Study of PWHT Microstructures and Mechanical Properties for Mild Steel and SA106B Pipe Material

by
MOHD AZAHARI MOHAMED BUANG

A project dissertation submitted to the
Mechanical Engineering Program
in partial fulfillment of the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
November 2010

STUDY OF PWHT MICROSTRUCTURES AND MECHANICAL PROPERTIES FOR MILD STEEL AND SA106B PIPE MATERIAL

MOHD AZAHARI BIN MOHAMED BUANG

(ID NO: 9508)

MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGY PETRONAS

NOVEMBER 2010

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude and thanks to everyone that has given me support and guidance throughout the whole period of completing this final year project report.

Firstly, I would like to take this opportunity to acknowledge the endless help and support receive from my supervisor, Mr. Mohd Faizairi bin Mohd Nor throughout the whole completing this final year project. Without his guidance and advices, I will not be able to achieve what I have today within the given duration. Apart from that, I would like extend my appreciation to all laboratory technicians who have given their help and assistance during my laboratory work.

I also would like to say thank you to Universiti Teknologi PETRONAS and the Coordinator of Final Year Project of Mechanical Engineering Department, Dr. Saravanan Karuppanan who has planned and coordinated all activities and made the necessary arrangement, especially on term of logistics and matters related to this study.

Lastly, I would like to convey thousands of thanks to my fellow colleagues for their ideas, assistance and facilitation throughout completion of this project. Thanks also to all who contributed directly and indirectly, your continuous assistance are highly appreciated.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CERTIFICATION OF APPROVAL

STUDY OF PWHT MICROSTRUCTURES AND MECHANICAL PROPERTIES FOR MILD STEEL AND SA106B PIPE MATERIAL

By

Mohd Azahari bin Mohamed Buang

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons.)
(MECHANICAL ENGINEERING)

Approved by,

____

Mr. Mohd Faizairi bin Mohd Nor
UTP Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
NOVEMBER 2010

CERTIFICATION OF ORIGINALITY

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

MOHD AZAHARI MOHAMED BUANG

ABSTRACT

Welding is a well-known process of steel fabrication especially in oil and gas industry. Nowadays, we all can see a lot of improvement of welding quality on steel fabrication sector. This is all involving remarkable finding about the behavior effect of steel welding especially on weld defect cases. Defect is an excessive condition and outside the acceptance limits. Weld defects include porosity, incomplete fusion, weld cracking, and undercut. In order to control the welding defect, many researches have been done including the heat treatment for weld. All of it is to avoid undesired failure that can lead to catastrophic. On a carbon steel material structure, defect usually occurs at the weld region.

Welding process involve the process of heating and cooling of material being weld together. This cyclic heat source from welding process will alter the base metal microstructure. The alteration of base metal microstructure can cause the mechanical properties at the welded structure to changes. Localized expansions also exist due to heat from welding or molten metal. When the weld cools, some areas cool and contract more than others. This contraction with the bulk metal surrounding weldment will provide residual stresses. This residual stress is often become cause a premature failure of critical component like bridge bar links and pressure vessel. One way to overcome this problem is heat treatment.

Heat treatment is a method used to modify the physical properties of a material. The use of heat treatment is to heating or chilling the material to extreme temperature to achieve a desired result such stress relieving, hardening, or softening. Base on Iron-Carbon phase diagram, we are able to see the changes in microstructure during heating and cooling.

This research is to characterize the mechanical properties and its microstructure of the weld zone in order to avoid failure due to weld defect or microstructure refinement for carbon steel material. This research is to characterize the mechanical properties by subjecting the material microstructure to post weld heat treatment (PWHT). This study will provide relationship of the steel microstructure, mechanical properties, and PWHT.

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

The material involve with this research is low carbon steel which is mild steel. Carbon steel is widely used because of lower cost and much easier to weld. Carbon steel will be weld according to ASME IX, Article I, II, III, and IV standard. In industry especially in oil and gas industry, heat treatment usually used to relieve residual stress cause by welding process. For example is pressure vessel fabrication. Heat treatment is not only being used to relieve internal stress on the vessel, but also as a solution to reduce the risk of brittle fracture. For coded vessel, heat treatment criteria and parameter usually referred from ASME VIII, 2007 edition, division 1, UCS-56.

The welded joint will be send to metallurgy laboratory for mechanical properties testing. This is to determine the level of welding quality. Before heat treatment the product, it is important to make sure all the welding are within the acceptance limit. Iron-Carbon phase diagram is a good material to understand the effect or heat treatment relative to microstructure. With microstructure examination, we are able to categorized microstructure shape and its mechanical properties. For example, martensitic iron which have brittle properties. Material characterizations can be made according to the relationship between mechanical properties, microstructure, and post weld heat treatment.

1.2 PROBLEM STATEMENT

Cyclic heating from welding process will alter the base metal microstructure. For a carbon steel structure or part, the failure usually occurs at the welded region. It is beneficial to understand the interaction between material microstructure, heat treatment, and mechanical properties will provide at the welded region.

1.3 OBJECTIVES AND SCOPE OF STUDY

The research is to characterize the mechanical properties and microstructure of the welded mild steel before and after subjecting the material to post-weld heat treatment.

CHAPTER 2
LITERATURE REVIEW

2.1 CARBON STEEL TYPE

The material involved in this project is carbon steel. Carbon steel is actually iron alloyed with carbon. The carbon atoms fit into the interstitial crystalline lattice sites of the body-centered cubic [BCC] arrangement of the iron atoms. This type of interstitial will affect the yield strength of steel. The interstitial carbon atoms will decrease the ability of iron atoms dislocations which gives the hardening effect to iron. Carbon steel has 2 types which is Low Carbon Steel or Mild Steel and Higher Carbon Steel.

2.1.1 Low carbon steel and Mild Steel

Low Carbon steel has properties similar to iron. Low carbon steel contains approximately 0.05 to 0.15% carbons and Mild steel contains 0.16 to 0.29% carbons. This type of carbon steel is neither brittle nor ductile. Mild steel has low tensile strength, cheap, and can be machining. The surface hardness can be increased by carburizing. Low carbon steel has two yield points which is the upper yield point and lower yield point. The material response is linear up until the upper yield point and drop dramatically after upper yield point.

2.1.2 Higher Carbon Steels

By increasing the carbon content, the steel will become harder and stronger but it will be more difficult to weld and less ductile. Carbon steel that have carbon content from 0.30 to 1.70% by weight can successfully undergo heat-treatment process. Higher carbon steel can be categorized to medium carbon steel, high carbon steel and ultra-high carbon steel.

1. Medium Carbon Steel

Medium carbon steel has approximately 0.30 – 0.59% carbon content. It has good wear resistance, balances ductility and strength.

2. High Carbon Steel

High carbon steel has approximately 0.6 – 0.99% carbon content. It’s very strong and usually use for springs and high-strength wire.

3. Ultra-high Carbon Steel

Ultra-high carbon steel has 1.0 – 2.0% carbon content. Steel with more than 1.2% carbon content are made using powder metallurgy. Carbon steel which contain above 2.0% carbon content is considered as cast iron. This steel can be tempered to great hardness.

Steel can be heat treated to allow part to be fabricated in an easy deformable soft state. Steel are often wrought by cold working methods. If steel have enough carbon content, the alloy can be hardened to increase strength, wear, and impact resistance.

2.2 THE METALLURGY OF CARBON STEEL

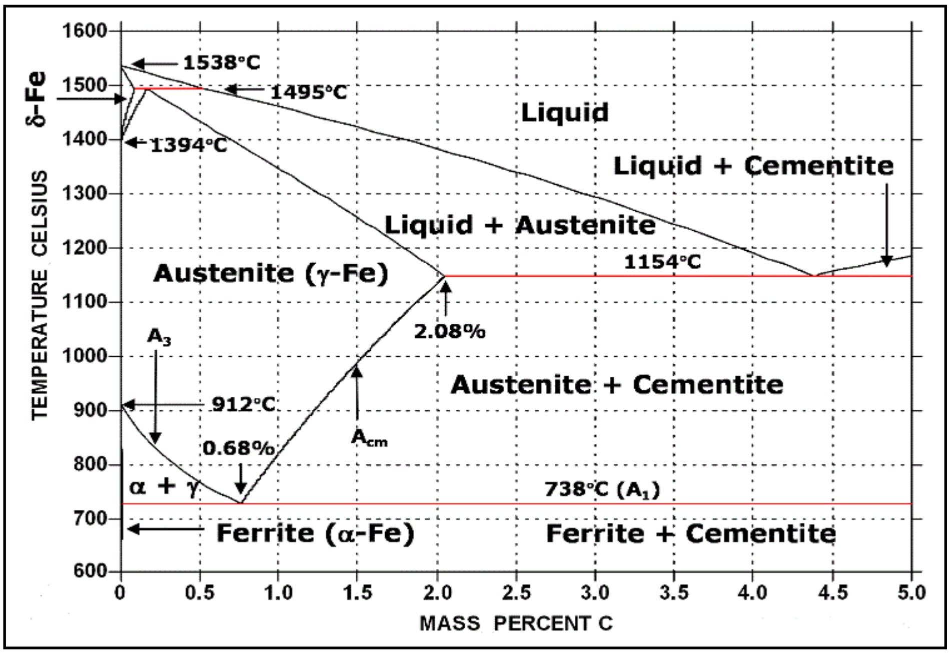


Figure 2.1: Iron-Carbon Phase

The diagram shown above is about transformation phase that occurs as a result of slow heating. Slow cooling will reduce the transformation temperature. The fast heating and cooling rates in welding will have a significant influence making the weld metallurgy prediction using this diagram become difficult.

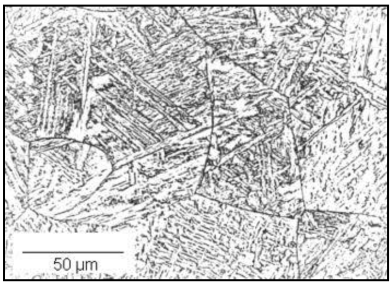
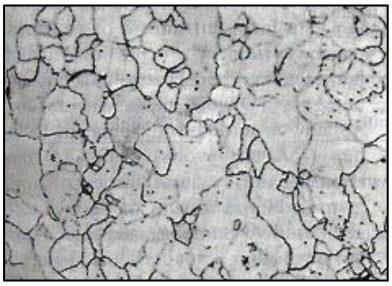
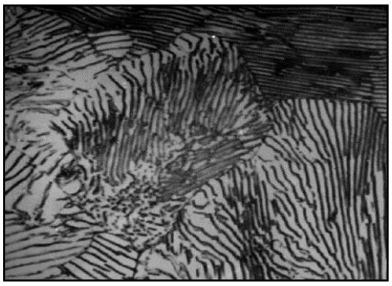
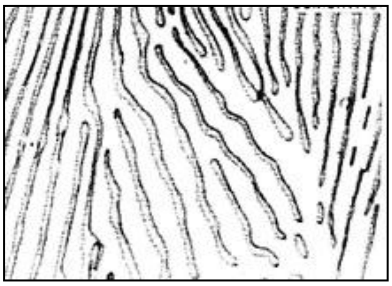
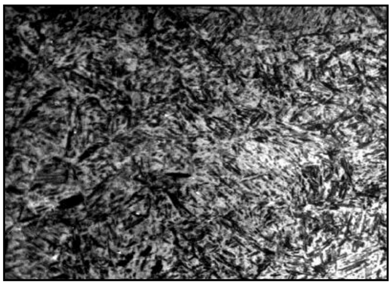
Iron Phase	Microstructure	Descriptions
Austenite		In liquid form, has Face Centre Cubic [F.C.C] atomic structure, contain up to 2% carbon.
Ferrite		This phase has Body Centre Cubic [B.C.C] atomic structure, hold very little carbon (0.0001% at room temperature), can be either alpha or delta ferrite.
Cementite		This is a very hard intermetallic compound having 6.7% carbon and remainder is iron, very hard, hardness reduced when mixed with soft ferrite layers, slow cooling gives course perlite which is easy to machine but low toughness, faster cooling produce very fine layers of ferrite and cementite which is harder and tougher.
Pearlite		Mixture of ferrite and cementite strips in single grain, distance between the plates and their thickness is depending on the cooling rate of the material. Fast cooling creates thin plates that are close together and slow cooling creates a much course structure having less toughness. Fully pearlitic structure occurs at 0.8% carbon
Martensite		Exist when rapid cooling from austenite, the F.C.C structure rapidly change to B.C.C giving enough time for the carbon to form pearlite. This will produce distorted structure that has visual of fine needles. Martensite is either forms or it does not which is not a partial transformation phase. Only the part that cooled fast enough will form martensite. Martensite hardness only depends on carbon content and it is usually very high except the carbon content is low

Table 2.1: Iron-Phase type and description

2.3 METAL ETCHING FOR OPTICAL MICROSCOPE OBSERVATION

Etching is to visually improve microstructural features such as grain size and phase features. There are many different chemicals and methods that may be used to etch different metals. In very general and basic terms the process of etching metal is the removal of some parts by applying a chemical corrosive while leaving others untouched by covering with a layer of resistant material. The purpose is to make the microstructure visible under optical microscope.

2.3.1 Preparation of metal

Before etching we should lightly sand the metal with fine wet/dry sandpaper to remove any oxidation and scratch.

2.3.2 Completion of the metal piece

After etching, the metal surface should be clean until the entire etching reagent or resist has been removed. The pattern will be visible if the etch has worked. Cleaning or sand too hard will remove the etched design. Instead, metal polishing compound, such as Autosol Metal to make the cleaning easier.

2.3.3 Common chemicals used for etching

Etchant	Composition	Application	Conditions
Kellers Etch	190 ml Distilled water 5 ml Nitric acid 3 ml Hydrochloric acid 2 ml Hydrofluoric acid	Aluminum Alloys	10-30 second immersion
Kroll's Reagent	92 ml Distilled water 6 ml Nitric acid 2 ml Hydrofluoric acid	Carbon steels, tin, and nickel alloys	Seconds to minutes
Nital	100 ml Ethanol 1-10 ml Nitric acid	Carbon steels, tin, and nickel alloys	Seconds to minutes
Kalling's Reagent	40 ml Distilled water 2 grams Copper chloride 40 ml Hydrochloric acid 40-80 ml Ethanol (85%) or	Wrought stainless steel, Fe-Ni-Cr alloys	Immerse or swab for few seconds to a few minutes
Lepito's Reagent	50 ml Acetic acid 50 ml Nitric acid	High temperature steels	Swab

Etchant	Composition	Application	Conditions
Marble's Reagent	50 ml Distilled water 50 ml Hydrochloric acid 10 grams Copper sulfate	Stainless steels, Nickel alloys	Immersion or swab etching for a few seconds
Murakami Reagent	100 ml Distilled water 10 grams $K_3Fe(CN)_6$ 10 grams NaOH or KOH	Wrought Stainless steel, tungsten alloys, Silver alloys.	Immerse or swab for seconds to minutes
Pieral	100 ml Ethanol 2-1 grams Picric acid	Iron and steel, Tin alloys	Seconds to minutes
Vilella's Reagent	45 ml Glycerol 15 ml Nitric acid 30 ml Hydrochloric acid	Stainless steel, Carbon steel, Cast iron	Seconds to minutes

