UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: **EFFECT OF WELDING PARAMETER ON MECHANICAL PROPERTIES OF WELDED CARBON STEEL**

SESI PENGAJIAN: 2011/20012

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Effect of Welding Parameters on Mechanical Properties of Welded Carbon Steel

MUHAMMAD QAIDIR BIN ABDILLAH

BACHELOR OF ENGINEERING

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Effect of Welding Parameters on Mechanical Properties of Welded Carbon Steel

MUHAMMAD QAIDIR BIN ABDILLAH

Thesis submitted in fulfilment of the requirement
for the award of the degree of
Bachelor of Mechanical Engineering

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MAY 2012

UNIVERSITI MALAYSIA PAHANG
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I certify that the project entitled "Effect of Welding Parameters on Mechanical Properties of Welded Carbon Steel" is written by *Muhammad Qaidir Bin Abdillah*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Dedicated, truthfully for supports,
encouragements and always be there during hard times,
my beloved family.

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ABSTRACT

The main purpose of this project is to study effect of welding parameter on mechanical properties of welded carbon steel. Current problem is cracking happen on the bridge frame after a long time period being used and welding process need to be used to joint back the cracking. The objective of this study is to study the effect of welding parameter such as speed, current and voltage to the mechanical properties of carbon steel. Tensile test, microstructure view, hardness test and optical measurement view is used to define the mechanical properties for welded specimens and as received specimen. The welded specimen being compared with unwelded to study the change of metal before and after welded process. Metal Inert Gas (MIG) welding is used and the liner type was mild steel liner. The hardness study was conducted using a Vickers Hardness Tester MMT-X7 to analyze the conditions change at each region which are weldment zone, heat affected zone and base metal zone area. Low carbon steel show increased in hardness test especially on fusion zone following by heat affected zone due to heating process by the welding. There is a change on microstructure view where the base metal changing and create dendrite shape at weldment area and columnar at heat affected zone area. Optical measurement view test shown the depth of penetration affect the tensile test result. This project is significantly to show that different parameter setup will give different strength and must be the important considered by the welder.

ABSTRAK

Tujuan utama dari projek ini adalah untuk mempelajari kesan kajian bahan parameter kimpalan ke atas sifat mekanikal keluli karbon yang dikimpal. Masalah masa pada masa kini adalah keretakan berlaku pada rangka jambatan selepas tempoh masa yang lama digunakan dan proses kimpalan perlu digunakan untuk menyambung semula keretakan yang berlaku. Objektif kajian ini adalah untuk mengkaji kesan parameter kimpalan seperti kelajuan, arus dan voltan kepada sifat-sifat mekanikal keluli karbon. Proses kimpalan telah dijalankan untuk mengimpal bersama dua logam keluli karbon. Ujian tegangan, pandangan mikrostruktur, ujian kekerasan dan pandangan ukuran optic dijalankan untuk menentukan sifat-sifat mekanik untuk bahan yang dikimpal dan bahan yang diterima seadanya. Spesimen yang dikimpal dibandingkan dengan specimen yang diterima seadanya untuk mengkaji perubahan logam sebelum dan selepas proses kimpalan. Inert Gas (MIG) proses digunakan dan jenis pelapik yang digunakan adalah pelapik keluli lembut. Kajian kekerasan telah dijalankan menggunakan Vickers Hardness Tester MMT-X7 untuk menganalisa perubahan keadaan di setiap kawasan iaitu zon kimpalan, zon haba yang terlibat dan kawasan zon logam asas. Keluli rendah karbon menunjukkan peningkatan dalam ujian kekerasan terutama pada zon kimpalan diikuti zon haba yang terlibat hasil dari proses pemanasan kimpalan. Terdapat perubahan pada pandangan mikrostruktur di mana perubahan logam asas dan mewujudkan bentuk dendrite di kawasan hasil kimpalan dan kolumnar di kawasan terkesan haba. Ujian pandangan ukuran optik menunjukkan kedalaman penembusan yang mempengaruhi keputusan ujian tegangan. Signifikan projek ini adalah untuk menunjukkan bahawa persediaan parameter yang berbeza akan memberi kekuatan yang berbeza dan mesti menjadi keutamaan untuk dipertimbangkan oleh pengimpal.

