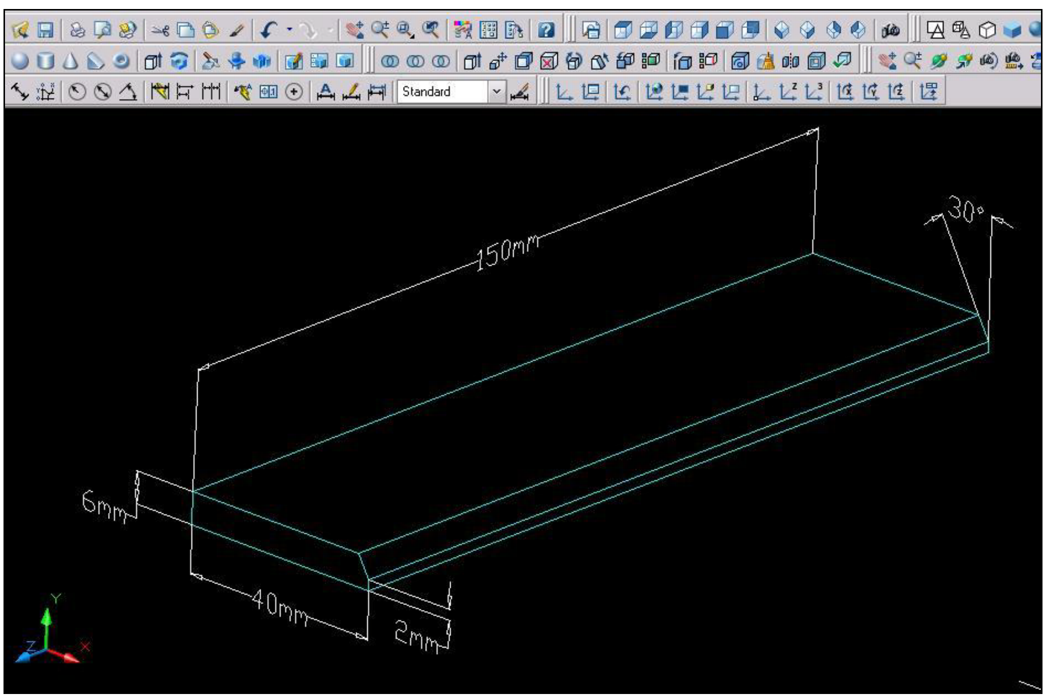

Figure 3.2: Bevel Configuration

Figure 3.3, 3.4 and 3.5 shows the material preparations and technical drawing for V joint arrangement for welding process according to API 1104.

Figure 3.3: Finish Bevel Material

Figure 3.4: Milling Process for Beveling.

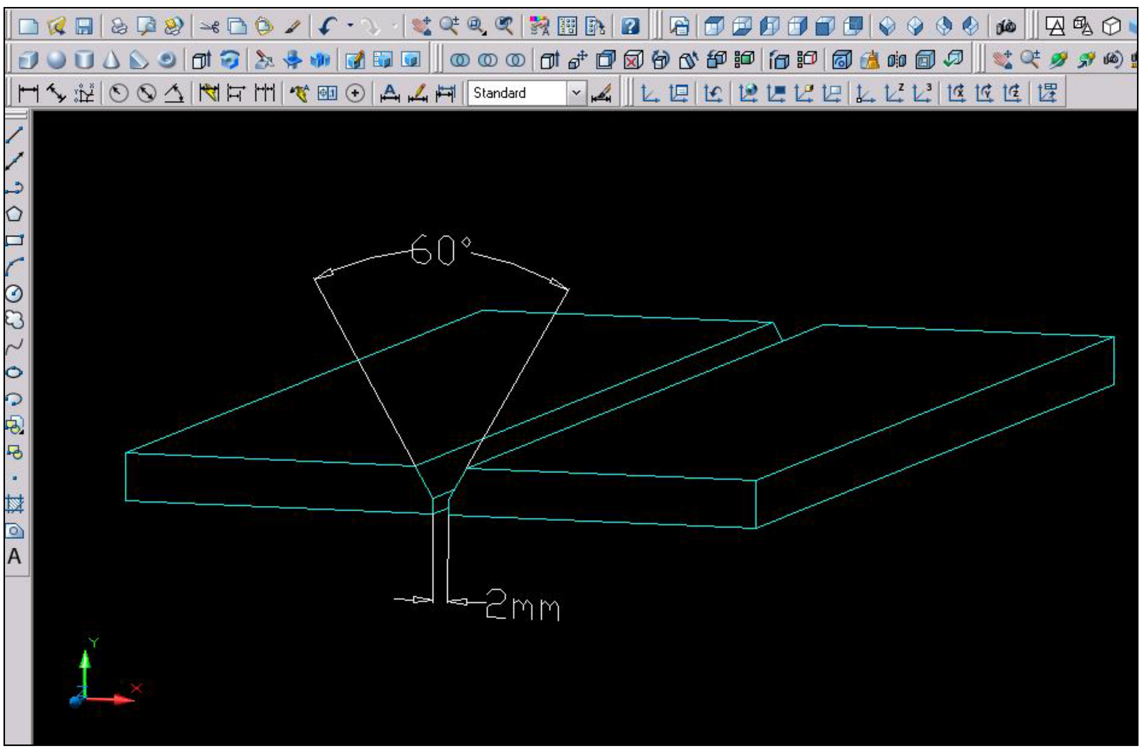

Figure 3.5: V Joint Arrangement for welding

3.1.2 Welding Process – Shielded Metal Arc Welding (SMAW)

All weld test pieces were prepared using the mild steel electrodes. Figure 3.6 and 3.7 below shows welding process is conducted and the finished welded material. A stop watch was used to time the welding process for each pass and efforts were made to maintain the time for each specimen run. This was carried out for the various thicknesses of plates.