Table 2.2: Common etching reagents used for various steel etch

2.4 HEAT TREATMENT

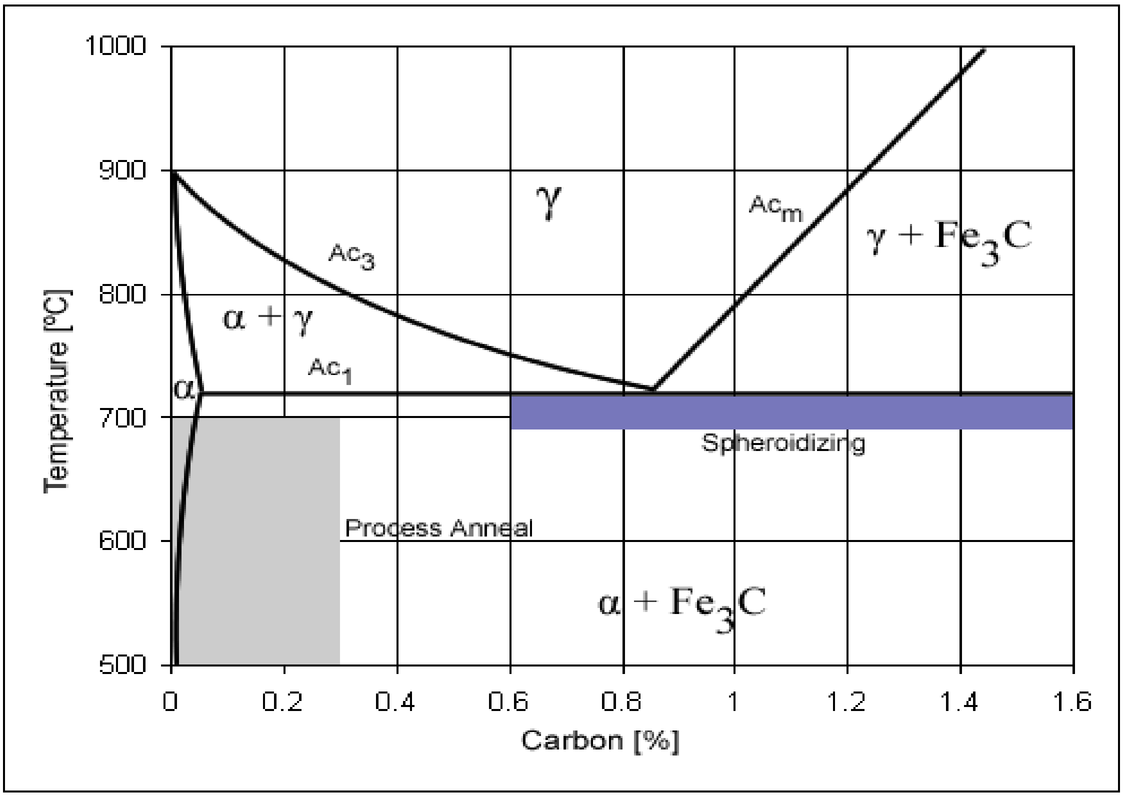


Figure 2.2: Heat Treatment Temperature on Phase Diagram

2.4.1 Post Weld Heat Treatment

The post weld heat treatment is normally performed to reduce the risk of brittle fracture. Post weld heat treatment is the most widely used form of stress relieving on completion of fabrication of welded structures. This stresses exist when a weld cools and its contractions is restricted by the bulk of the material surrounding it. Post weld heat treatment will generally result in a modification of the microstructure of both the weld metal and heat affected zone. With alloy steels, the thickness at which post weld heat treatment becomes mandatory is much less. Typically, the range is 13 – 20 mm, and even below 13 mm, a series of strict conditions have to be met before post weld heat treatment can be waived

2.4.2 Process Annealing

Annealing is a technique used to recover cold work and relax stresses within a metal. A process used to relieve stress in cold-worked carbon steel with less than 0.3 wt% C. The steel is usually heated up to 550–650 °C for 1 hour, but sometimes temperatures as high as 700 °C. The image rightward shows the area where process annealing occurs.

2.4.3 Full annealing

Carbon steel is heated to approximately 40 °C above Ac3 or Ac1 for 1 hour; this assures all the ferrite transforms into austenite. The steel must then be cooled slowly, in the realm of 38 °C (100 °F) per hour. Usually part allowed to cool in the furnace. This result in a coarse pearlitic structure, which means the "bands" of pearlite are thick. Fully-annealed steel is soft and ductile, with no internal stresses.

2.4.4 Isothermal annealing

It is a process in which hypoeutectoid steel is heated above the upper critical temperature and this temperature is maintained for a time and then the temperature is brought down below lower critical temperature and maintained. Then finally it is cooled at room temperature. This method rids any temperature gradient.

2.4.5 Normalizing

Carbon steel is heated to approximately 55 °C above Ac3 or Acm for 1 hour; this assures the steel completely transforms to austenite. The steel is then air-cooled, which is a cooling rate of approximately 38 °C (68 °F) per minute. This results in a fine pearlitic structure, and a more-uniform structure. Normalized steel has a higher strength than annealed steel; it has a relatively high strength and ductility.

2.4.6 Quenching

To harden by quenching, carbon steel with at least 0.4 wt% C is heated to normalizing temperatures (austenitic crystal phase) and then rapidly cooled (quenched) in water, brine, or oil to the critical temperature. This results in a martensitic structure. Thus quenched steel is extremely hard but brittle, usually too brittle for practical purposes. These internal stresses cause stress cracks on the surface. Quenched steel is approximately three to four (with more carbon) fold harder than normalized steel.

2.4.7 Tempering

Untempered martensite (after quenching), very hard and strong, is too brittle to be useful for most applications. A solution for this problem is called tempering. Most applications require quenched parts to be tempered (reheating quenched steel to a temperature below the eutectoid temperature, often 150°C then cooling) to impart some toughness (restore ductility, but reduces hardness).

2.5 WELDING

2.5.1 Shielded Metal Arc Welding (SMAW)

SMAW is the most widely use of arc welding type. Compared to others arc welding, SMAW is more economical and its equipment is more portable and less complex. SMAW is performed by striking an arc between coated-metal electrode and base metal. Arc established and molten metal from electrode tip flow together with molten metal from base metal edge to form a joints (known as fusion).

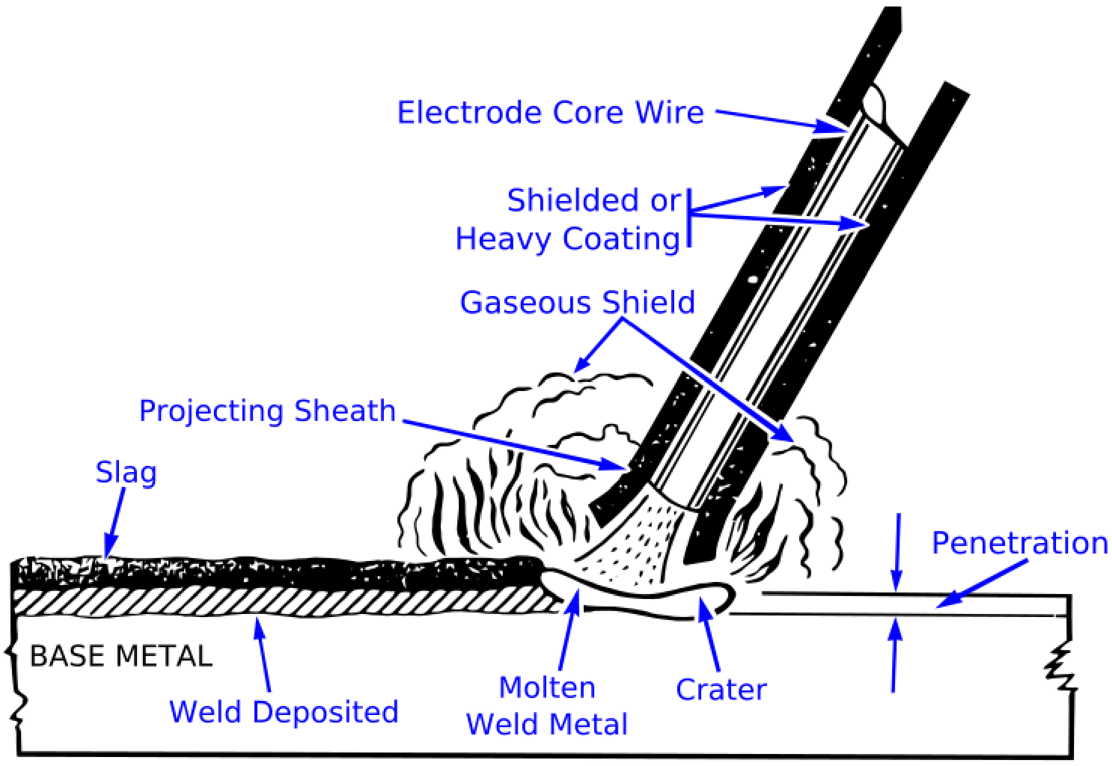


Figure 2.3: SMAW illustration

2.5.2 Electrodes for SMAW

Since the base metal to weld is mild steel, the suitable electrode is E6013 RB-26 (AWS Specification). This electrode type is common used for welding light sheet metals, light duty steel structures, and for surfacing thick-section welds. The coating type for E6013 is high titania potassium. The current range for this electrode is 80-140 amps.

"E" stands for electrode, the first two digits, "60" is the minimum tensile strength 60,000 p.s.i, the second last digit, "1" indicates that this electrode suitable for all position, and the last digit, "3" is the type of current. In this case is Direct Current Reverse Polarity (electrode positive), Direct Current Straight Polarity (electrode negative), or Alternative Current. The "R" in RB-26 stands for Rutile, which is major ingredient in the coating flux. While the "B" means a slag-shield covered electrode. "26" represent the 26^{th} year of the show era of japan, relative to 1951 when it was developed.

2.5.3 Welding Joints and Position

Welding joints for this project is single-v butt joint. Single sided preparations are normally made on thinner materials, or when weld access from both sides is restricted. The welding position used is Flat position 1G as in ASME IX, 2007, Article I, QW-110.

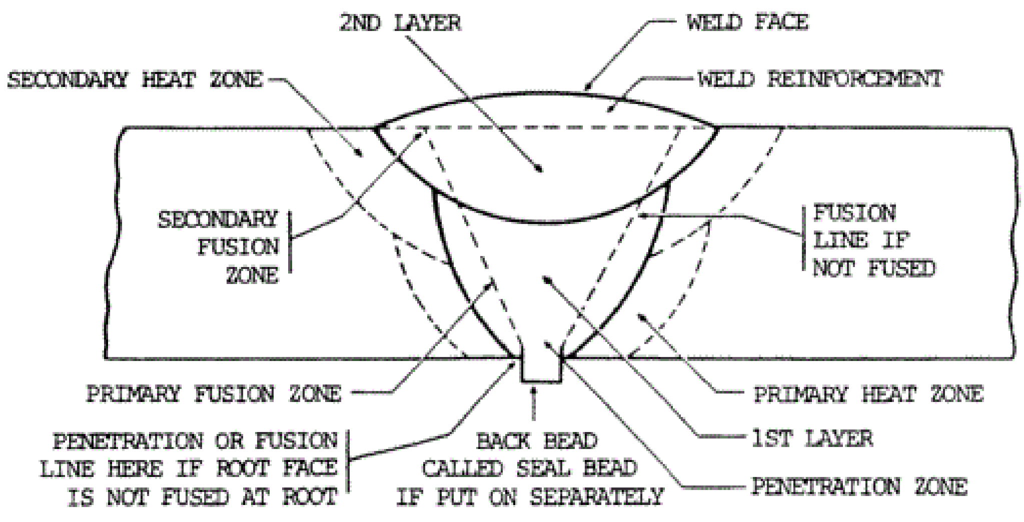


Figure 2.4: Terms of a Butt Welded Butt Joint

2.6 MECHANICAL TESTING

Hardness is one of the important mechanical properties, which is measurement of material's resistance to plastic deformation. Hardness test are usually performed because of inexpensive, simple, non-destructive (only small indentation), and from hardness data we can use it to estimate other mechanical properties such as tensile strength.

2.5.2 Brinell Hardness Test

In Brinell hardness testing, a hard spherical indenter is pressured into the surface of the test sample. The diameter of the indenter is 10 mm and the standard loads range between 500 to 3000 kg with 500 kg increments. During the test, the load is maintained constant for 10 to 30 second. The diameter of indentation is then measured and converted to Brinell Hardness Number using a chart. The reference used for this testing is ASTM E 10, Standard Test Method for Brinell Hardness of Metallic Materials

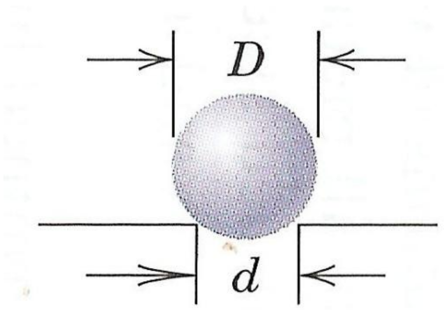


Figure 2.5: Side view during indentation

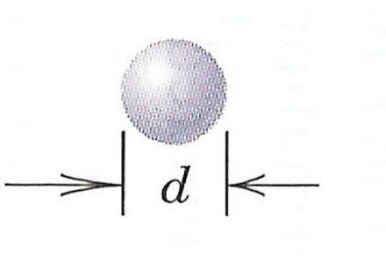


Figure 2.6: Top view of indentation on test sample

Brinell harness number can be calculated using the formula:

$$\mathrm{HB} = \frac{2\mathrm{P}}{\pi\mathrm{D}[\mathrm{D} - \sqrt{\mathrm{D}^2 - d^2}]}$$

Where: HB: Brinell Hardness Number
P : Load
D : Indenter diameter
d : Resulting indentation diameter on test sample

2.5.3 Vickers Micro Indentation Hardness Test

Vickers hardness test use a very small diamond indenter having pyramidal geometry. During testing, this indenter will be forced into the surface of the specimen. Applied loads are much lower than Brinell hardness test (ranging between 1 to 1000g). The result of indentation impression is observed under a microscope and measured according to figure 2.8.

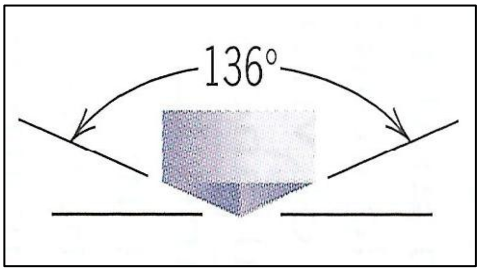


Figure 2.7: Shape of Indentation (side view)

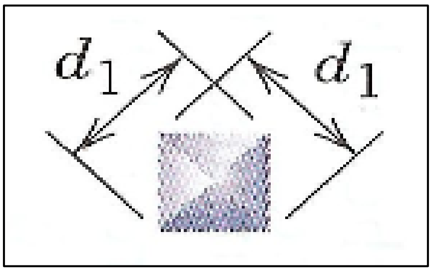


Figure 2.8: Example of Indentation Impression on test sample

This measurement of d_1 is then converted into a hardness number using formula for hardness number;

$$\mathrm{HV} = \frac{1.854P}{d_1^2}$$

Where: HV: Vickers Hardness Number
P : Applied Load
d : Size of impression

2.5.3 Tension Test

The purpose of tensile test is to determine the tensile strength of the weld metal. This test is suitable for groove butt joint in plate. The usual size and shape of the specimens as in figure below:

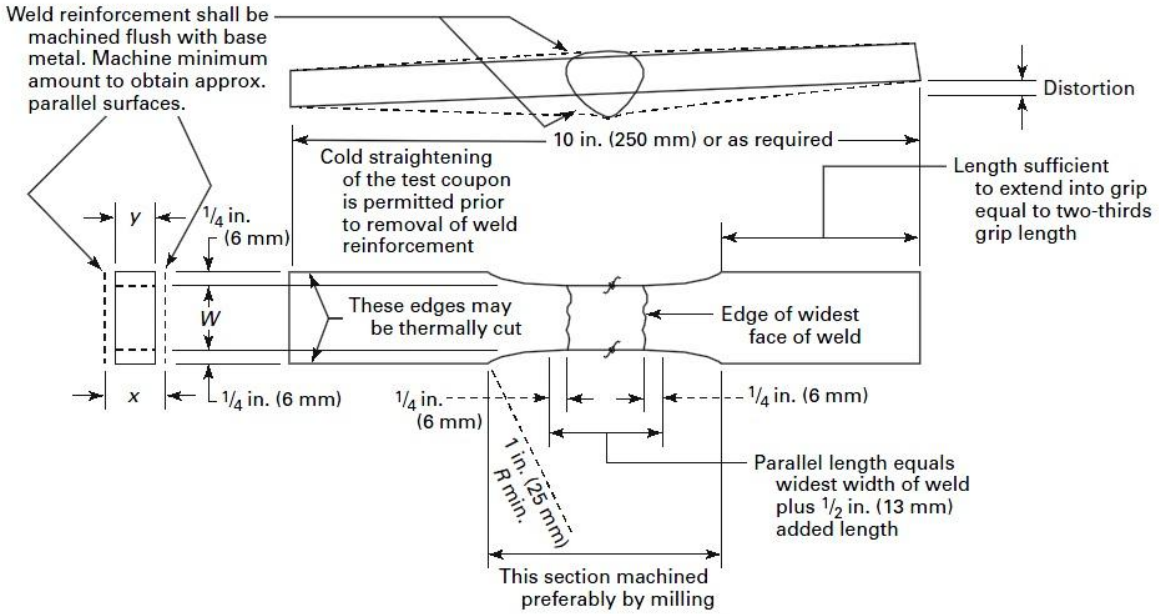


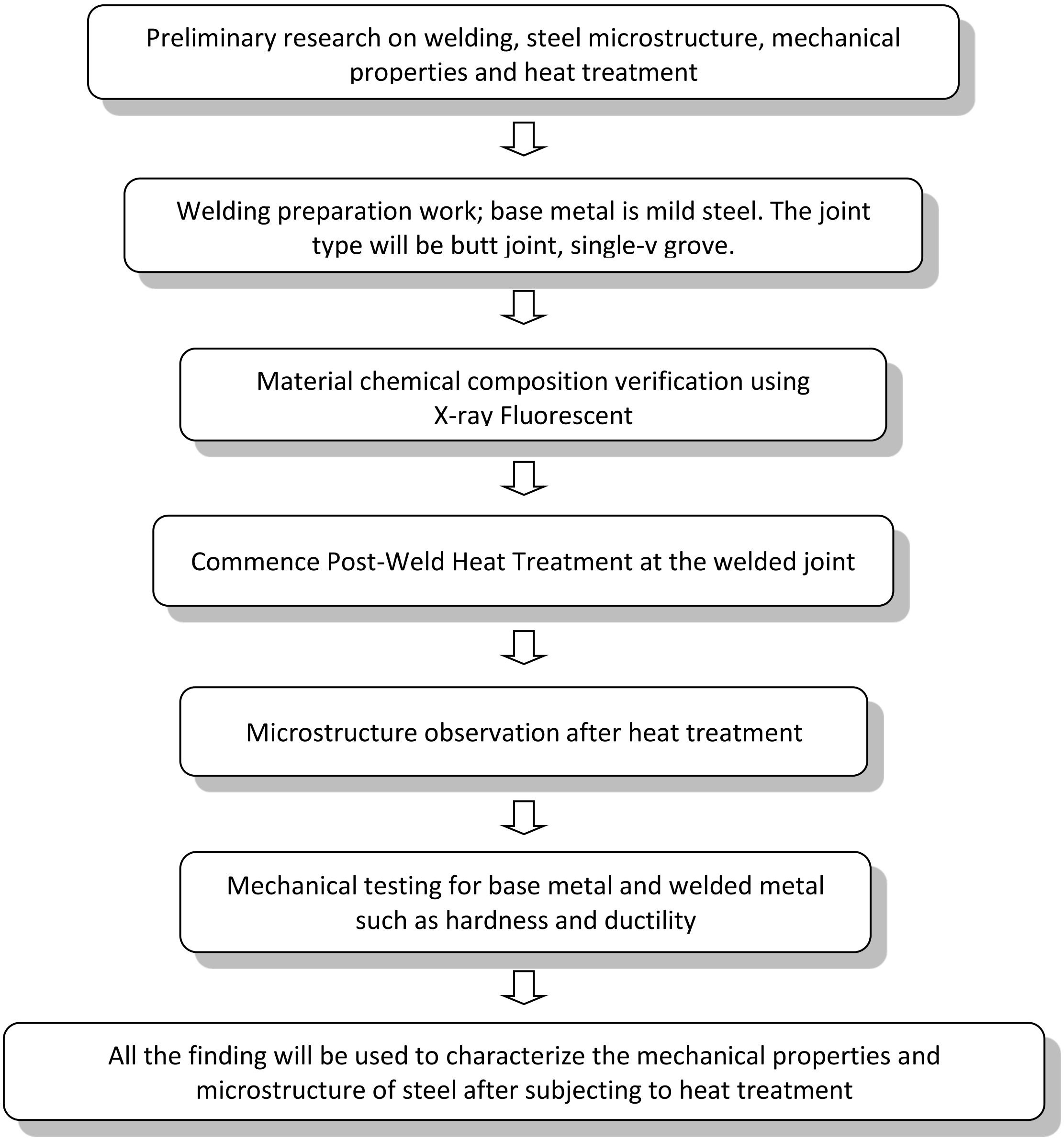
Figure 2.9: Tension specimen for plate (reference: ASME IX, 2007, QW-462)

From the figure above, specimen width, W is equal to 19 mm and the grinding mark must be parallel to the tensile force otherwise it may have a notch effect.

CHAPTER 3

METHODOLOGY and PROJECT WORK

3.1 METHODOLOGY FLOWCHART



3.2 X-RAY FLUORESCENCE SAMPLE PREPARATION

Test sample for X-Ray Fluorescence prepared as in figure 3.1. The diameter for test sample is 40 mm with 6 mm thickness, which machined using Electric Discharge Machine. This sample has been polished using power brush and polisher machine using sand paper.

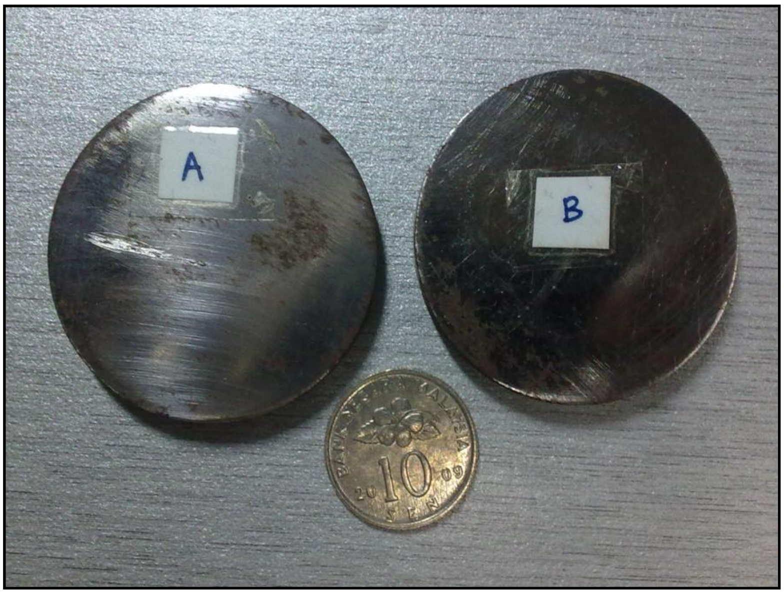


Figure 3.1: Test Sample for X-Ray Fluorescence

The sample must be clean from any contaminant on the surface even the finger print can affect the accuracy of result. The steel was polished to ensure no corrosions to avoid present of oxide in the XRF final result.

3.3 CARBON STEEL WELDING PROCEDURE

3.3.1 Single-V Bevel Weld Preparation

The choice of weld preparation is to compromise between maintaining adequate access and minimizing the weld volume. I am using a typical pipe butt weld set-up. The included angle would be 60°, ± 3 mm root gap, and zero to 2 mm thick root face.

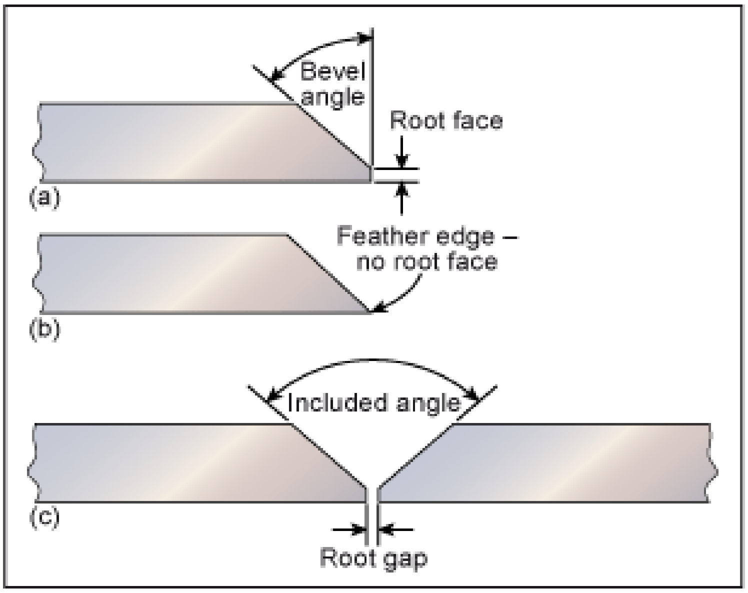


Figure 3.2: Bevel preparation illustration

This single-v bevel weld preparation was done by using conventional lathe machine. Conventional lathe is to roughly shape the bevel into the desired angle. After that we use file to remove corrosion or dirt around the area to be weld. The thickness of the metal plate to be weld is about 7 mm. Therefore, one path of shielded metal arc welding is sufficient to weld the plate.

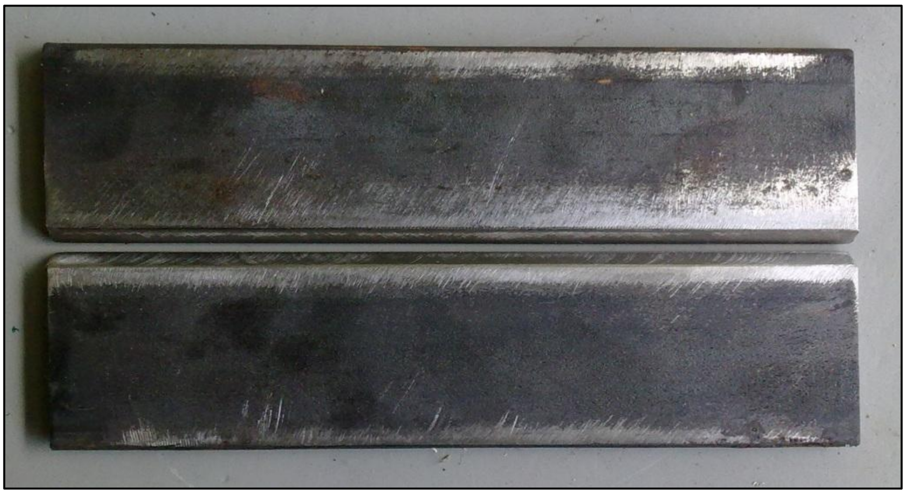


Figure 3.3: Bevel preparation

3.3.2 Welding Electrode

Since the steel is low carbon steel, the suitable electrode is E6013 RB-26 according to AWS Specification. The current range for this electrode is between 80 Amps to 140 Amps. The minimum tensile strength for this electrode is 60,000 Psi and it is slag-shield covered electrode.

Figure 3.4: Electrode E6013 RB-26, 3mm diameter

3.3.3 Joints Welding

The type of welding used is shielded metal arc welding which is commonly used for carbon steel welding. The references used for welding process are taken from ASME IX, 2007 Edition Article I (for determining the weld orientation, and position for groove welds), Article II (Welding Procedure), Article III (Welding variables), and Article IV (Welding data).

Welding position performed is flat position (1G) base on ASME IX, 2007, Article I, QW-110. The welding process consists of root or penetration welding and finish up with capping (see figure 3.5).

Figure 3.5: Shielded Metal Arc Welding

3.4 SAMPLE PREPARATION FOR MICROSTRUCTURE OBSERVATION

Previously welded mild steel cut into perpendicular cross section to weld path. After that, sample will be mounted for easy grip during grind and polishing.

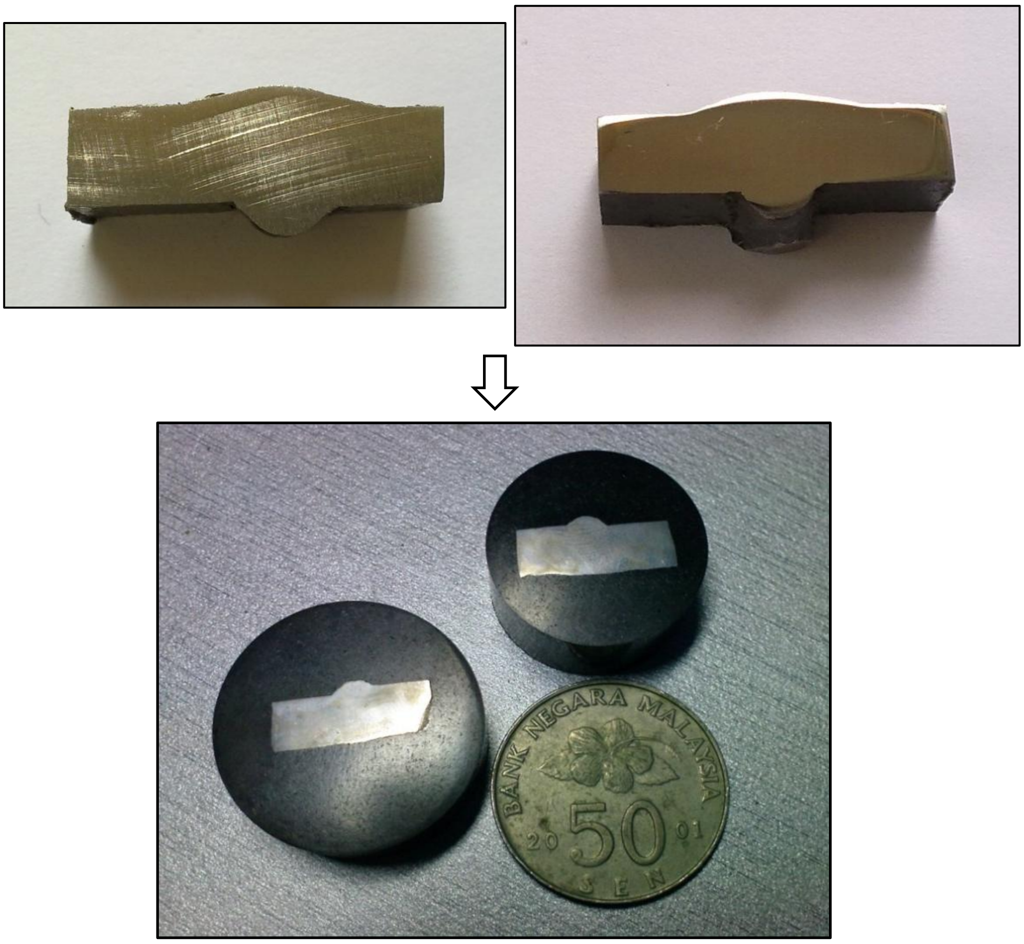


Figure 3.6: Example of metallurgical sample

There are a few type of sand paper used. After cutting, we need rough sand paper (grit 60) to remove deep scratch first. After that follow by less roughness sand paper which is Grit 120, Grit 240, Grit 320, Grit 400, Grit 2400, and Grit 4000 in order.