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LIST OF SYMBOLS

%	Percent
B.C	Before century
C	Carbon
P	Phosphorus
Mn	Manganese
S	Sulphur
Fe	Ferum
kg	Kilogram
m	Meter
Mpa	Mega pascal
Gpa	Giga pascal
mm	Milimeter
F	Force
d	Diameter
°	Degree
N	Newton
Cr	Chromium
Al	Aluminium
Cu	Cuprum
V	Voltage
A	Ampere
s	seconds
min	Minutes

µ	micron
gf	Gram force

LIST OF ABBREVIATIONS

ASTM	American Standard Testing Method
AISI	American Iron and Steel Institute
MIG	Metal Inert Gas
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
FZ	Fusion Zone
CJP	Complete Join Penetration
CNC	Computer Numerical Control
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
BCC	Body Centered Cubic

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Steel is a metal alloy created from a mixture of iron and carbon. Iron is a key component in steel and carbon content in the steel which varies between below than 0.2% until above 0.5% mass depending on the grade of steel. Metal alloys are also commonly known as cast iron because of the carbon content in which it affects the low melting point and easy to be poured into molds.

Steel is commonly used in building construction, infrastructure such as bridge, tools equipment, machinery, ship, vehicle components and weapon. This is because the mechanical properties of ductile steel which is easy to set up and cost-effective, high work hardening rate, high yield strength, resistance to impact loading, and has a very goods surface (Sacks and Bonhart, 2005). Researchers have done a deeper study for steel material about the grain refinement which to increase the yield strength for steels and the toughness simultaneously.

Low carbon steel is a type of metal that has an alloying element made up of a relatively low amount of carbon. Typically, it has a carbon content that ranges between 0.05% and 0.30% and a manganese content that falls between 0.40 and 1.5% (William, 2006). Since it has a low amount of carbon in it, the steel is typically more malleable than other kinds of steel. As a result, it can be rolled thin into products like car body panels and also in used as low carbon steel pipe to transmitting substances such as gas and oil (Sack and Bonhart, 2005).

Low carbon steel has better mechanical properties of steel in terms of high hardness, high wok hardening rate, yield strength of the end, and on the high forces. This factor causes the material of low carbon steel is mostly used in industries at this moment especially in construction industry, automotive and oil and gas industry. In construction industry, this material is used to build the bridge. This is because of the the material properties which is ductile, can hold high impact load and effective cost cause of the common material (Karadeniz, 2007).

Low carbon steel have high ductility. Then it will effect in the process of formation. In addition, the end result of the formation process of high carbon steel is also very good because of the final surface is flat and does not required a machining. Sometimes, this material also will crack and need to be weld to make sure the crack will not continued. But at which condition the welding process is good enough to make sure it can hold the crack by changing the parameters to weld (Gural, 2007).

1.2 PROBLEM STATEMENT

The bridge construction industry activities are carrying out actively from day to day not only in the city but even in village areas. This is to prevent rural communities from left behind about current development progress. Safety factor is a major factor to be concerned in construction activity because it will involves lives of the bridge user. From this, the factor of safety in depends on the type and quality of materials used in build a strong bridge frame. High quality materials that have good mechanical properties and the ability to withstand high loading forces in build the bridge frame to make sure it will not collapse easily during and after it was built (Mark Rossow, 2009).