Figure 3.6: Welding Process – Shielded Metal Arc Welding

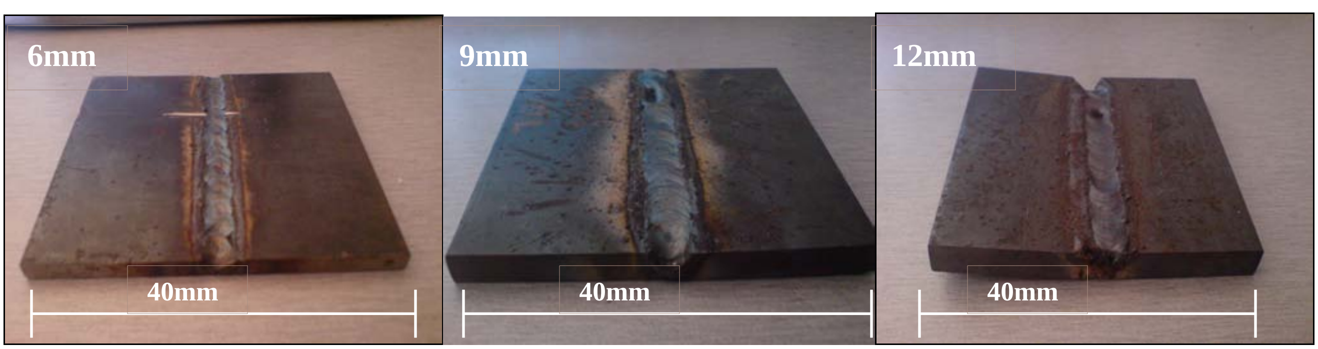

Figure 3.7: Finished Welding Material for Thickness of 6mm, 9mm and 12mm.

3.1.3 Metallographic Examinations

The weld was then cut out and prepared for hardness tests. In addition, specimens were cut for metallographic sample preparation examination as shown by Figure 3.8. These were hot mounted in a thermoplastic material using a mounting press. The thermoplastic material was molded at a temperature under 200 ^{0}C, which was low enough to avoid any structural damage to the specimen. The specimen was then ground on a grinding machine mounted with successively finer grades of abrasive and lubricated by a stream of water. The gauges of emery papers used ranged from 320 to 4000 to create a very smooth surface. Polishing was then carried out on a rotating cloth pad impregnated with aluminum oxide powder. Light pressure was applied in a circular motion until the surface of the specimen was free from scratches and shone like a mirror. It was then washed in warm water, swabbed with methylated spirit and dried in air. Etching was carried out by immersing the specimen in natal agitating vigorously for a few seconds. It was quickly transferred into running water to wash away excess reagent. On completion of the etching the specimen was washed and dried.

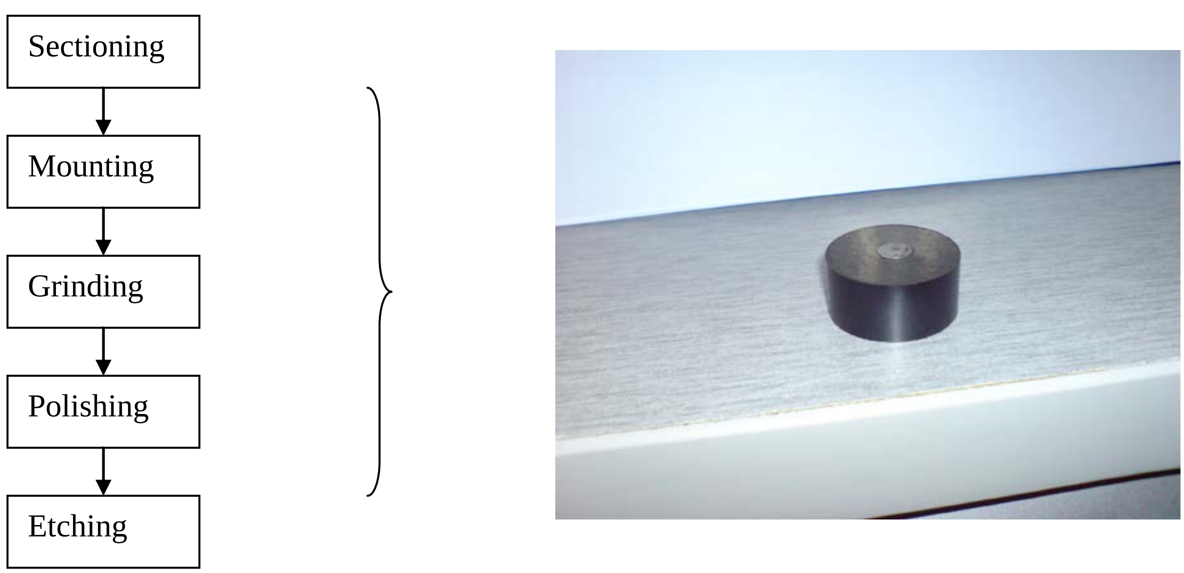

Figure 3.8: Metallographic sample preparation and example of specimen.

3.2 Equipments/Tools

The tools and equipment which are required in this Final Year Project are:

1. Optical microscope (LEICA Microsystems 251794),
2. Abrasive cutter (BUEHLER 102145-400),
3. Mounting machine (BUEHLER 20-1415),
4. Grinding machine (BUEHLER 95-2829),
5. Polishing machine (IMPTECT 302 DVT)
6. Milling Machine (ASSURICH 5VM)
7. Welding Machine – SMAW (NICHIA ND 500)
8. Vickers method for hardness testing,
9. Others useful tools such as knife, sand paper, wrench and camera.

Software use is window base PC Microsoft for writing report and presentation. AutoCAD software is used to draw bevel configuration as technical drawing. Gantt chart for the project can be seen in Appendix B.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Preliminary Examination

Figure 4.1 shows the finished welded material using Shielded Metal Arc Welding process. The dimensions of the plate can be seen below:

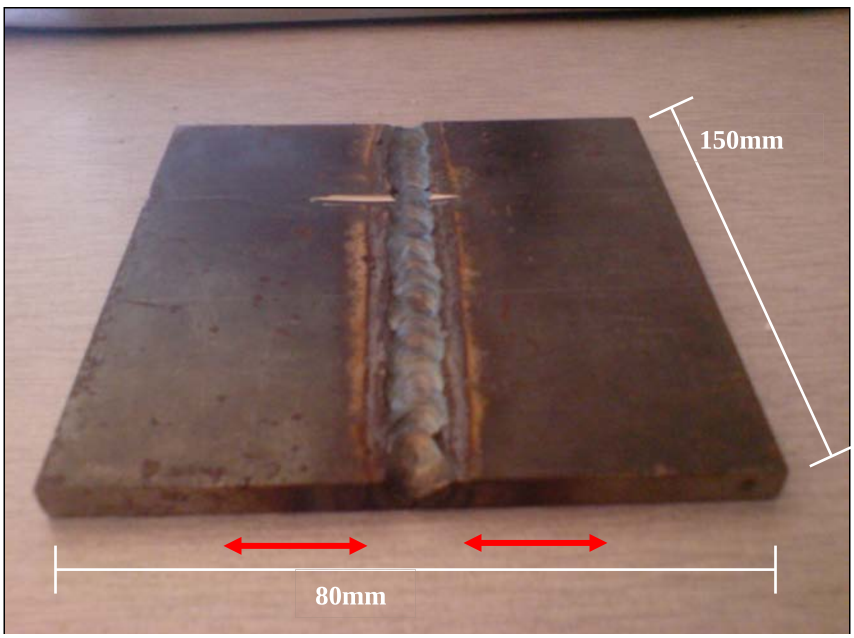

Figure 4.1: Area which Exposed to High Temperature.