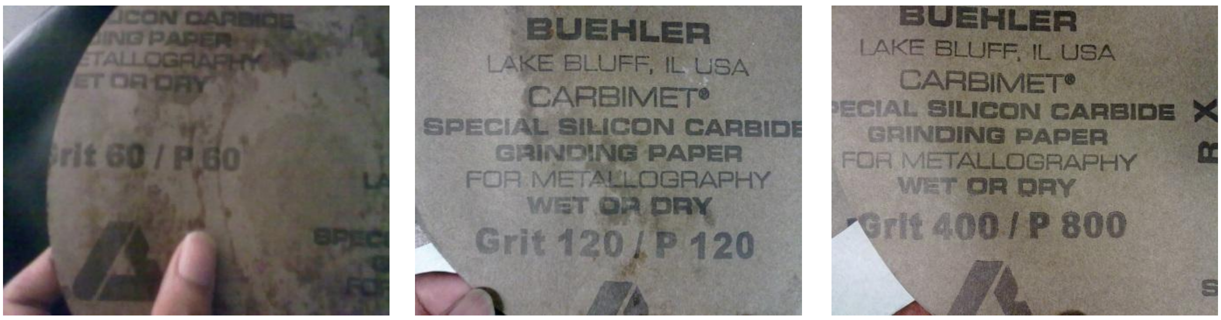
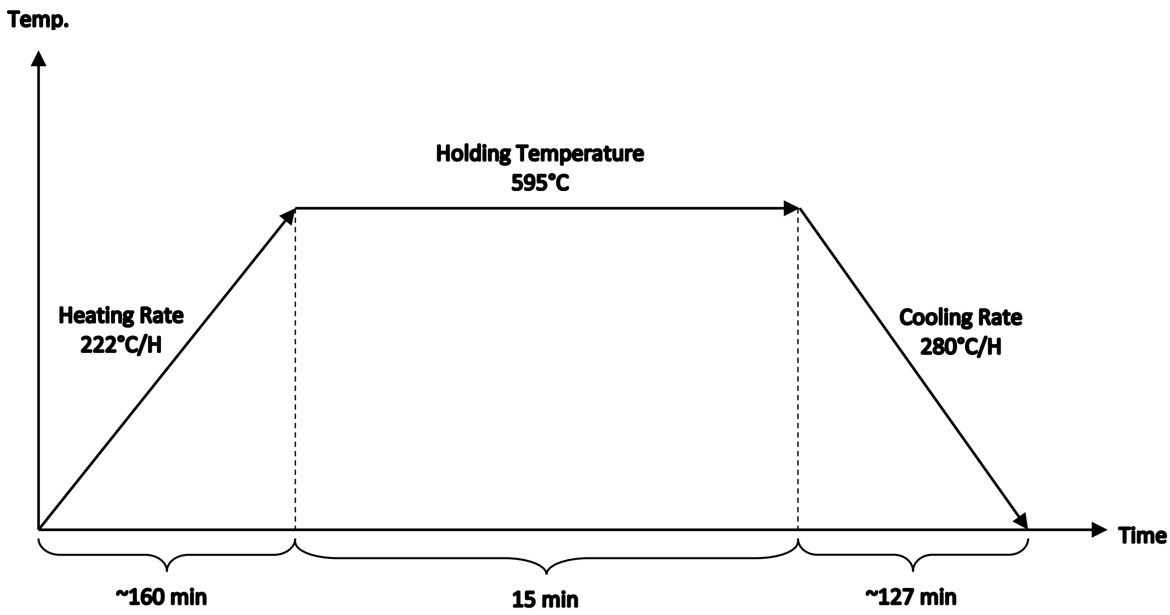


Figure 3.7: Example of sand papers discs

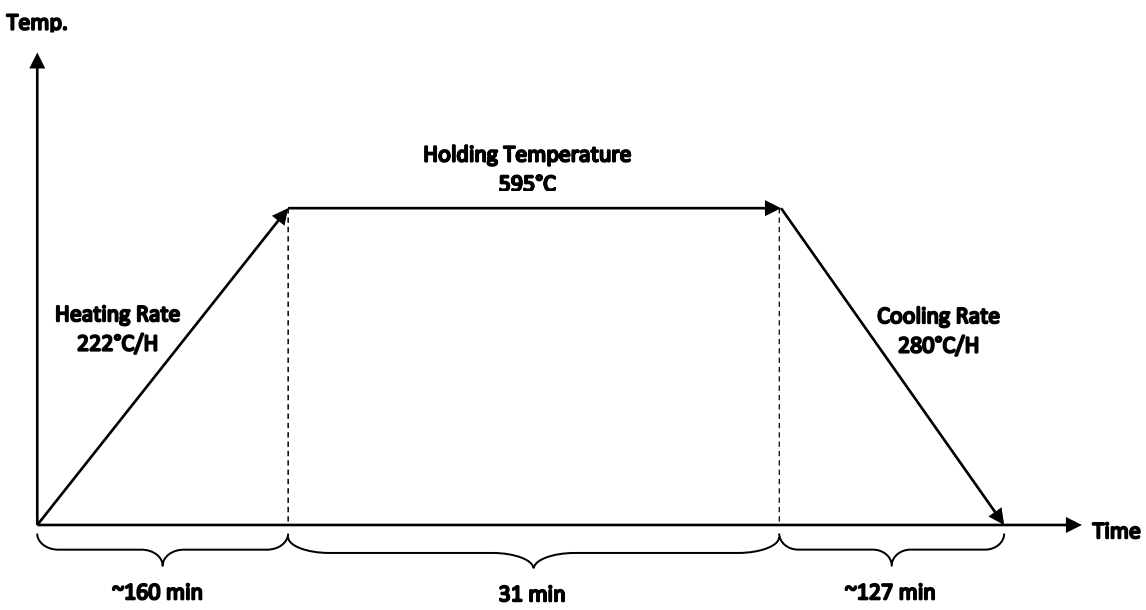
3.5 CARBON STEEL HEAT TREATMENT PARAMETER

The standard used for post weld heat treatment is in ASME VIII, DIV I, UCS-56. The carbon steel welding has been heat treated according to calculation and graph below:

Weld thickness: 6mm = 0.24 inch
Heating rate : 222°C/hr ÷ 0.24" = 925°C/hr (maximum 222°C/hr)
Cooling rate : 280°C/hr ÷ 0.24" = 1167 °C/hr (maximum 280°C/hr)
Soak time : 0.24" x 60 min = 15 min (minimum)



Weld thickness: 13mm = 0.51 inch
Heating rate : 222°C/hr ÷ 0.51" = 435°C/hr (maximum 222°C/hr)
Cooling rate : 280°C/hr ÷ 0.51" = 549 °C/hr (maximum 280°C/hr)
Soak time : 0.51" x 60 min = 31 min (minimum)



3.6 VICKERS HARDNESS TEST

The hardness of the sample measured using Vickers Micro Indentation machine. The load used is 300gram with pyramid indentation shape. The reason for using Vickers hardness test because of it is more convenient to do hardness test at selected microstructure area.

Hardness test for sample consist of three areas which is base metal, weld metal and heat affected zone. The base metal is indicated by the red dot in the figure 3.8 below. Next is the weld metal or also known as fusion metal. This area indicated by green dot in the figure 3.8 below. The last area is the heat affected zone which is in the boundary between weld metal and the base metal. This area indicated in between the yellow line in the figure 3.8 below.

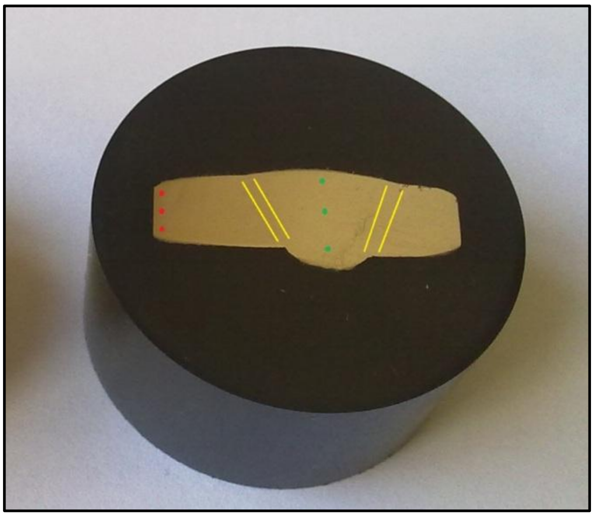


Figure 3.8: Hardness test area. (Red dot: base metal, green dot: weld metal, between yellow line: HAZ)

3.7 TENSILE TEST

Tensile test sample machined using EDM to get the “dog bone” shape. The total length of the test sample is 203.2mm. The tensile test performed using 100kN capacity tensile test machine.

Measurement of Samples	Sample 1	Sample 2
Specimen Length	203.2mm	203.2mm
Original Gauge Length	34mm	34mm
Original Width	19mm	19mm
Original Area	133mm^2	133mm^2
Testing Speed Rate	0.006mm/s	0.006mm/s

Table 3.1: Tensile test sample dimension and parameter

CHAPTER 4
RESULT AND DISCUSSION

4.1 X-RAY FLUORESCENCE (XRF) RESULT

The purpose of XRF is to verify the steel used is low carbon steel. From the result, we can determine the chemical composition of the steel (table 4.1 and table 4.2). The amount of carbon in the steel used is low therefore it is difficult to be detected. The absent of carbon in the XRF result verify the steel is in low carbon content.

Sample: Steel A
Measurement Method: Elemental

Oxide (O)	Aluminium (Al)	Silicon (Si)	Sulfur (S)	Chromium (Cr)	Manganese (Mn)	Iron (Fe)
0.3 KCps	1.0 KCps	4.0 KCps	1.3 KCps	9.6 KCps	58.9 KCps	9982.7 KCps
30	0.0683	0.237	0.0304	0.0553	0.4665	68.48

Nickel (Ni)	Copper (Cu)	Zinc (Zn)	Molybdenum (Mo)	Terbium (Tb)	Sulfur Trioxide (SO_3)
5.0 KCps	33.0 KCps	2.1 KCps	3.9 KCps	32.8 KCps	1.3 KCps
0.0689	0.406	0.0082	0.0105	0.0705	1.132

Table 4.1: XRF results for steel A

Sample: Steel B
Measurement Method: Elemental

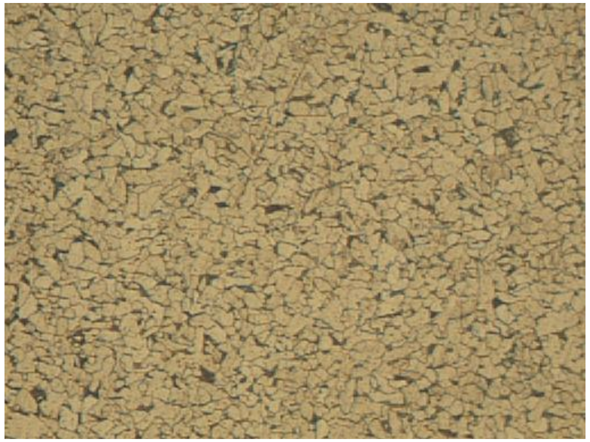
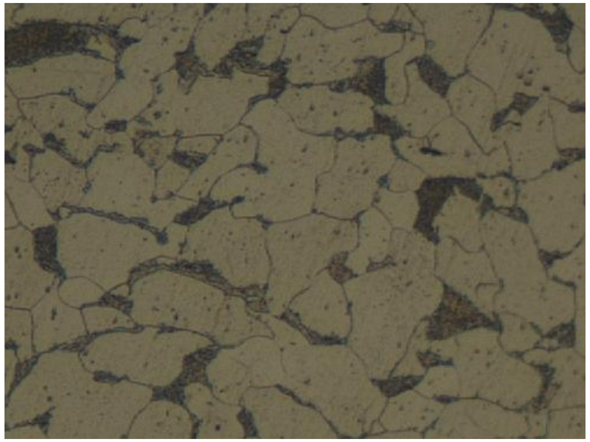
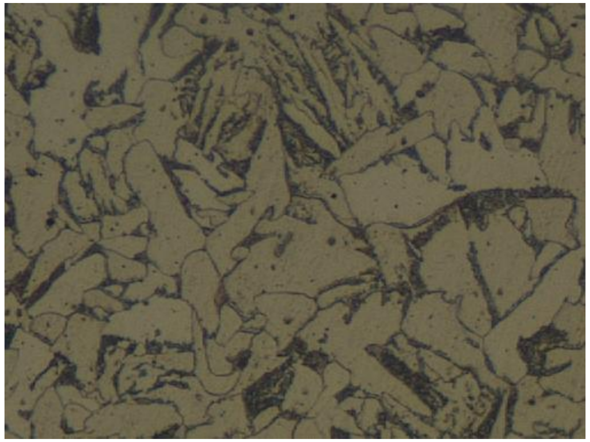
Oxide (O)	Aluminium (Al)	Silicon (Si)	Sulfur (S)	Chromium (Cr)	Manganese (Mn)	Iron (Fe)
0.3 KCps	0.6 KCps	3.1 KCps	1.1 KCps	9.4 KCps	58.9 KCps	9674.7 KCps
30	0.040	0.185	0.0272	0.0559	0.4817	68.56

Nickel (Ni)	Copper (Cu)	Zinc (Zn)	Molybdenum (Mo)	Terbium (Tb)	Sulfur Trioxide (SO_3)
5.1 KCps	32.3 KCps	2.3 KCps	3.8 KCps	33.1 KCps	1.1 KCps
0.0737	0.412	0.0114	0.0106	0.0782	1.168

Table 4.2: XRF results for steel B

4.2 MICROSTRUCTURE OBSERVATIONS FOR 6MM MILD STEEL THICKNESS (BEFORE PWHT)

Mild Steel Microstructure before Heat Treatment

	50x magnified	100x magnified	500x magnified
Base Metal			
Heat Affected Zone			

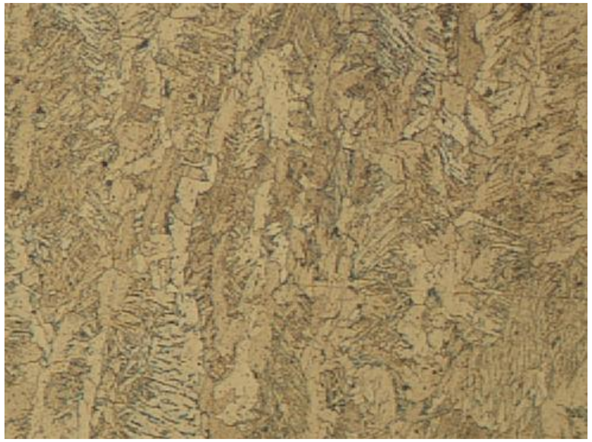
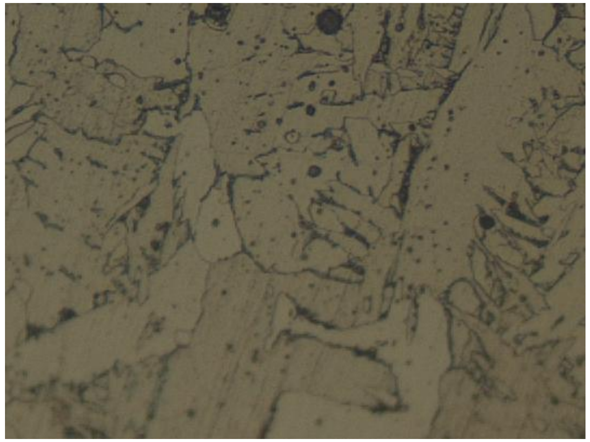
	50x magnified	100x magnified	500x magnified
Weld Metal			

Table 4.3: Mild steel microstructure after welding before heat treatment

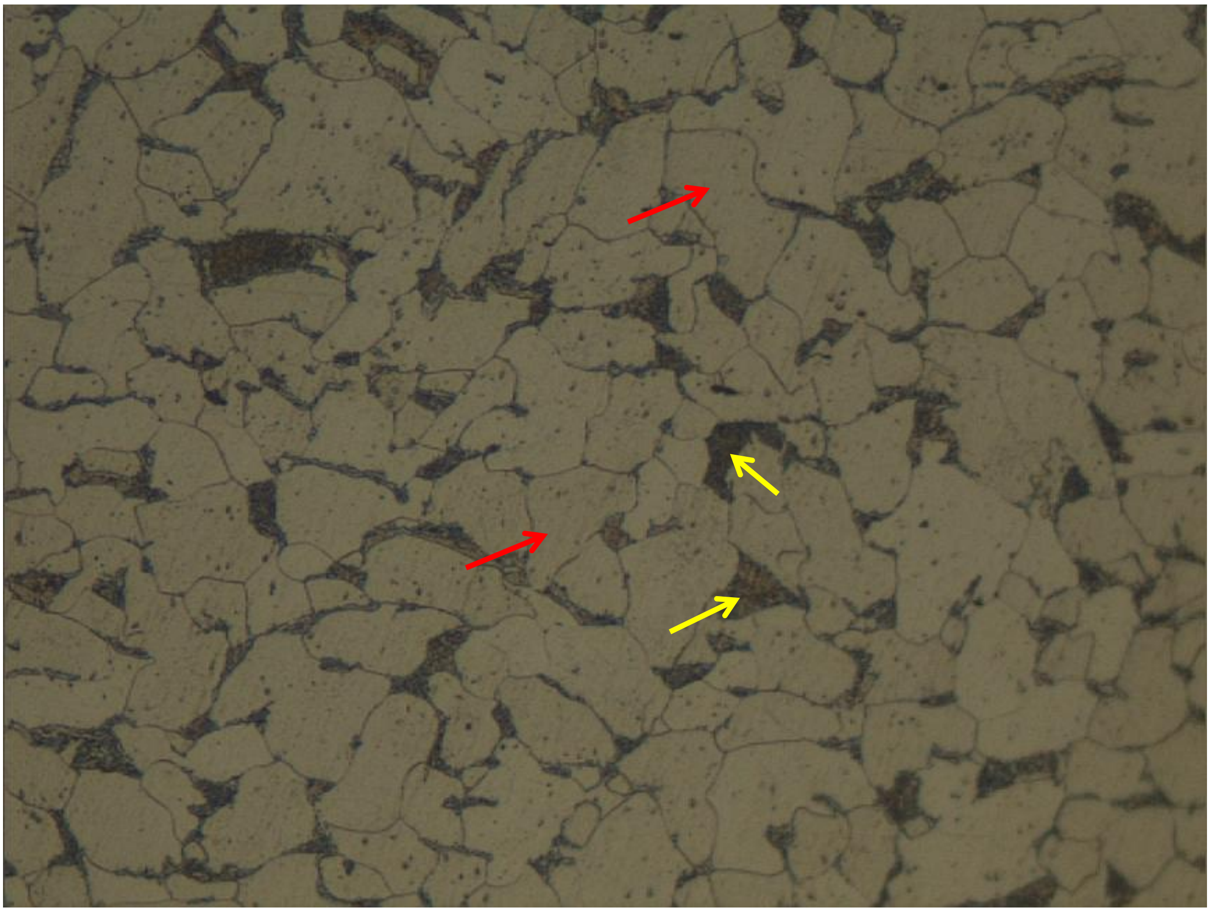


Figure 4.1: Mild Steel microstructure under 500x magnification by optical microscope.