Figure 1.1: Bridge frame using low carbon steel

Source: Mark Rossow (2009)

Most of bridge frame normally will be used low carbon steel material as shown in Figure 1. The biggest bridge need to be build, the larger force that need to be hold by the frame bridge. As the aged of bridge increased, some defects will happen and one of it is crack. To patch the crack, welding process need to be done but at which parameter the welding process will be the best to hold the crack. Because of that, low carbon steel that being used as a bridge frame construction will be analysed by running the tensile test, hardness test, and microstructure deform after the welding process between two parts of low carbon steel plate. The parameter will be changed such as the speed, voltage and current to see which parameter will effect the material and also will causes the material to fail.

1.3 OBJECTIVE OF PROJECT

The objective for this analysis is purposely to study the effect of welding parameter such as speed, current and voltage to the mechanical properties of low carbon steel.

1.4 SCOPES OF PROJECT

In order to achieve the objective, it should have proper arrangement of scopes project. The lists of scopes are as followed:

i) Sample preparation including raw material preparation and cutting process
ii) Compositional analysis before and after welding process
iii) Welding process with different welding speed, voltage and current using Metal Inert Gas (MIG) process to the mechanical properties of low carbon steel.
iv) Tensile test, hardness test and microstructural analysis test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Steel in other name is refined pig iron or an alloy of iron and carbon. Steel is made up of carbon as important composition, silicon, sulfur, phosphorus and manganese. At this time, low carbon steel can be obtain easily in most local industry especially in construction industry and one of it can be found in bridge construction industry. Other than that, it can be found in ships, tank, pipes, railroad cars and automobiles (Sacks and Bonhart, 2005). There are lots of methods and studies have been conducted to increase the performance and the ability of low carbon steel to make sure the utilization can be improved to others applications that more sophisticated. In bridge construction application, the low carbon steel is used a lot on bridge because of the hardness and strength at low carbon steel and a good material in absorbed the forces that being given. To increase the strength or high performance of bridge frame material, the carbon content in steel must be less which ensure the toughness and weldability (Guo et al, 2009).

2.2 LOW CARBON STEEL

The first recorded use of iron was the ancient Assyrians about 3700 B.C. This given them an advantage compares to other nation since it was in making weapons (Sacks and Bonhart, 2005). Low carbon steel is steel that contain fine grain and it started being designed since years of 1960. Low carbon steel can be classified when the carbon content is lower than 0.2 percent (American Society for Testing and Materials). Low carbon steel is widely used in fabrication industry due to excellent to weight ration and one of the applications are in automobile industry (Khodabakhshi *et al*, 2011). This material is suitable to use in automotive industry because it can absorb high impact force without cracking. This happen because it has low carbon which make it as ductile material compare to high carbon steel that more brittle and easy to crack although it have more strength.

The used of low carbon steel is not limited just on creating the frame for bridge construction or building construction only but low carbon steel also is used a lot in making car chasis for automotive industry because of the high strength, brittle and easily to welding. This material also good in weight because it reduces the weight of material that being used which can help to reduce oil consumption at once decrease the gas emissions and improves crash safety (Naderi *et al*,2011).

Now through studies and sophisticated technology will expand the application of low carbon steel in the used for bridge construction industry. Low carbon steel is used as a bridge frame. Low carbon steel also work as a link for bridge construction in many way purposely for strengthen the bridge frame structure to make sure it will not easily deflected or strain experienced because of high loading force. Other than that, it also will be welding between two part of low carbon steel is carried out to combine and usually strengten the frame of bridge.

Low carbon steels contain up to 0.15% carbon (William, 2006). The largest category of this class of steel is flat-rolled products which is sheet or strip usually in the cold-rolled and annealed condition. The carbon content for these high formability steels is very low, less than 0.10% with up to 0.4% manganese. Typical uses are in the automobile body panels, tin plate and wire products. This material also used for stampings, forgings, seamless tubes and boiler plate where the carbon the containing may be increased to approximately 0.30% with higher manganese up to 1.5% for rolled steel structural plates and sections (American Society for Testing and Materials). Table 2.1 show the chemical composition for low carbon steel with more detailed according to ASTM.