The heat affected area can be predicted next to the weld area which exposed to high temperature during welding process. However, the precise size of HAZ must be determined further. Theoretically, the microstructure at HAZ is altered and generates residual stress.

4.2 Metallographic Examination

4.2.1 Unaffected Area (Parent Metal)

Unaffected or parent metal region is the zone where the heat from the welding process did not reach and has no effect on microstructure. Generally, parent metal is located farthest from fusion boundary. Figure 4.2 and 4.3 show the parent metal microstructure.

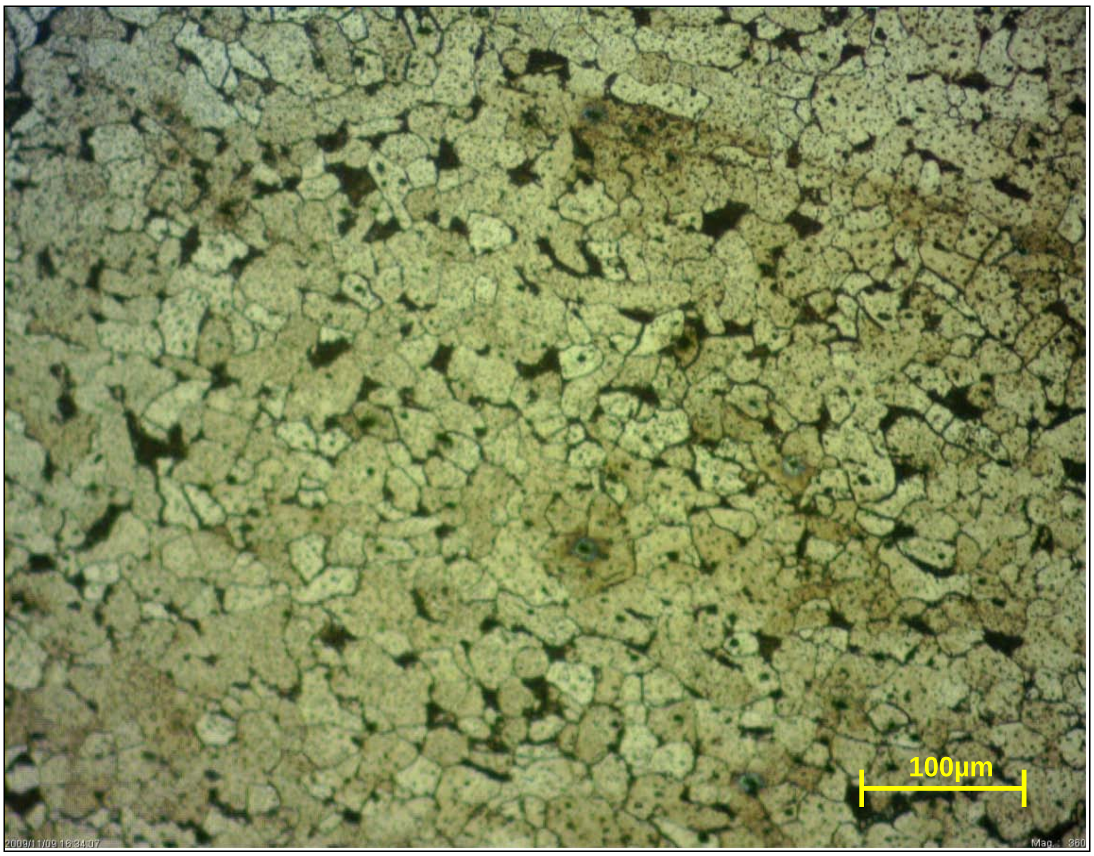

Figure 4.2: Unaffected Area (10x zoom)