The light areas are ferrite (red arrow) has a body-centered cubic (BCC) crystal structure. It is soft and ductile and imparts these properties to the steel. Very little carbon (less than 0.01% carbon will dissolve in ferrite at room temperature). Ferrites are often known as alpha-iron (α-Fe). This pure iron transform into austenite face-centered cubic if heated above 910°C. Further heating up to 1394°C to 1538°C, austenite will change to body-centered cubic structure again and known as delta-ferrite (δ-Fe).

The darker areas are pearlite (yellow arrow) which is a laminated structure of ferrite (α-Fe) and cementite (Fe_3C). The strength of cementite combined with ductility of ferrite which can provide new variation of steels properties. The laminar structure also can prevent crack movement and gives it toughness.

Cementite is a combination of iron and carbon (iron carbide, Fe_3C). It is hard and brittle and its presence in steels causes an increase in hardness and a reduction in ductility and toughness which is ferrite properties.

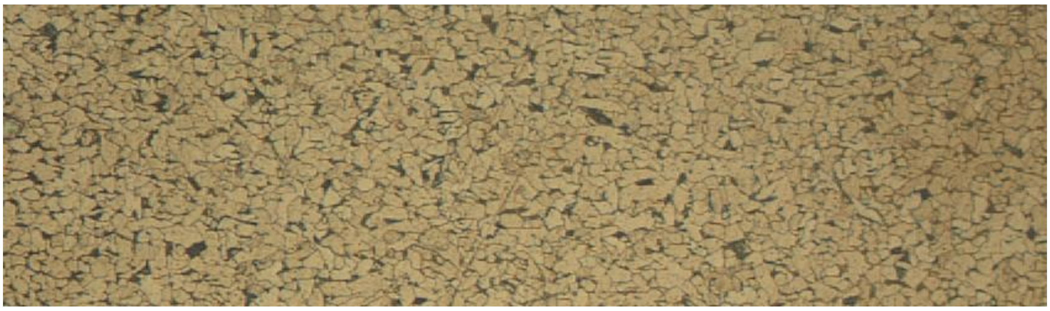


Figure 4.2: Base/Parent Metal microstructure under 100x magnification

Figure 4.3: Weld/Filler Metal, also known as fusion zone microstructure under 100x magnification

Base metal microstructure is almost the same grain size everywhere. It consists of more ferrite (light area) and pearlite (darker area). The microstructure of the base metal is totally different from the weld metal region in term of grain size and shape and also its phase properties.

Weld metal have longer grain and bigger than the base metal. The direction of the structure is toward the welding electrode. Less pearlite found in the base metal compared to base metal (red arrow in figure 4.3). Due to rapid cooling after welding, some of the martensitic structure exists along the weld metal (yellow circle in figure 4.3). Martensitic is a very hard needle-like structure of iron and carbon.

From figure 4.3, inside the red circle, we can also identify the ferrite with non-aligned MAC (martensite, austenite, and carbide). This constituent called ferrite with aligned second phase (can also regarded as bainite). This second phase is mainly the iron carbide cementite. Other constituents such as martensite and retained austenite (retained phases) are present in small quantities.

Meanwhile, inside the black rectangular in figure 4.3 is the ferrite with aligned MAC. The lighter grain shown by green arrow in figure 4.3 is the pro-eutectoid ferrite.

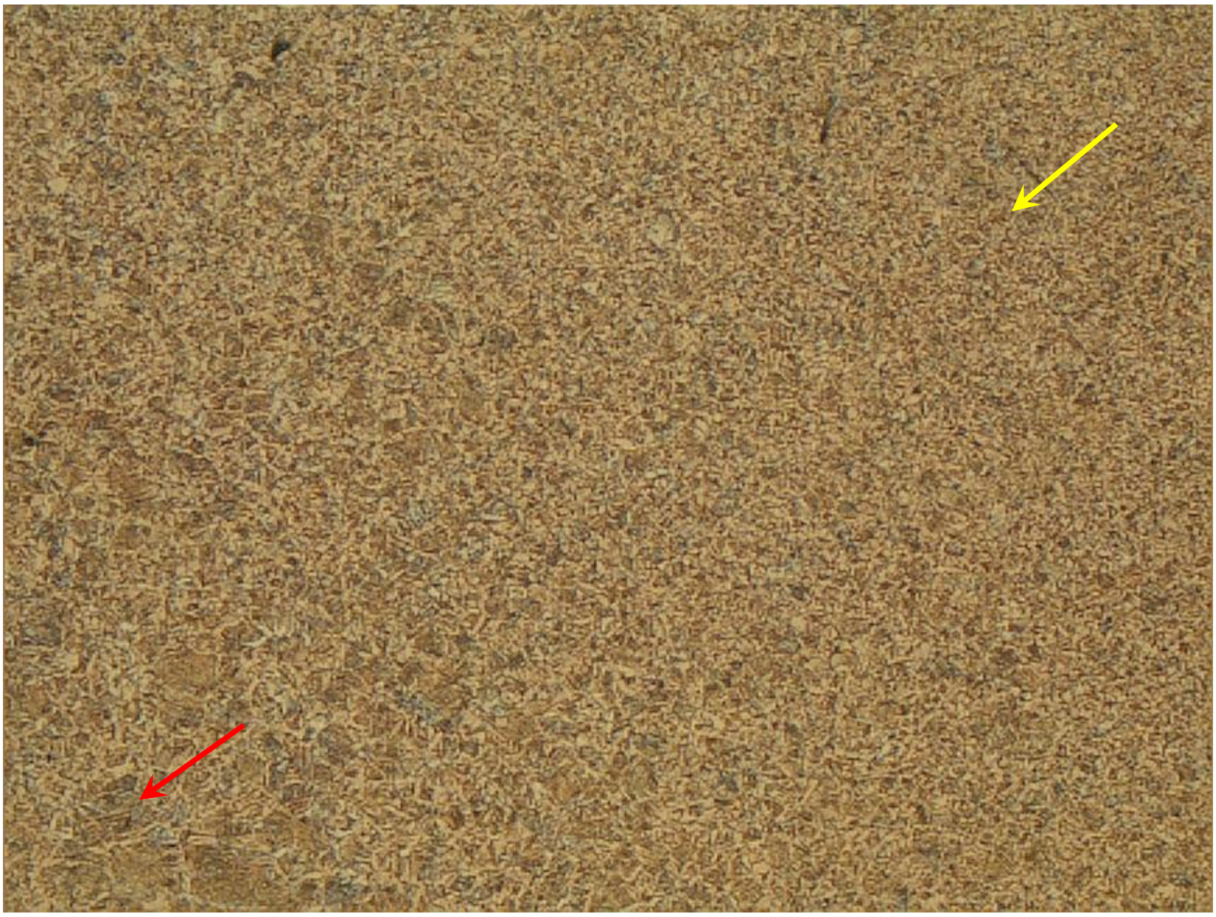
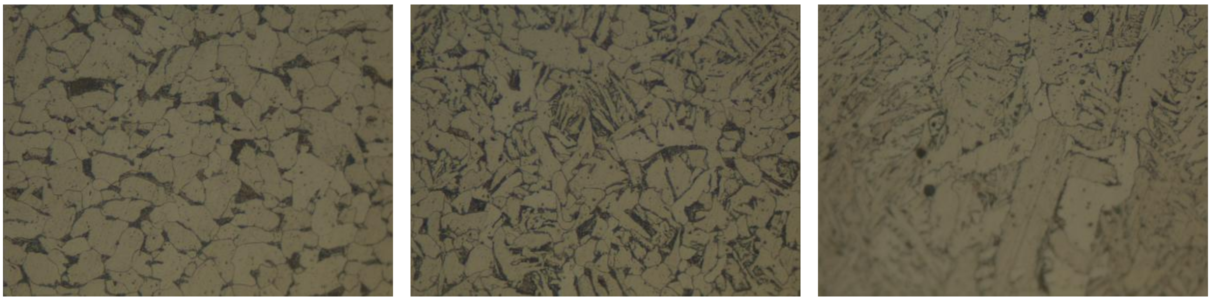


Figure 4.4: Heat Affected Zone microstructure under 50x magnification

As we observe the microstructure from the base metal (areas at the yellow arrow in figure 4.4) to the weld metal (areas at the red arrow in figure 4.4), we can see the microstructure grain changes from small to larger size. These changes happen at the boundary between base metal and the weld metal which is known as heat affected zone (areas in the middle between yellow and red arrow). Heat affected zone is relatively small depends on the thermal diffusivity of the base metal. For clearer comparison between base metal, heat affected zone, and fusion zone, see figure 4.5 below.

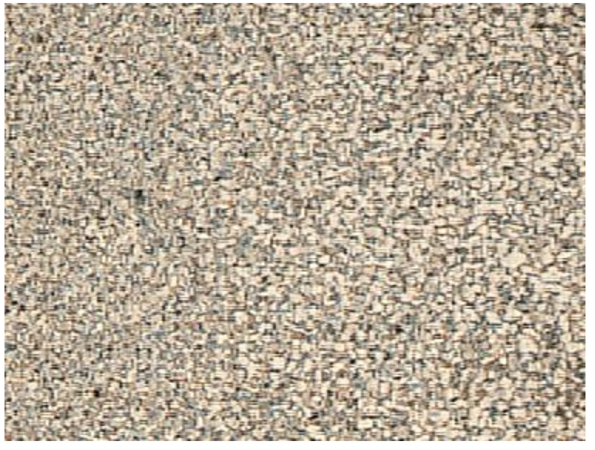
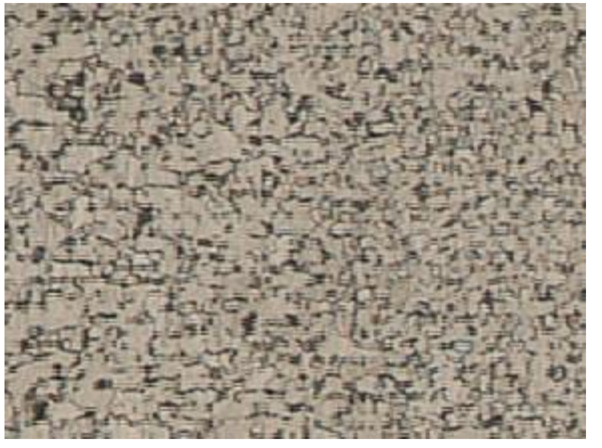
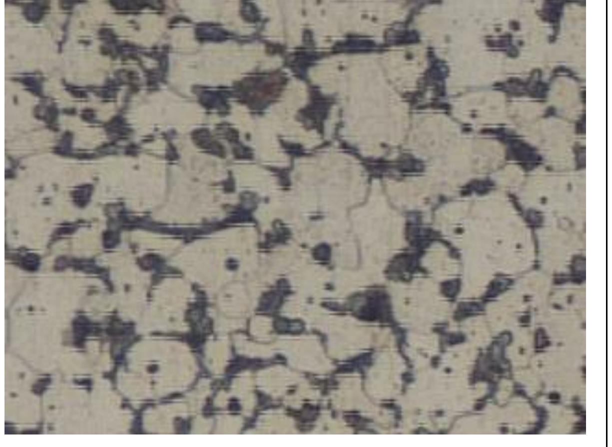
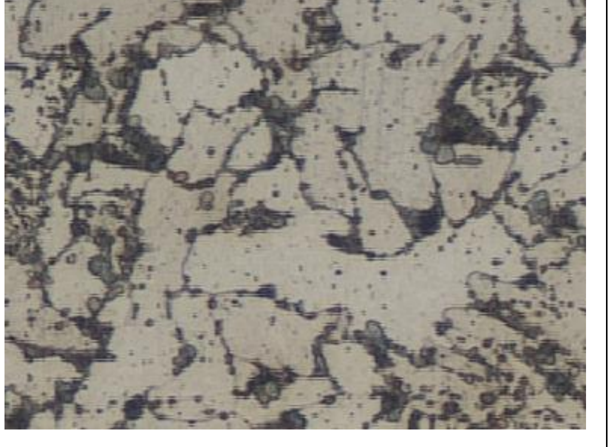


(a) (b) (c)

Figure 4.5: Microstructure of mild steel under 500 x magnifications at (a) Base metal, (b) Heat affected zone, (c) Fusion zone.

4.3 MICROSTRUCTURE OBSERVATIONS FOR 6MM MILD STEEL THICKNESS (AFTER PWHT)

Mild Steel Microstructure after Heat Treatment

	50x magnified	100x magnified	500x magnified
Base Metal			
Heat Affected Zone			

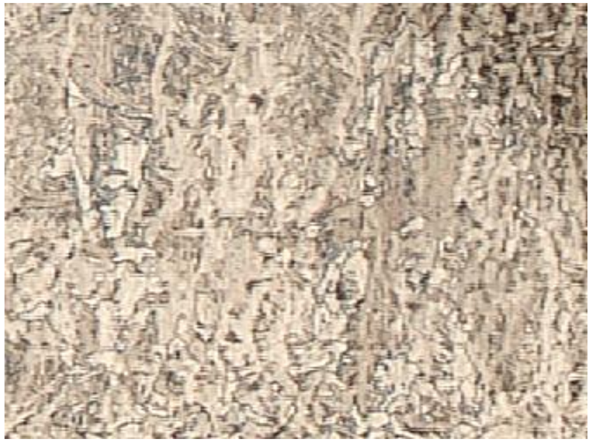
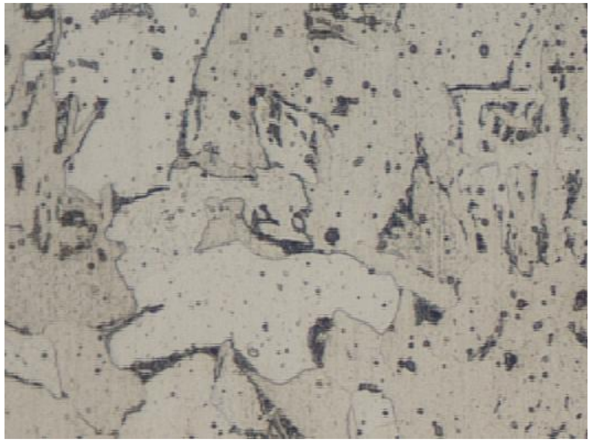
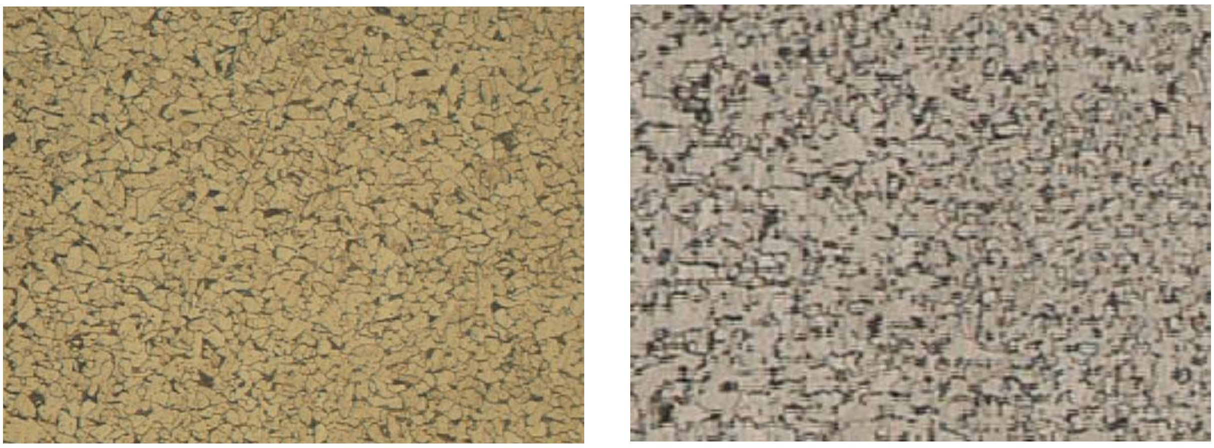
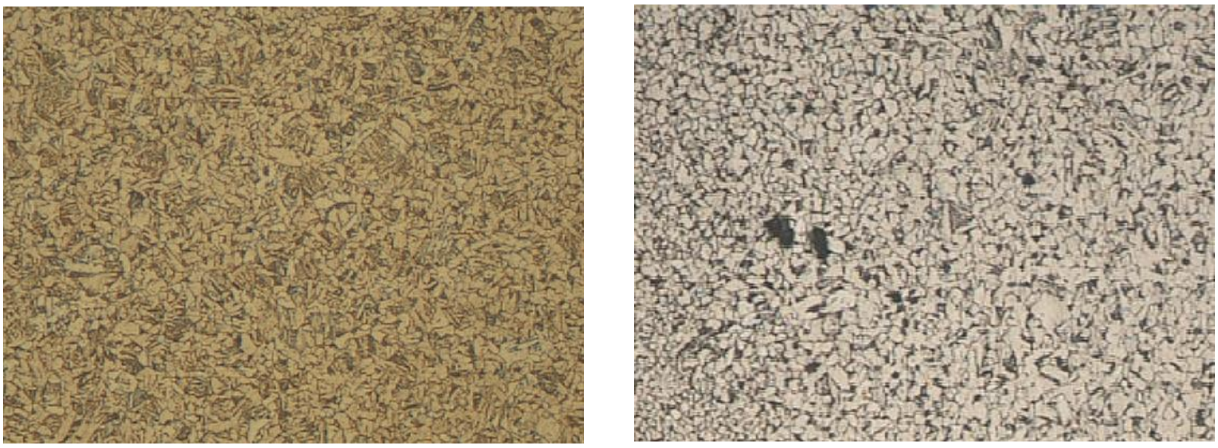
	50x magnified	100x magnified	500x magnified
Weld Metal			