Table 2.1: Chemical composition low carbon steel

C (% Mass)	P (% Mass)	Mn (% Mass)	S (% Mass)	Fe (% Mass)
0.05-0.15	<0.04	0.30-0.60	<0.05	99.18-99.62

Source: American Society for Testing and Materials (ASTM)

The added elements in the steel is purposely to increase the hardness, strength and chemical reaction for low carbon steel.

2.3 PROPERTIES FOR LOW CARBON STEEL

Low carbon steel is a steel that contain fine grain with ferrite phase structure. The mechanical properties for low carbon steel is better because of soft matric ferrite with good ductility. This become the factor to low carbon steel to have good mechanical properties which is from the high in yield and tensile strength and also high absorption foce.

Other than that, mechanical properties for low carbon steel is depends on others various factor such as ferrite mechanical properties which contains carbon and fine grain size (Qu et al, 2008). The added others element alloy into low carbon steel such as molybdenum with the quantity between 0.1-0.2% mass will produce grain structure that more soft and also increase the effect of precipitate hardening through elements of others alloy.

Final strength for ferrite structure is determined through the decrease of carbon content in the material (Qu et al. 2008). The reduction of carbon indirectly will increased the elongation of low carbon steel when there is a tensile load. This show that ductility properties of the material is increased. The ductility of the low carbon steel is also being influence by the increment of fraction grain boundaries which will increase the number of dislocation sources which in turn would increase the frequency of the dislocation density and high strength carbon steel (Calcagnotto et al. 2010).

Low carbon steel will be able to absorb a high shock impact and this mechanical properties is really needed in construction industry to absorb any force that being given to the bridge frame to make sure the structure of bridge always in strong condition and did not collapse easily (Sack and Bonhart, 2005).

Welding process that created on the low carbon steel material is a one of the factor that influence the change in mechanical properties because this process will control the material phase size, volume fraction and others phase formation in low carbon steel material. This is because, welding process will created heat which is being called heat affected zone (HAZ). The heated given on low carbon steel will come from welding process which change the ferrite phase to and austenite phase and back into ferrite phase. This will increased the strength of material but the ductility will decreased because of hardness material is increased. Next it will decreased the level of absorption shock that being given to the material. **Table 2.2** and **table 2.3** show the physical properties and mechanical properties for low carbon steel.

Table 2.2: Physical properties of low carbon steel

Physical properties	
Density	7870 kg/m^3

Source: www.matweb.com

Table 2.3: Mechanical properties for low carbon steel

Mechanical properties	
Final tensile strength	>=380 MPa
Yield strength	205MPa
Elongation before fracture	25.0 %
Shear Modulus	80 GPa
Bulk modulus	140 GPa

Source: www.matweb.com

Low carbon steel is produce for various applications such as in automotive industry and construction industry. Mechanical properties for low carbon steel is greatly influenced by the phase structure of the material and others alloy elements that being added into low carbon steel. The content in low carbon steel influenced the ferrite phase structure in the material. Figure 2.1 show the microstructure ferrite phase and pearlite for low carbon steel (Gural, 2007).