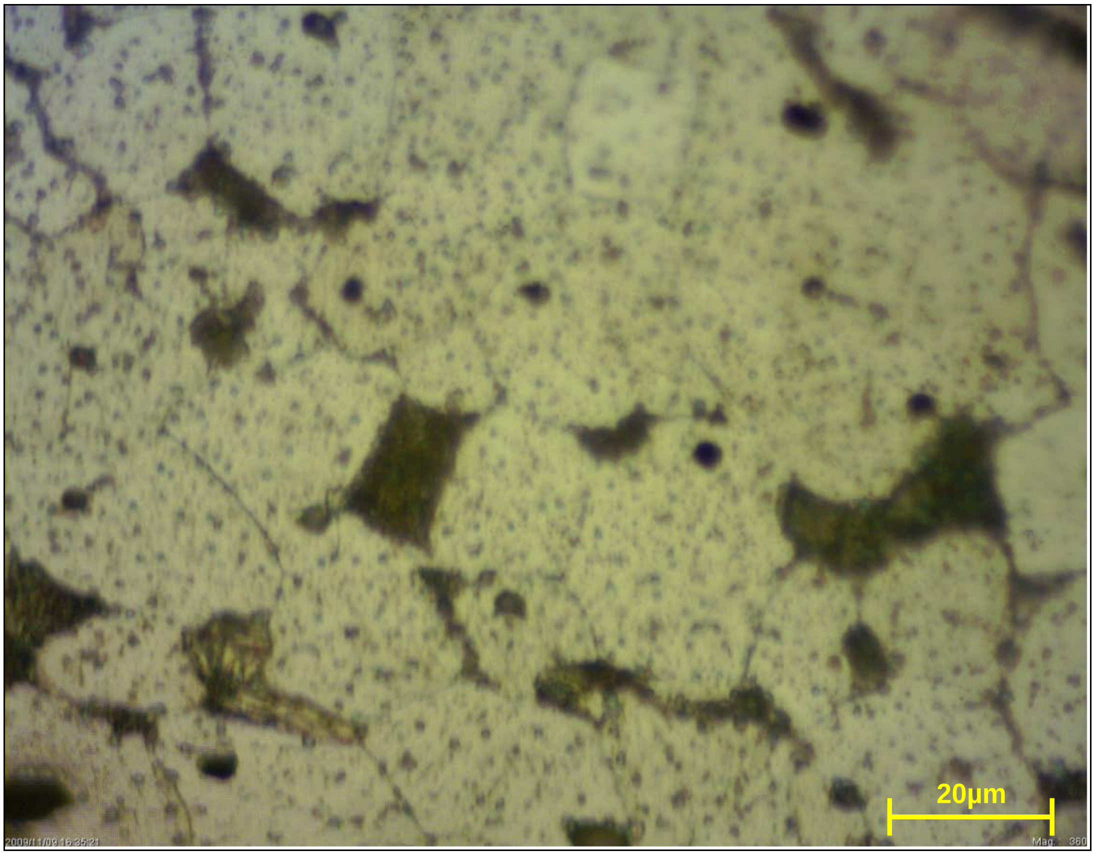

Figure 4.3: Unaffected Area (100x) zoom

The metallographic examination was done by observing the microstructure under optical microscope. Figures above show the microstructure of the parent metal which is not exposed to the high temperature during welding process. Carbon steel consists mostly of ferrite, with increasing amounts of pearlite as the carbon content is increased. Ferrite or alpha iron (α-Fe) is a solid solution with iron as the main constituent, with a body centered cubic crystal structure. In pure iron, ferrite is stable below 910 °C (1,670 °F). Above this temperature, ferrite will transform to Cementite (Iron Carbide, Fe_3C).

4.2.2 Affected Area (Exposed to High Temperature)

Figure 4.4 and 4.5 below show heat affected zone which is adjacent to the fusion boundary. These regions were exposed to high temperature that altered the microstructure.