Table 4.4: Carbon Steel Microstructure after PWHT



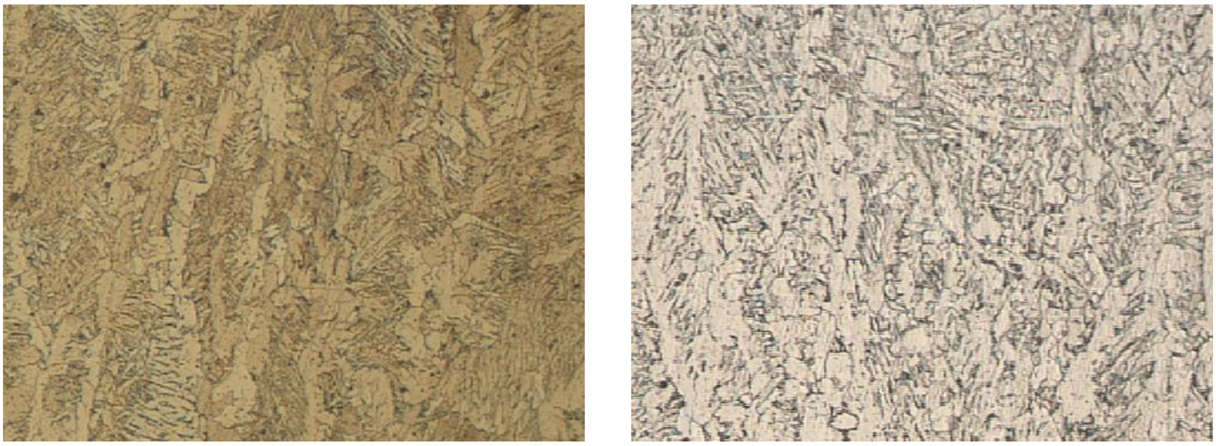
(a) (b)

Figure 4.6: Microstructure comparison of 6mm mild steel thickness under 100 x magnifications at base metal. (a)Before PWHT, (b) After PWHT



(a) (b)

Figure 4.7: Microstructure comparison of 6mm mild steel thickness under 100 x magnifications at HAZ. (a)Before PWHT, (b) After PWHT

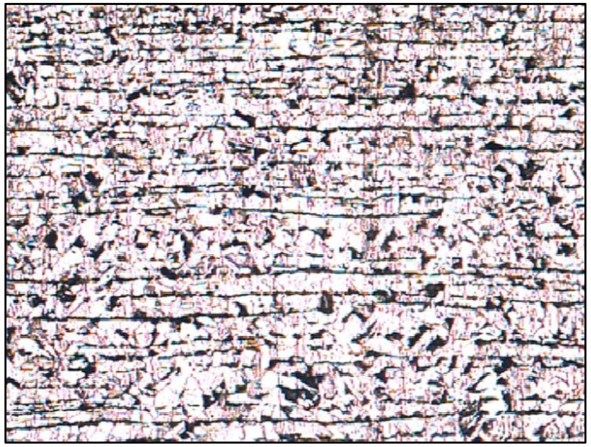
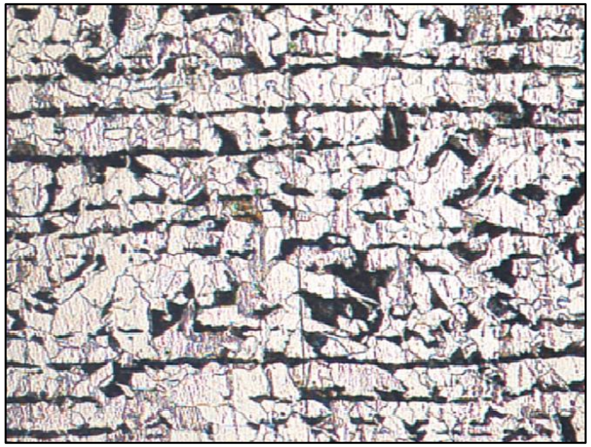
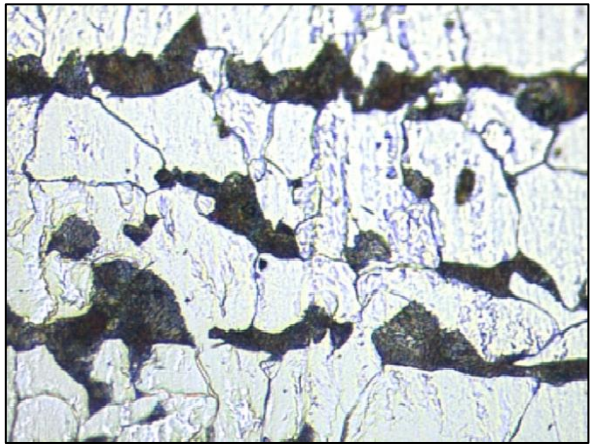
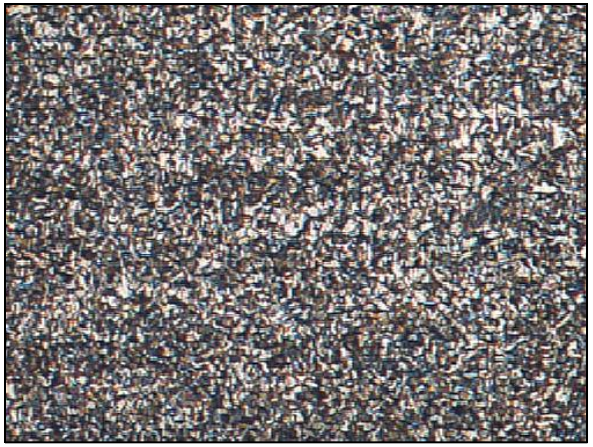
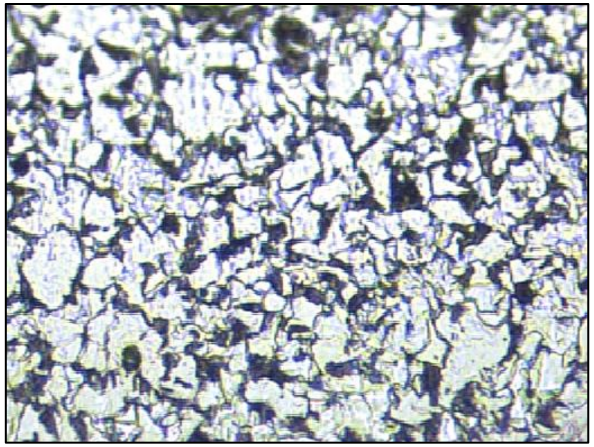


(a) (b)

Figure 4.8: Microstructure comparison of 6mm mild steel thickness under 100 x magnifications at weld metal. (a)Before PWHT, (b) After PWHT

4.4 MICROSTRUCTURE OBSERVATIONS FOR 13MM SA106B STEEL THICKNESS (BEFORE PWHT)

SA106B Steel Microstructure before Heat Treatment

	50x magnified	100x magnified	500x magnified
Base Metal			
Heat Affected Zone			

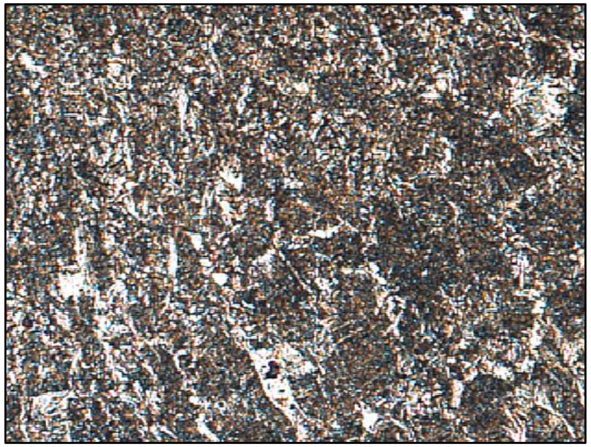
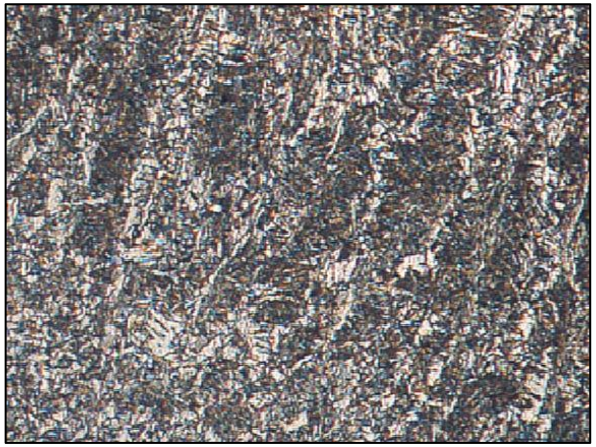
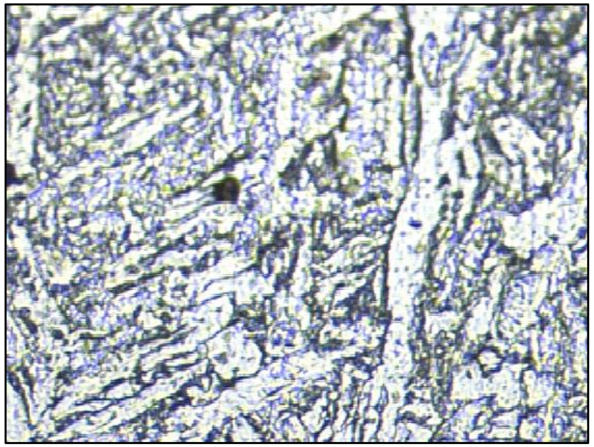
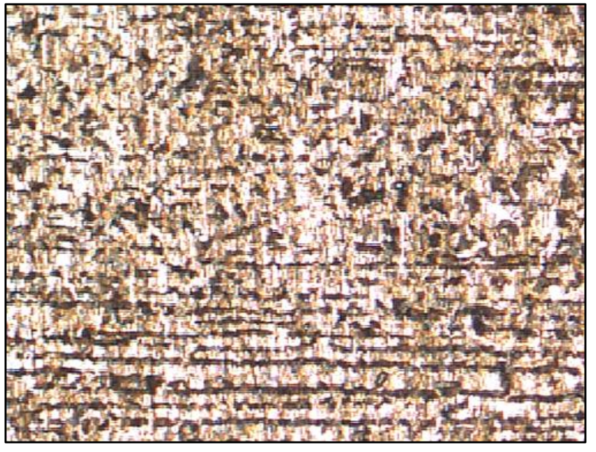
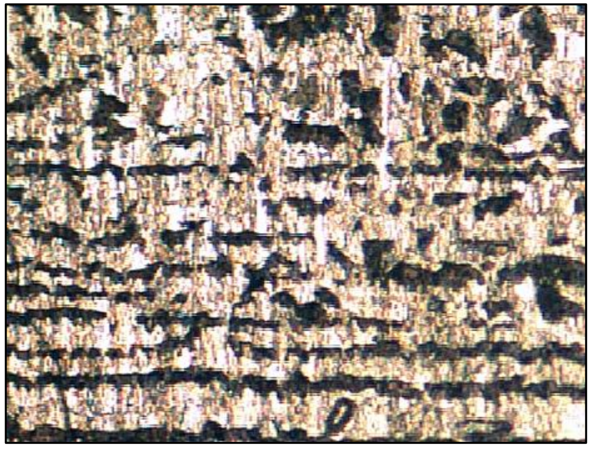
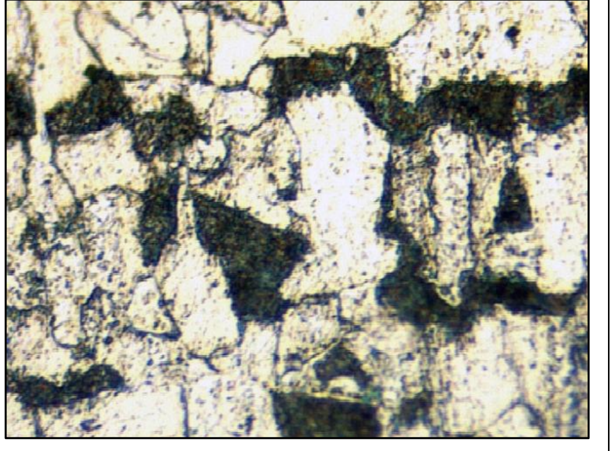
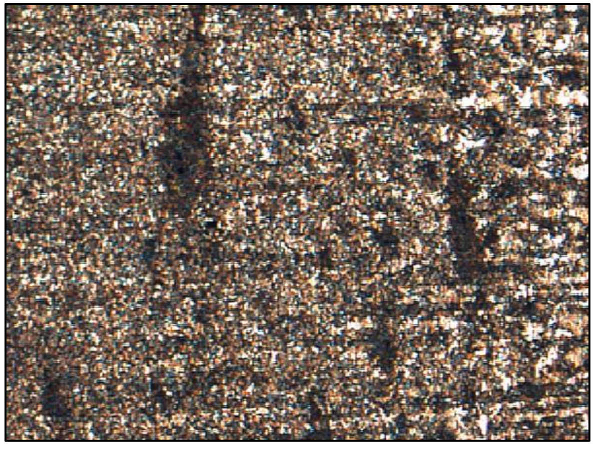
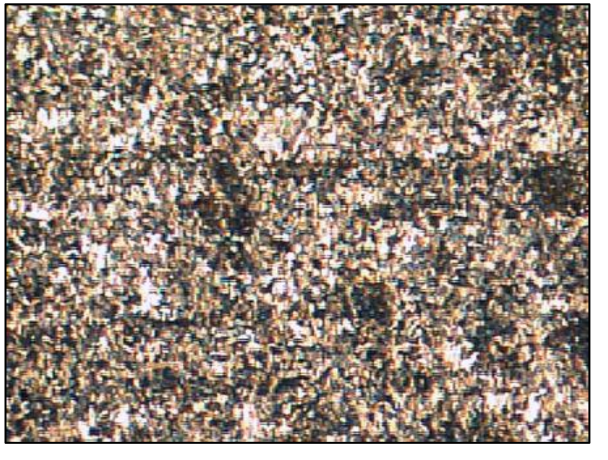
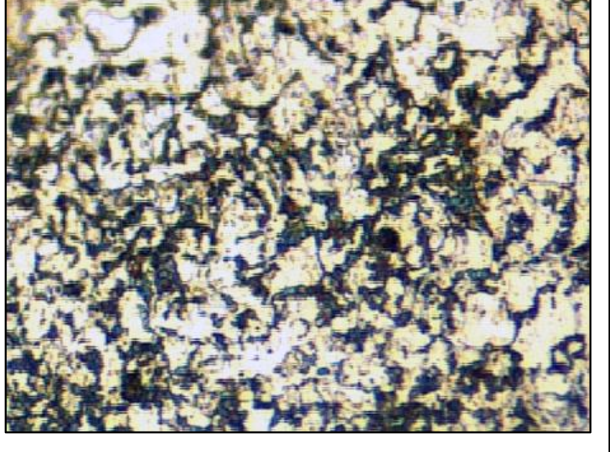
	50x magnified	100x magnified	500x magnified
Weld Metal			