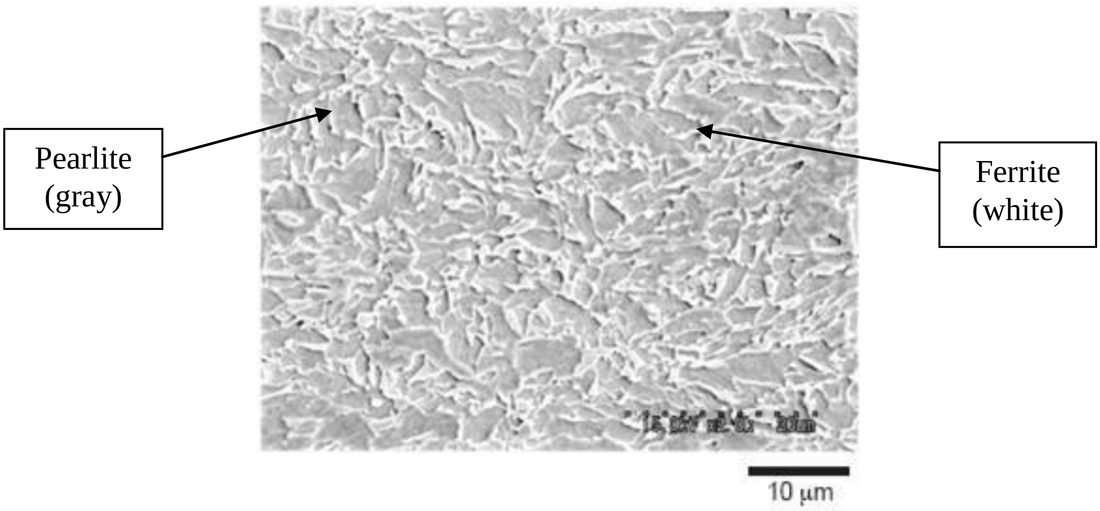

Figure 2.1: Microstructure low carbon steel

Source: www.keytometals.com/

2.4 METALLOGRAPHIC EVALUATION

In order to investigate the microstructure, Scanning Electron Microscopy (SEM) is used (Li Zhuang, 2009) by using a QUANTANA600 microscope. This process is to study the mechanical properties of the low carbon steel. There are several process needed to be done before the mircrostructure can be analyzed which is sectioning, grinding and polishing and etching. Finally the specimen were ready to be viewed on the SEM. Images being scanned on a digital imaging system by computer enhancement or be taken by using an attached camera. The solution is be used to etched the material is natal solution which is combination between ethanol and acid nitric (Li Zhuang, 2009). Sectioning is involved the cutting process which taken the best part to be analyzed. Grinding and polishing is a process to clean the surface and make the microstructure more cleared before etching process taken the place.

2.5 TENSILE TEST FOR LOW CARBON STEEL

One of the methods to evaluate the mechanical properties of one material is by using tensile test. Tension test that has been conducted on low carbon steel has given information about mechanical properties that material. Tension test for low carbon steel given the high and lower yield strength which is influenced by the dislocation associated with carbon and nitrogen contains in the material but this theory not yet approved for metal that has body-centered-cubic (bcc) and face-centered-cubic (fcc) structure .

Yield strength, tensile strength, uniform elongation of material and work hardening exponent can be obtained through tension test to know the effect onto material deformation (Hwang & Lee, 2010). Other than that, tension test also can determine whether that material is fail in brittle or ductile behaviour. This can be known through material fracture surface experiment after going the tension test.

Brittle material will not experienced elasticity deformation but it will experience plasticity deformation. Elongation and deformation for brittle material would not so obvious. This is because material dislocation is limited. The surface fracture for brittle material is the same as in figure 2.2. Metal that has hexagonal-closed position is brittle due to number of slip system are at least 3.

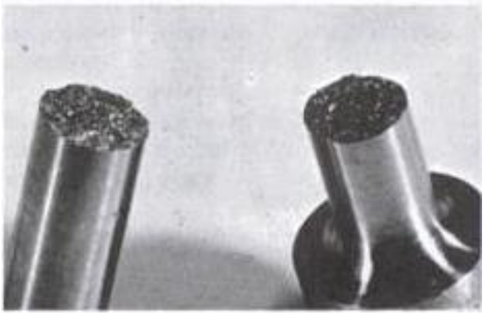

Figure 2.2: brittle fracture

Source: www.sv.vt.edu/

For ductile material, it elastic deformation will occur before plastic deformation. It is the ability of material to stretch by loading and finally fracture (Sacks and Bonhart, 2005). Before the material fail or fracture, material cross section area will decrease. This shown, the dislocation occur on decreasing cross section area. The surface fracture for ductile material is in the shape of cup and cone. Metal with body-centered cubic structure is the most ductile because of the number of the slip system were 48 (William, 2006).