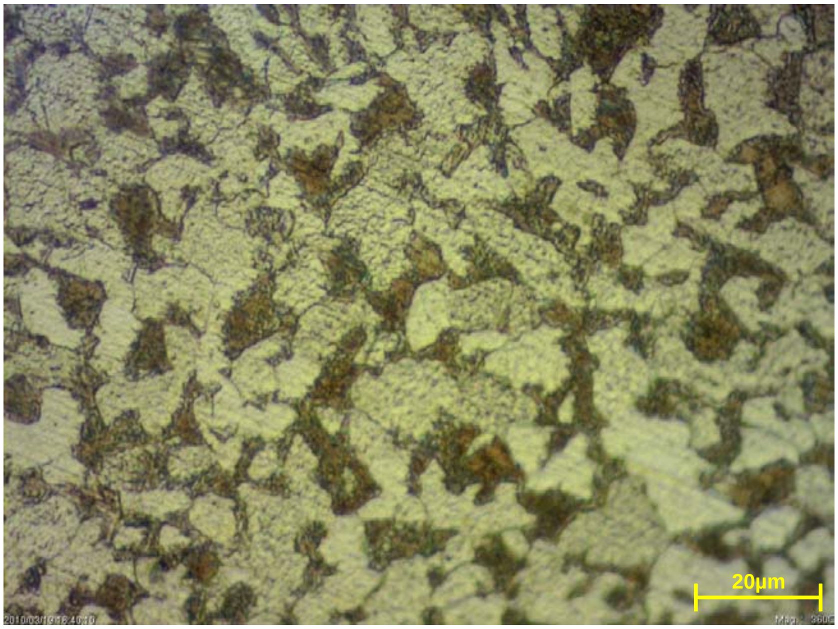

Figure 4.4: 6mm (100x) Zoom

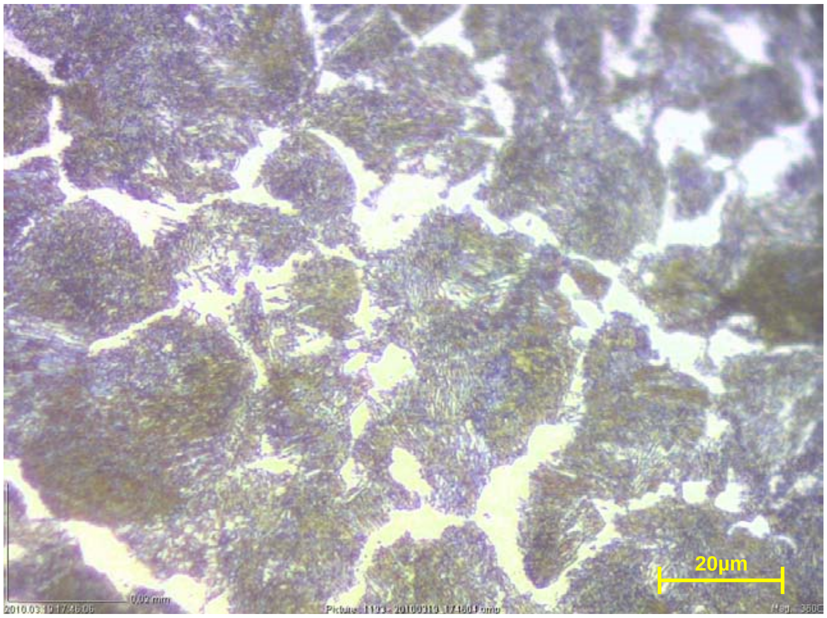

Figure 4.5: 9mm (100x) Zoom

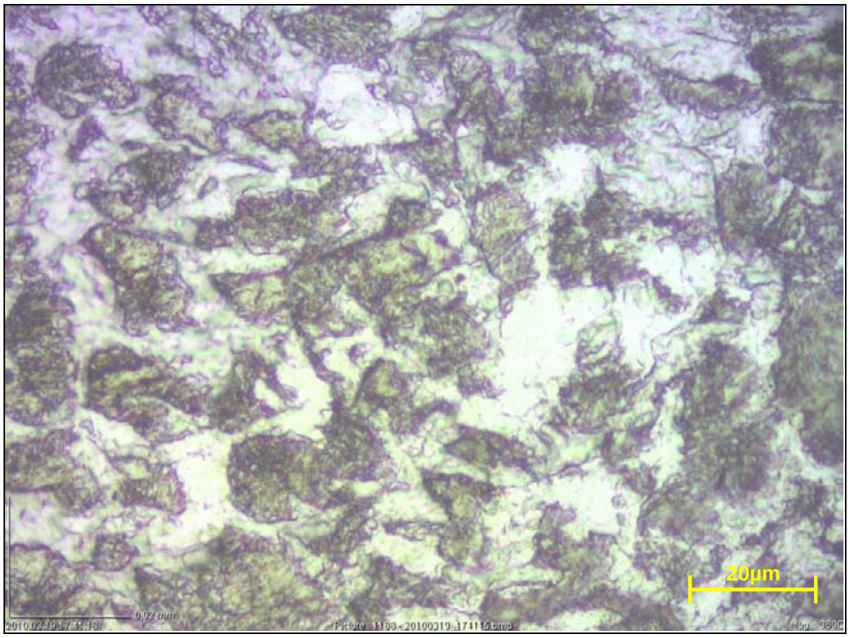

Figure 4.6: 12 mm (100x) Zoom

The microstructures above prove that the area of heat affected zone is altered. There is increasing in pearlite region due to transformation during welding. Pearlite is a two-phased, lamellar (or layered) structure composed of alternating layers of alpha-ferrite (88 wt%) and cementite (12%) that occurs in some steels and cast irons. During slow cooling pearlite forms by a eutectoid reaction as austenite is below 727°C (the eutectoid temperature).

4.2.3 Comparison Between Unaffected And Affected Zones

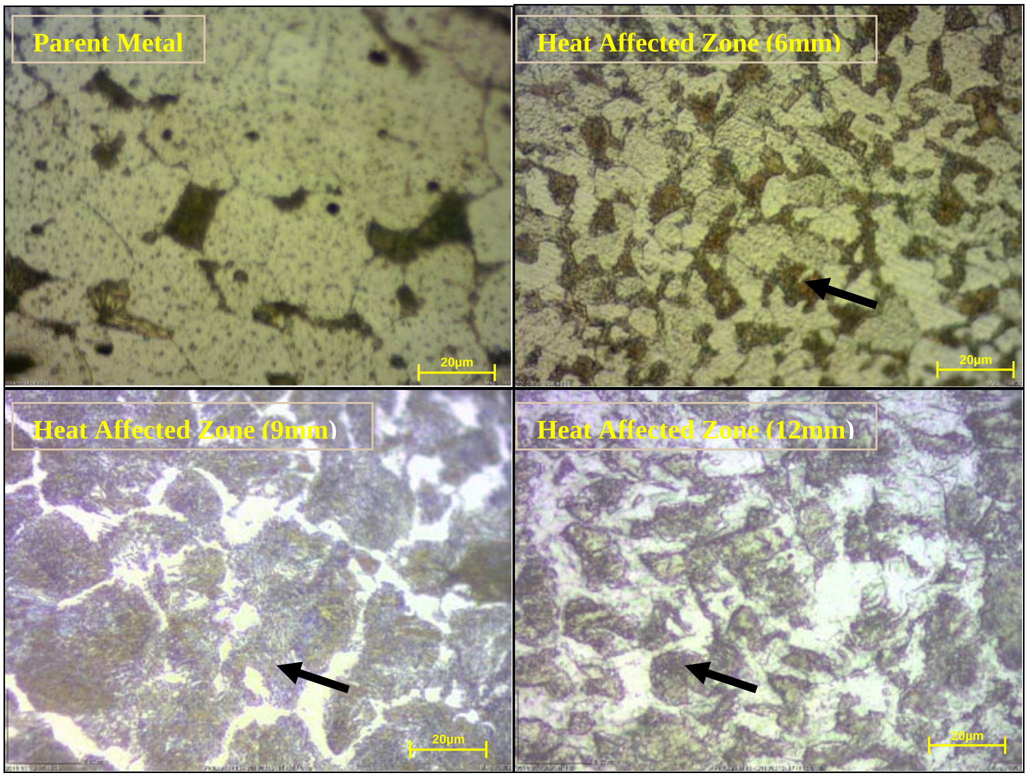

Figure 4.7: Comparison Microstructure between Parent Metal (100x) area and Heat Affected Zone (100x). Pearlite Microstructure layer (lamellar) can be seen clearly at arrow shown above.

For unaffected region, the microstructures consist of ferrite (white) and pearlite (darker) which is typical grain structure for low carbon steel. Once the material exposed to high temperature, the pearlite region increase which resulting in large pearlite region and smaller ferrite region. Coarse pearlite is indicating at the HAZ area due to slow cooling. However, the more distance from the weld area, the finer pearlite microstructure. Slow cooling gives the material soft and easy to machine but poor toughness.

4.3 Mechanical Testing (Vickers Hardness, HV)

Hardness testing was conducted to verify the mechanical characteristic in order to identify the pattern of hardness for increasing in material thickness. Thus, the materials were cut into small pieces, mounting and grinding for easier handling and clean up the surface. The aim of the testing is to determine the hardness profile for different thickness and also to compare hardness between heat affected zone and unaffected zone. The result for hardness testing can be seen in Table 4.1. Therefore, the testing was performed at particular area (D1, D2, D3, and D4) which represent different metallurgical distinguished region. The areas are as following:

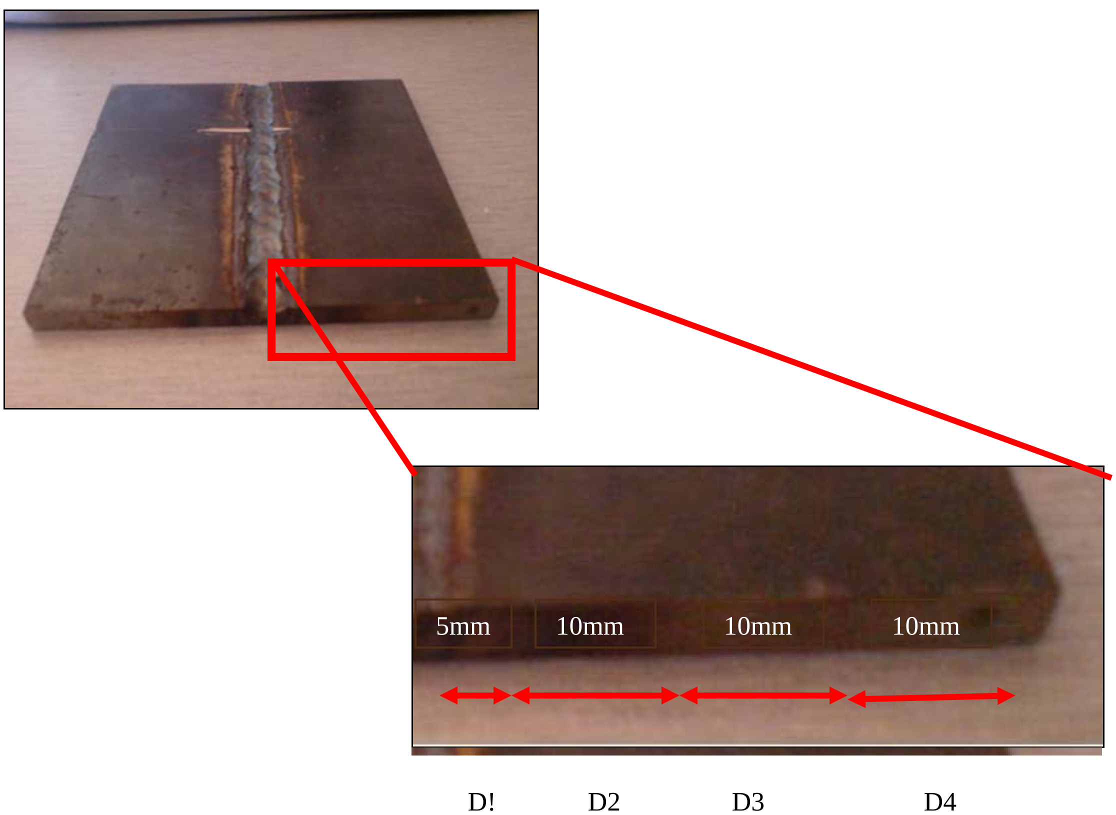

Figure 4.8: Testing areas adjacent to the fusion zone.

Table 4.1: Results for hardness testing

Material Thickness	Distance from Fusion Area			
	D1	D2	D3	D4
6mm	202.78 HV	160.52 HV	175.76 HV	171.54 HV
9mm	227.94 HV	215.86 HV	243.24 HV	222.18 HV
12mm	284.88 HV	192.84 HV	222.20 HV	206.44 HV

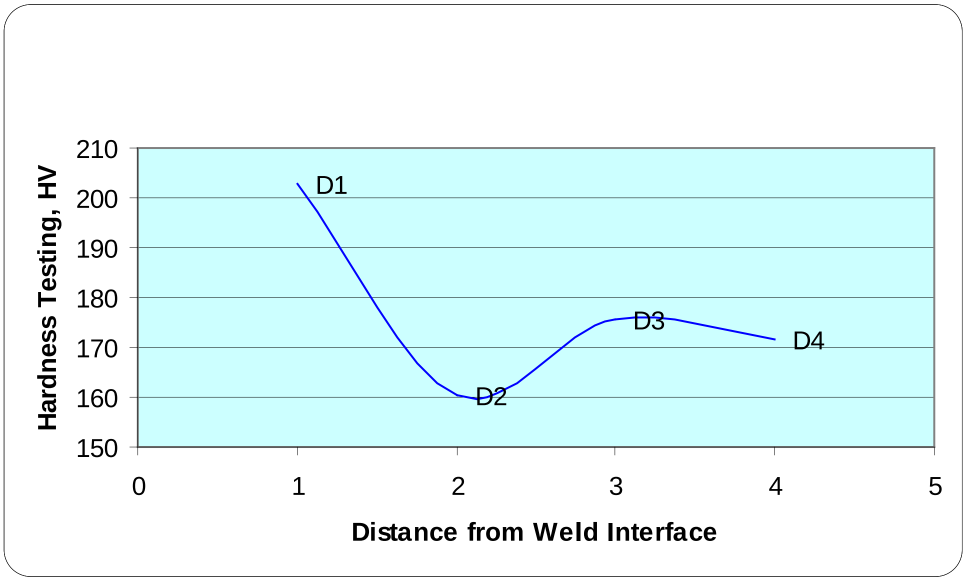

Figure 4.9: Hardness testing profile against distance from weld interface for 6mm thickness

From the graph above, the highest hardness is at D1 (202.78 HV) and the lowest is at D2 (160.52 HV). These circumstances can be interpreted that D1 is fusion boundary and D2 is heat affected zone theoretically. The fact that D2 has low hardness, it was due to the exposing to high temperature during welding which transform the microstructure of the material. D3 and D4 are harder than D2 but softer than D1. These two regions have quite similar hardness due to the distance from weld fusion which means less exposing to high temperature.

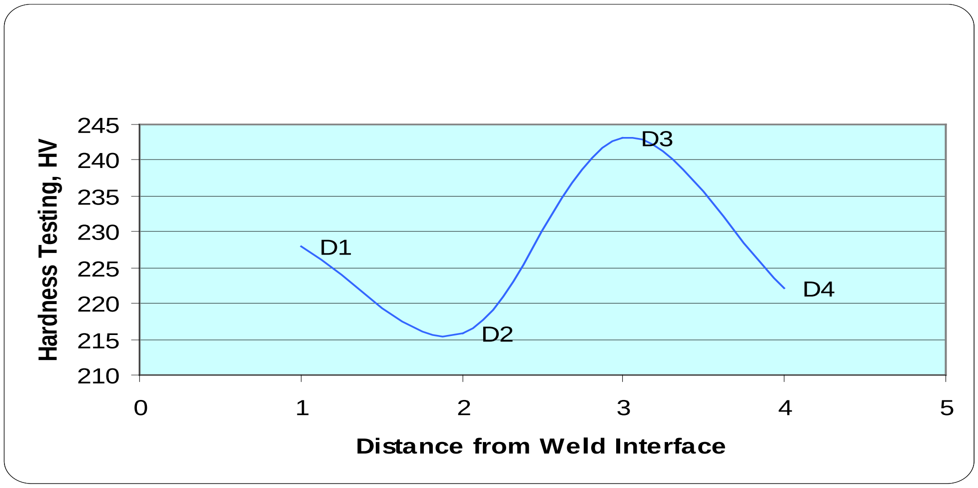

Figure 4.10: Hardness testing profile against distance from weld interface for 9mm thickness