Table 4.5: SA106B steel microstructure after welding before heat treatment

4.5 MICROSTRUCTURE OBSERVATIONS FOR 13MM SA106B STEEL THICKNESS (After PWHT)

SA106B Steel Microstructure after Heat Treatment

	50x magnified	100x magnified	500x magnified
Base Metal			
Heat Affected Zone			

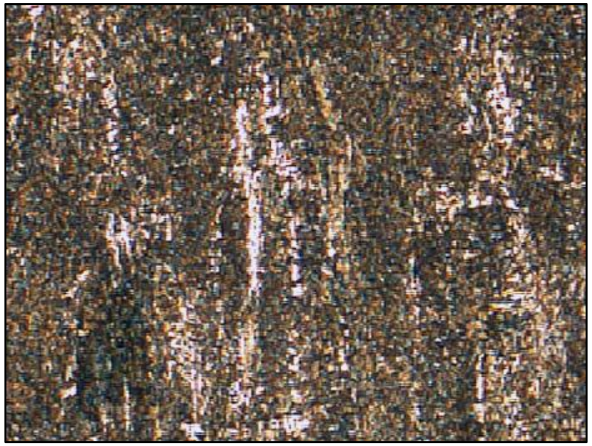
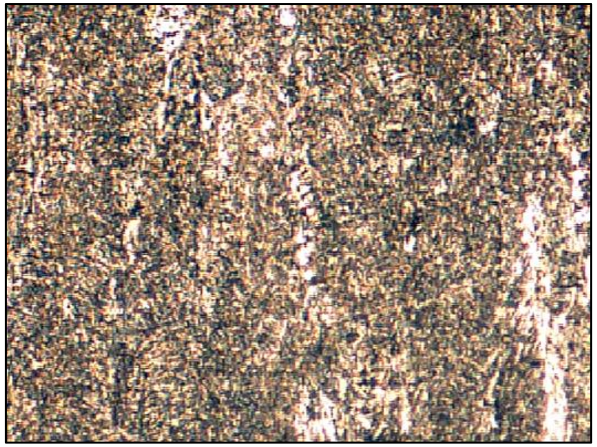
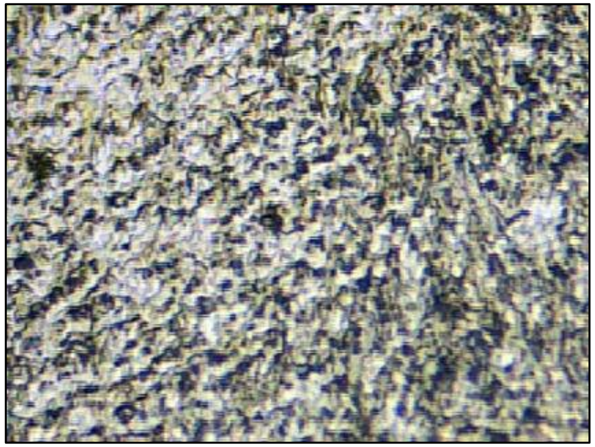
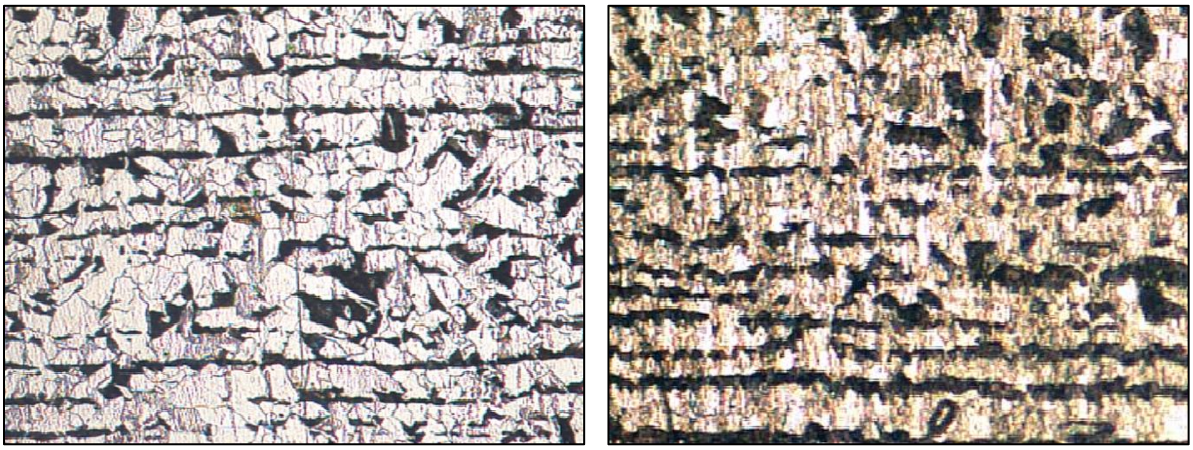
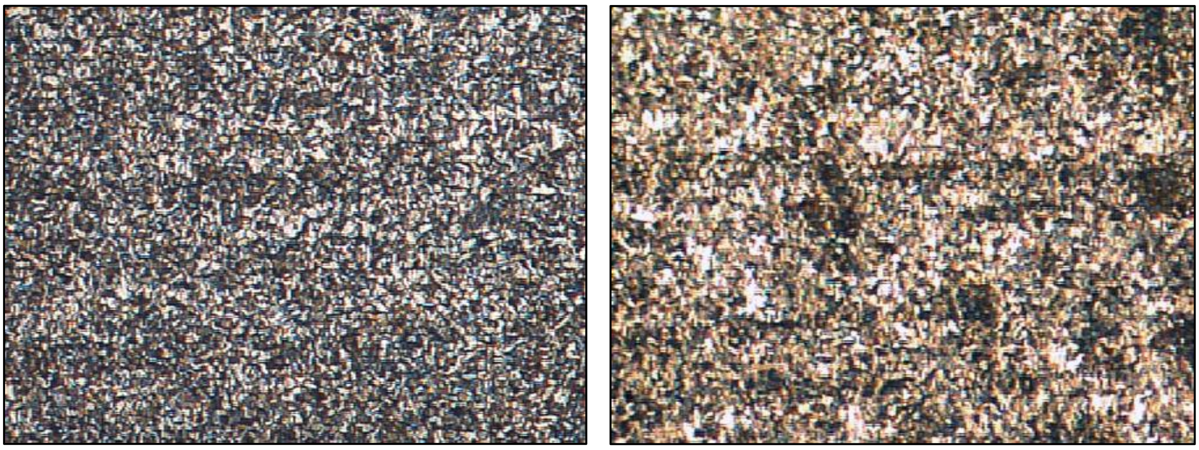
	50x magnified	100x magnified	500x magnified
Weld Metal			

Table 4.6: SA106B steel microstructure after welding before heat treatment



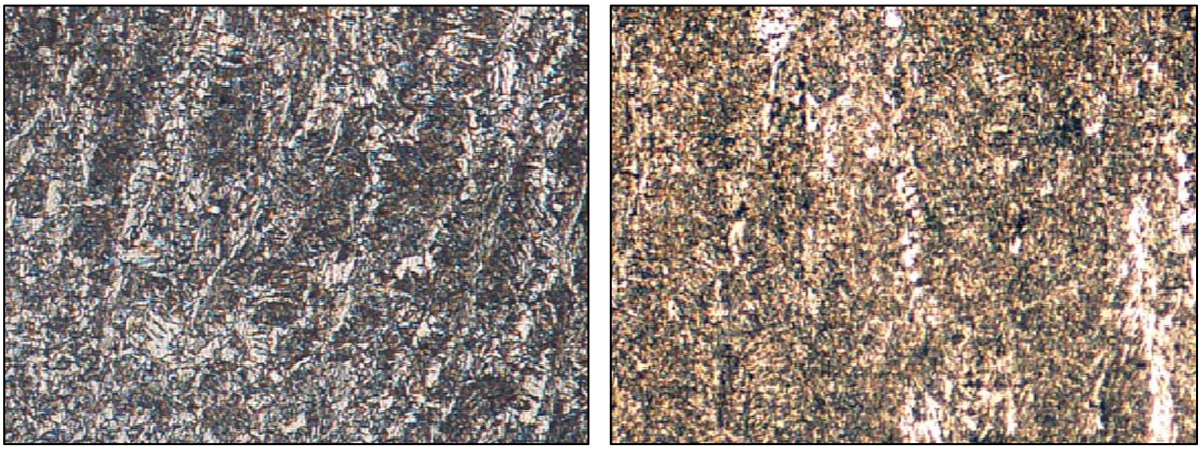
(a) (b)

Figure 4.9: Microstructure comparison of 13mm SA106B thickness under 100 x magnifications at base metal. (a)Before PWHT, (b) After PWHT



(a) (b)

Figure 4.10: Microstructure comparison of 13mm SA106B thickness under 100 x magnifications at HAZ. (a)Before PWHT, (b) After PWHT



(a) (b)

Figure 4.11: Microstructure comparison of 13mm SA106B thickness under 100 x magnifications at weld metal. (a)Before PWHT, (b) After PWHT

4.6 VICKERS MICRO HARDNESS TEST RESULT

The purpose of hardness test is to measure the sample ability to resist plastic deformation from a standard load. The results for both before and after heat treatment are presented in the next subsection.

4.6.1 Hardness test result for 6mm mild steel thickness

	First Reading (HV)	Second Reading (HV)	Third Reading (HV)	Mean (HV)
Base Metal	161.5	173.7	168.0	167.7
Weld Metal	212.0	193.4	212.8	206.1
HAZ	200.2	185.8	209.1	198.4

Table 4.7: Vickers Micro Hardness Results (before heat treatment)

	First Reading (HV)	Second Reading (HV)	Third Reading (HV)	Mean (HV)
Base Metal	197.2	193.4	188.1	192.9
Weld Metal	206.5	211.2	216.0	211.2
HAZ	176.1	171.8	177.9	175.3

Table 4.8: Vickers Micro Hardness Results (after heat treatment)

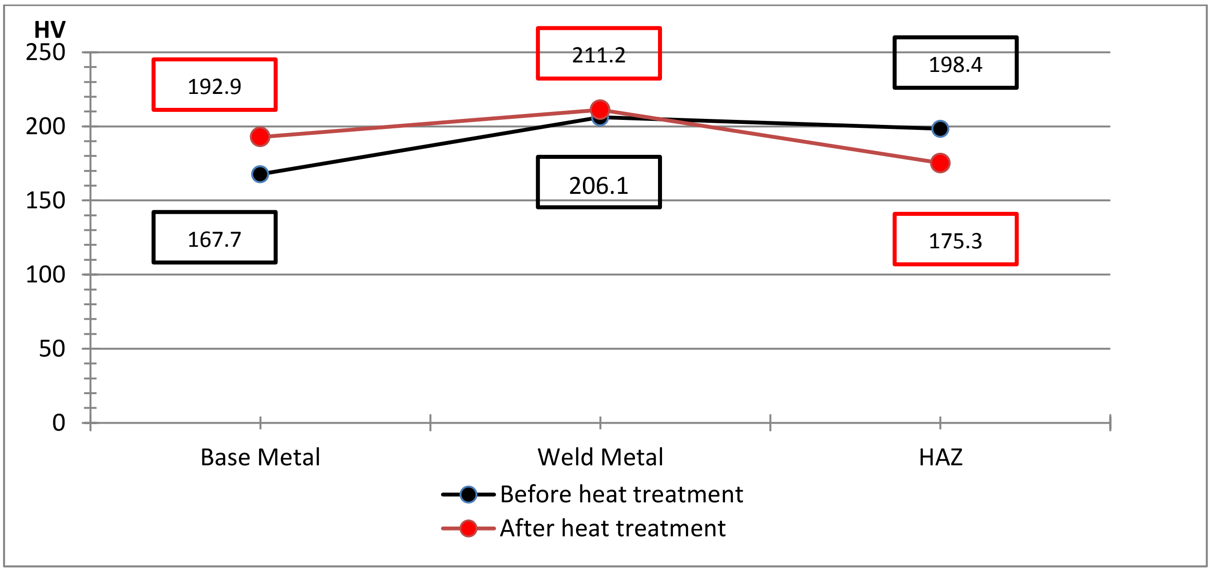


Figure 4.12: Mild steel hardness comparison before and after heat

After heat treatment, hardness value at the base metal has increase from HV167.7 to HV192.9. Inside the weld metal, there are no significant changes in hardness value due to heat gain from welding process. Hardness value in the heat affected zone decrease from HV198.4 to HV175.3. Ductility has been increase at the heat affected zone after heat treatment.

Base on ASM Metals Reference Book, third edition, we can convert the hardness value into approximate tensile strength. However, this conversion is limited to comparative purposes only.

	Mean (HV)	Approx. TS (MPa)
Base Metal	167.7	539
Weld Metal	206.1	656
HAZ	198.4	632

Table 4.9: Approximate tensile strength converted from Vickers Hardness (before heat treatment)

	Mean (HV)	Approx. TS (MPa)
Base Metal	192.9	617
Weld Metal	211.2	671
HAZ	175.3	563

Table 4.10: Approximate tensile strength converted from Vickers Hardness (after heat treatment)

4.6.2 Hardness test result for 13mm SA106B steel thickness

	First Reading (HV)	Second Reading (HV)	Third Reading (HV)	Mean (HV)
Base Metal	161.8	173.4	159.8	165.0
Weld Metal	184.8	202.5	230.4	205.9
HAZ	196.1	194.3	202.0	197.5

Table 4.11: Vickers Micro Hardness Results (before heat treatment)

	First Reading (HV)	Second Reading (HV)	Third Reading (HV)	Mean (HV)
Base Metal	174.5	164.0	188.6	175.7
Weld Metal	195.0	196.6	201.0	197.5
HAZ	175.2	178.0	184.7	179.3

Table 4.12: Vickers Micro Hardness Results (after heat treatment)

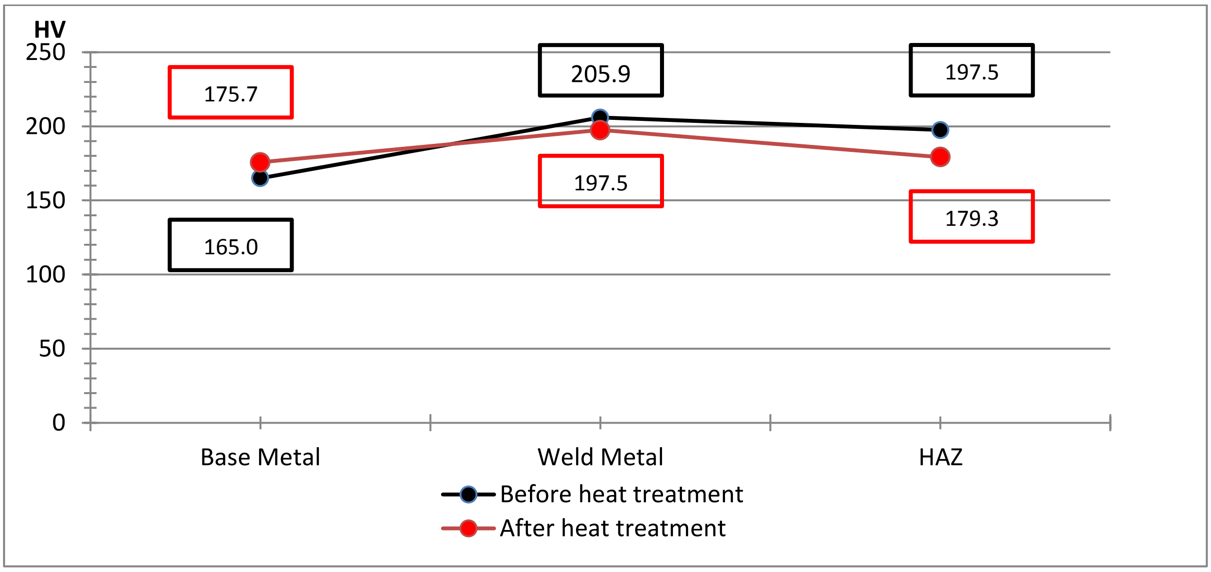


Figure 4.13: SA106B Steel hardness comparison before and after

Hardness value for the base metal has increase from HV165.0 to HV175.7 after heat treatment. Inside the weld metal, same results as 6mm thickness, there are no significant changes in hardness value. Hardness value in the heat affected zone decrease from HV197.5 to HV179.3 which is the same behavior as 6mm.