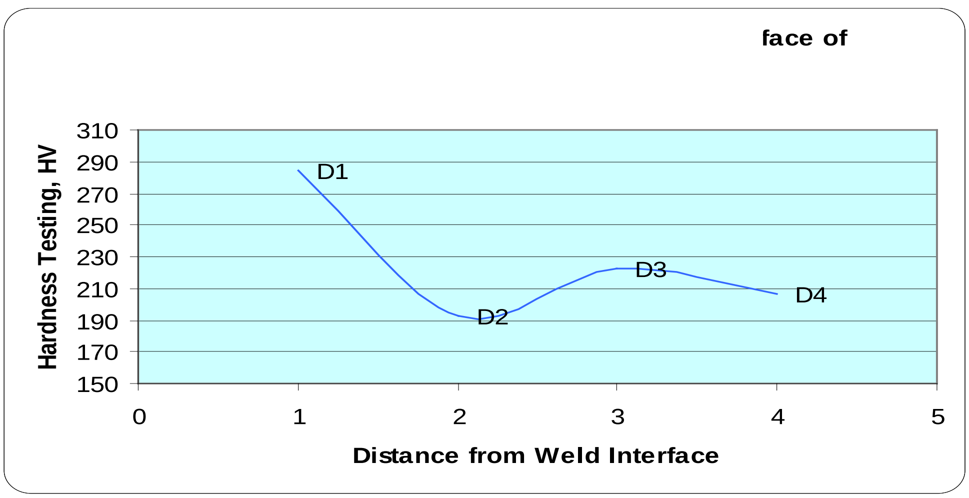

Figure 4.11: Hardness testing profile against distance from weld interface for 12mm thickness.

For Figure 4.10, the D1 value is 227.94 HV and D2 is 215.86 HV. The hardness for material is increasing with thickness increasing. As stated earlier, the lowest part which is D2 is heat affected zone as the grain has altered.

For Figure 4.11, the hardness is higher than 9mm and 6 mm thickness. The value for D1 is 284.88 HV and D2 is 192.84 HV. D3 and D4 are constant and higher than D2 as for different exposure temperature.

Comparison between different plate thicknesses for hardness testing was done as fulfilling the project objective which can be seen in Figure 4.12.

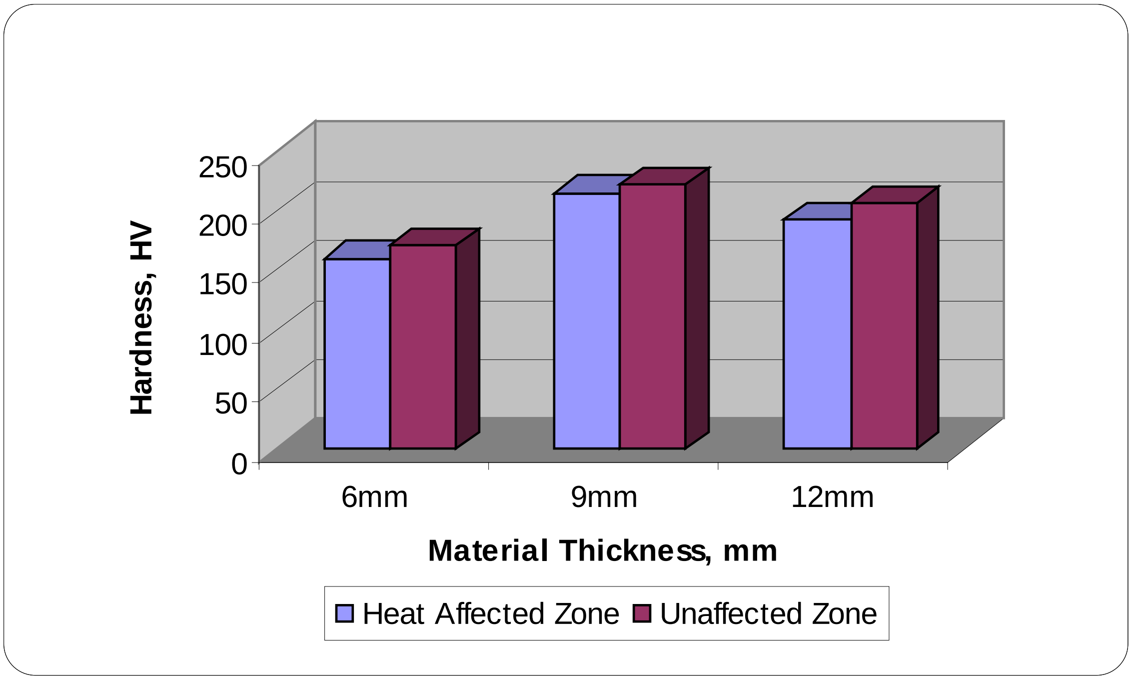

Figure 4.12: Comparison between heat affected zone and unaffected zone for various thickness.

The graph above gives the comparison for three thicknesses which related to heat affected zone and unaffected zone. It can be deduce that, the hardness is increasing with thickness. As a matter of fact, the thermal diffusivity plays important role toward temperature distribution. High diffusivity means high cooling rate and vise versa. For thicker material, the diffusivity is higher. It is because thermal diffusivity is the ratio of thermal conductivity to volumetric heat capacity. Material with high diffusivity can conduct heat quickly to their surrounding since they contain more volume.

Heat affected zone is a region adjacent to the weld that may have experienced microstructure and property alterations. As for heat affected zone, it show the lowest hardness compare to other regions. This was due to slower cooling than other region. Upon cooling, residual stress may form in this region that weakens the joint. During material heating at high temperature, the original microstructure transform to austenite. Then, upon cooling to room temperature, the type of microstructures depends on cooling rate. Slow cooling give coarse pearlite which soft and poor hardness. The rate of cooling tends to increase with the increase distance from weld boundary. Therefore, finer pearlite microstructures emerge as weld distance increased.

The physical difference between fine and coarse pearlite is in the thickness of the layers. Fine pearlite has finer layers making up which can resist slipping relative to each other. On the other hand, coarse pearlite layer still be able to stretch out. This is the main reason for differences in hardness. Finer pearlite is formed at lower temperature than coarse pearlite. Therefore, fine pearlite cooled down quicker than coarse pearlite.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

At the region immediately adjacent to the weld metal zone, the microstructure showed that the structure was coarsening and large regions of pearlite and smaller ferrite could be seen. This is due to the transformation of ferrite to pearlite as the microstructure was heated above 900 ^{0}C. The microstructure of the parent metal that was not heated sufficiently to change its microstructure showed the typical grain structure of the parent metal which is ferrite (white) and pearlite (dark).

The mechanical properties of the structural steel were different with welding speed, plate thickness and arc current. All the parameters influenced the heat input during welding process which gives different variation of heat affected zone. Therefore, dissimilar heat affected zone present different mechanical properties. It is recommended that welding process must be conducted according to the standard and correct procedure and also welding parameters such as speed, distance and angle for SMAW process to reduce the residual stress from heat affected zone.

The heat-affected zone was weakest at the weld. Most welding failure originated in this zone. Coarse pearlite resulting from slow cooling produces soft and poor hardness material.

5.2 Recommendations

Recommendations are an important part for any work or project which helps to improve the work progress and provide better outcome. Following are the several recommendations which are relevant to this project.

Welding parameters give variation of output toward material. The most parameter that controls the size of heat affected zone is heat input. For this project, effort was made to maintain the other constraint to get similar heat input. Therefore, all the work must use same equipment regarding the efficiency of the machine. Every input for the process must be equivalent such as current, voltage and others.

For welding process, technique and skill is very crucial in order to gain the best end result. Speed, angle and distance from the material need to be pay attention to give similar heat input. Thus, it is better to have qualified personnel to perform the welding process. Qualified welder has received training and they continuously involved in this matter. Hence, average person skill need to be reduced as much as possible for accurate result.

As for mechanical properties, HAZ show the weakest area compared to other region. Consequently, failure might occur originated from this zone. Thus, quenching method can be one of the options to resolve this problem. Quenching method change the microstructure to martensite which is known as the hardest microstructure. Quenching can be done by cooling the material with oil, water or brine for rapid cooling. However, martensite is too brittle for certain application. Therefore, tempered martensite can be performing to enhance the ductility and tensile strength of the material.

Microstructure examination can be improved or verify with other method such as scanning electron microscope (SEM), transmission electron microscope (TEM) and X-Ray microscope. These techniques can overcome the limitations set by the diffraction limit of visible light which other microscopes have been designed to use other waves.

The other recommendations are to reduce human error and parallax error as much as possible for accuracy. These can be done by ensuring all equipment and tools in good conditions and operate according to standard. For hardness testing, average reading must be taken to reduce the inaccuracy of data. Comparison to the journal, technical report, article and standard is crucial to deduce the correct outcome.

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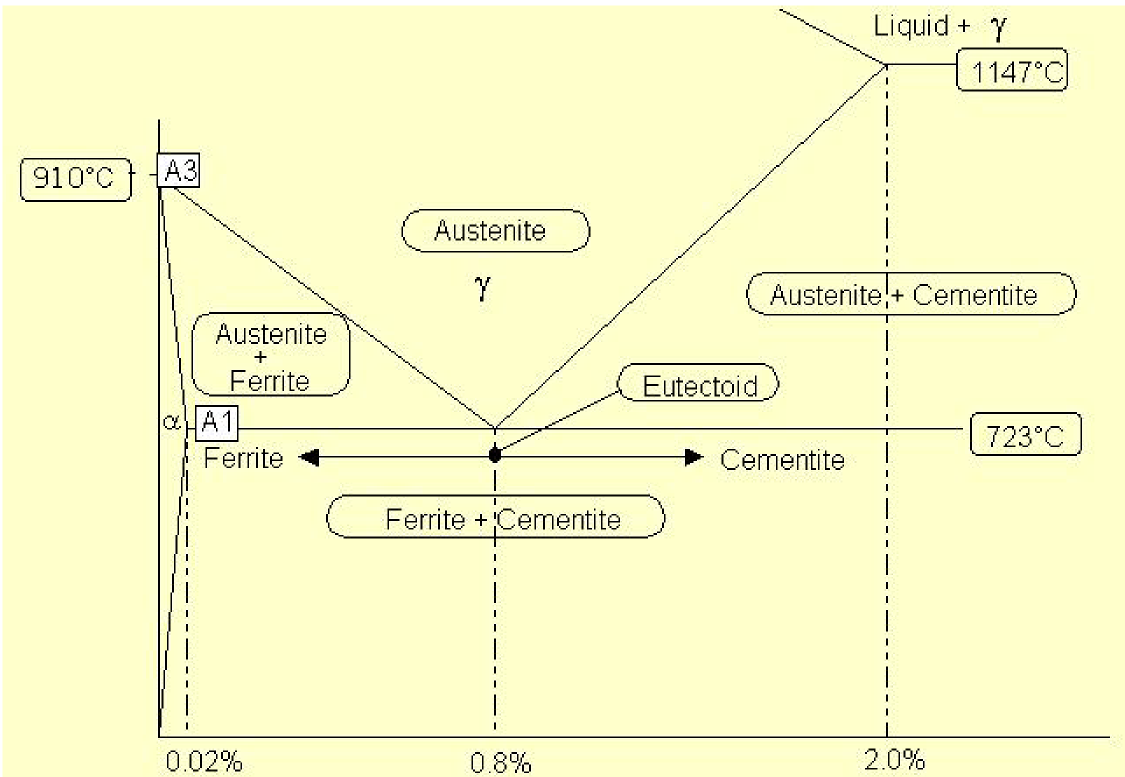
APPENDICES

APPENDIX A

IRON-CARBON DIAGRAM



Adapted from Binary Alloy Phase Diagrams, T.B Massalski, (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH [2]

APPENDIX B

PROJECT GANTT CHART

Final Year Project

Title: The Effect of Welding Different Plate Thickness on Heat Affected Zone Microstructure and Hardness

Activities	FYP 1 (2009)																**FYP 2 (2010)**													
	August				September				October				November				February				March				April				May		
	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3	Wk 4	Wk 1	Wk 2	Wk 3
Progress Report		■	■	■	■	■	■																								
Seminar								▲																▲							
Interim Final Report					■	■	■	■	■	■	■																				
Oral Presentation 1													▲																		
Sample Preparation							■	■	■	■	■	■	■																		
Welding Process																															
Bevelling & welding													■	■	■	■	■	■	■												
Progress Report																							▲								
Metallographic Examination																															
microstructure analysis																		■	■	■	■	■	■	■							
Mechanical Testing																															
Hardness																							■	■	■	■	■				
Final Report																			■	■	■	■	■	■	■	■	■	■	■	■	■
Oral Presentation 2																															▲

■ Progress ▲ Milestone