*This conversion is limited to comparative purposes only.

	Mean (HV)	Approx. TS (MPa)
Base Metal	165.0	533
Weld Metal	205.9	656
HAZ	197.5	629

Table 4.13: Approximate tensile strength converted from Vickers Hardness (before heat treatment)

	Mean (HV)	Approx. TS (MPa)
Base Metal	175.7	566
Weld Metal	197.5	629
HAZ	179.3	575

Table 4.14: Approximate tensile strength converted from Vickers Hardness (after heat treatment)

4.7 TENSILE TEST RESULT

The following result is only for SA106B steel only. This is due to limited sample availability for Mild Steel. The test consists of two samples. Sample two has gone to post weld heat treatment and sample one is not undergo any heat treatment after welding.

4.7.1 Tensile Test Result for Sample 1 (Before Heat Treatment)

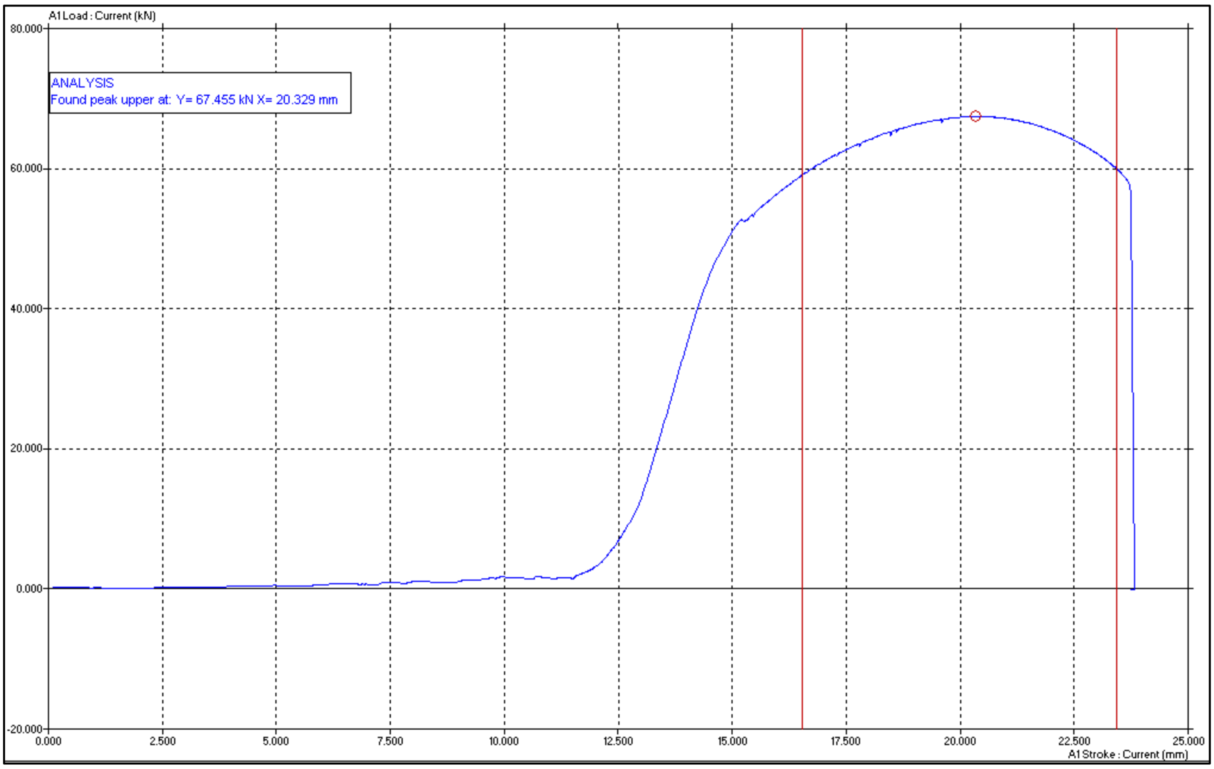


Figure 4.14: Force versus Strain for SA106B Steel (Before Heat Treatment)

According to figure 4.14, the ultimate tensile strength before heat treatment is 57.455kN. The lower yield strength is 52.407kN meanwhile the upper yield strength is 52.757kN. The force at which the test samples rupture is at 56.672kN. The young modulus calculated from the graph with reference to the tensile log file is 22.22kN/mm.

4.7.2 Tensile Test Result for Sample 2 (After Heat Treatment)

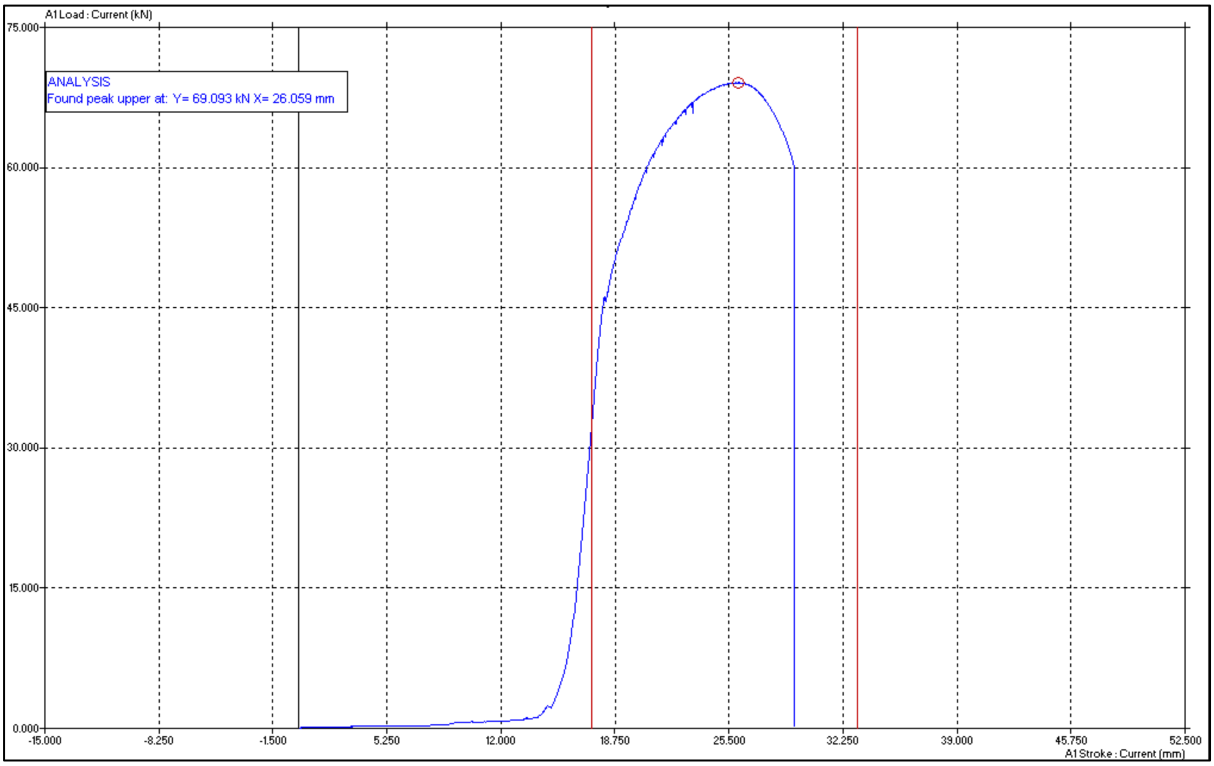


Figure 4.15: Force versus Strain for SA106B Steel (After Heat Treatment)

Referring to figure 4.15, the ultimate tensile strength after heat treatment is at 69.093kN. The upper yield strength is at 46.169kN and the lower yield strength is at 45.612kN. This sample ruptures at 59.238kN. The young modulus for this sample is 15.47kN/mm.

Measurement of Samples	**Sample 1**	**Sample 2**
Specimen Length	203.2mm	203.2mm
Original Gauge Length	34mm	34mm
Original Width	19mm	19mm
Original Area	$133mm^2$	$133mm^2$
Testing Speed Rate	0.006mm/s	0.006mm/s
Ultimate Tensile Test	67.455kN	69.093kN
Force at Fracture	56.672kN	59.238kN
Final Gauge Length	48m	47mm
Final Width	15.10mm	14.22mm
Percentage Elongation After Fracture	4.38%	5.63%

Table 4.15: Tensile Test Properties Comparison Before and After Heat Treatment

CHAPTER 5
CONCLUSION

5.1 X-RAY FLUORESCENCE

Based on X-Ray Fluorescence result, I manage to identify the composition of the carbon steel. Unfortunately, one important element which is carbon, unable to be identify in the final result. The percentage of the carbon is very small causing the XRF unable to detect it properly. So, undetectable carbon verifies the steel is in low carbon content. Others factor like the unwanted present of oxide, which come from metal oxidation.

5.2 MICROSTRUCTURE

The image for carbon steel microstructure shown as expected earlier. For the base metal, the microstructure is almost the same size everywhere. However, when we observe from the base metal into the heat affected zone (HAZ) region, the microstructure started to change. The grain sizes become smaller as we move from the base metal zone into the HAZ zone. These changes happen along boundary between base metal and the weld metal.

Filler metal or the weld metal also seems to be difference from the base metal. The grain structure was bigger and long in size. After post weld heat treatment, the base metal show small variation in grain size. Some of the regions become smaller size and some remain the same. This could be cause by uneven heat distribution during heat treatment.

After heat treatment, inside the heat affected zone, the grain size changes to almost the same as base metal. Better carbon distribution at the heat affected zone make the grain size become larger. It is become harder to determine where the heat affected zone is. Microstructure inside the weld metal are not showing any significant changes although some of the weld metal having microstructure shape almost the same as heat affected zone.

5.3 HARDNESS TEST

The base metal hardness has been increase after the heat treatment. This mean the base metal has become harder than before heat treatment. Inside the heat affected zone, the results show a reduction in hardness. The heat affected zone has become softer. Some ductility has been imparted to this region. Hardness inside the weld metal is not showing any significant changes in hardness.

5.4 TENSILE TEST

Ultimate tensile strength increase from before to after post weld heat treatment. According to both graph, we can see the difference in graph direction. Graph for sample 2 shows the steel after heat treatment is more ductile than sample 1. Sample 2 has larger area below the force strain graph which mean sample 2 can absorb more energy than sample 1.

5.5 WORK CONTINUATION

The thickness of the steel is initially with 6 mm thickness. Welding with 6mm thickness usually not requires heat treatment. Therefore welding with 13mm thickness was introduced to compare with 6mm thickness. Unfortunately, because of 13mm thickness sample arrived late, some of the result for 13mm thickness not being able to gain.

Welding process also requires a lot of time and also depends on the laboratory and technician availability. It is difficult to produce suitable welding quality for the sample, especially welding for tensile test sample. Some of common problem is the lack of fusion, incomplete root penetration, and also undercut near the weldment. So the work has been repeated for a long time to acquire good sample.

Others problem contribution is machining for mechanical testing sample which is tensile and impact test. Since production laboratory does not have notching tool, so the notch has to make by using EDM machine. Present of impurities at the welded area cause the EDM cutting wire to break. The effect is not being able to continue cutting process (see figure 5.1). A suggestion for future work is to continue the mechanical testing.

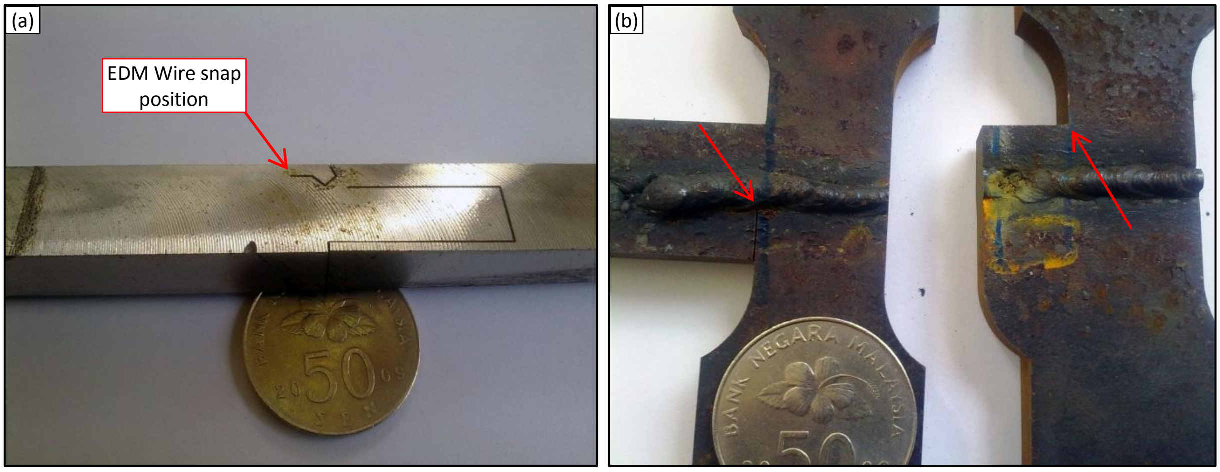


Figure 5.1: Example of sample unable to continue cutting.
(a) Impact test sample, (b) Tensile test sample

REFERENCES

1. William D. Callister, 2007. *Material Science and Engineering: An Introduction*, 7th Edition, John Wiley & Sons (Asia) Pte Ltd.

2. Serope Kalpakjian and Steven R. Schmid, 2006. *Manufacturing Engineering and Technology*, 5th Edition, Pearson Prentice Hall.

3. WIS5, 2002. *Welding Inspection*. TWI Limited.

4. D. J. Abson, Y. Tkach, I Hadley, V. S. Wright, and F. M. Burdekin, (2006). *Welding Journal: A review of postweld heat treatment code exemption - Part 1* (Volume 85, pp. 63-69).

5. ASME Boiler & Pressure Vessel Code, SECTION VIII DIV. 1 2004 EDITION.

6. ASME Boiler & Pressure Vessel Code, SECTION VIII DIV.1 2007 EDITION.

7. ASME Boiler & Pressure Vessel Code, SECTION IX, 2007 EDITION.

8. ASTM E8M-00b, Standard Test Methods for Tension Testing of Metallic Materials

9. D. Gandy. (2007). *Carbon Steel Handbook, Final Report, March 2007*, Retrieved from the Web June 16, 2010, http://www.scribd.com/doc/28247782/Carbon-Steel-Handbook#.

10. Prof. Kyung-Tae Park and Dong Hyuk Shin, (2001) *Journal on Microstructural Interpretation of Negligible Strain-Hardening Behavior of Submicrometer-Grained Low-Carbon Steel during Tensile Deformation* (Volume 33A, pp. 705-707).

11. D.A. Curry and J.F. Knot, (1976). *Journal on The relationship between fracture toughness and microstructure in the cleavage fracture of mild steel.*

12. Welding Technology Institute of Australia, (2004) *Post Weld Heat Treatment of Welded Structures* (Guidance Note 6, pp. 1-10).

13. M.J. SANTOFIMIA, L. ZHAO, and J. SIETSMA (2009) *Journal on Microstructural Evolution of a Low-Carbon Steel during Application of Quenching and Partitioning Heat Treatments after Partial Austenitization* (Volume 40A, pp. 46-56).

14. Raymond Sacks, 1981. *Welding: Principles & Practices*, Revised Edition, Glencoe/McGraw-Hill.

15. Norman Bailey, 1994, *Weldability of Ferritic Steels,* Abington Publishing.

16. RWK Honeycombe & HKDH Bhasdeshia, 1995, *Steels, Microstructure and properties,* 2th edition, Edward Arnold and Gray Publishing.

17. Leonard E. Samuels, 1999, *Light Microscopy of Carbon Steels*, ASM International.