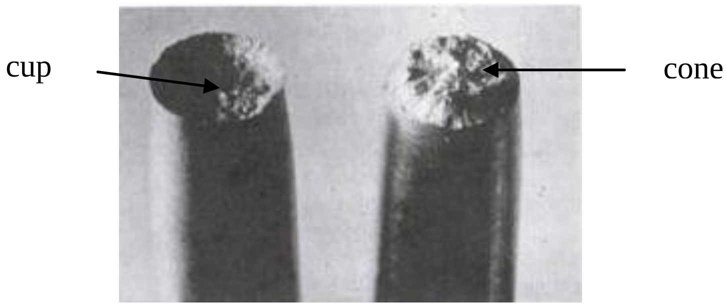

Figure 2.3: Ductile fracture

Source: www.sv.vt.edu/

In tension test, ductile material is different to brittle material. The strain force for ductile material is greater due to area of ductile material has elastic area and the energy needed by material to avoid deformation. For brittle material, strain force contained is very small and this can cause the material cannot avoid the deformation after stress force imposed on it. Next, it will make the material fail or fracture catastrophically. Figure 2.8 shown the differences between stress vs. strain graph for both type materials.

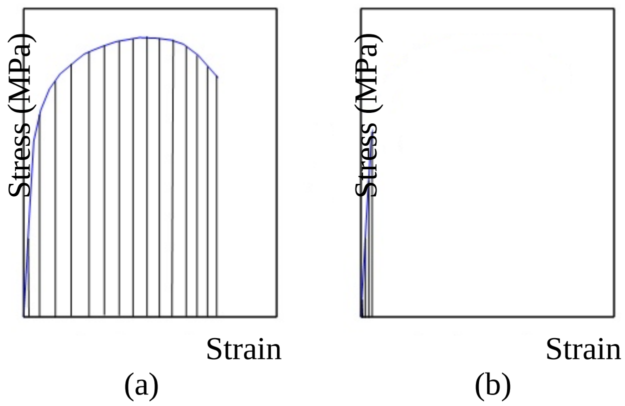

Figure 2.4: Different graph stress versus strain for (a) ductile fracture (b) brittle fracture

Source: www. met-engineering.blogspot.com/

2.5.1 Tensile Shape Size

There is a standard size to create the tensile shape size. It can be divide into two which is for sheet metal and plate metal. For sheet metal the size is according to figure below where the thickness must not exceed than 0.005m.

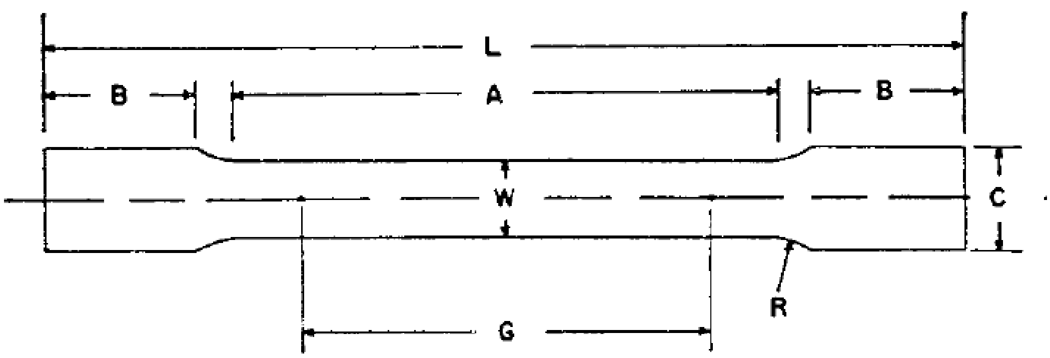

Figure 2.5: Standard Dimensions to create tensile shape for sheet metal

Source: American Society for Testing and Materials (ASTM)

Table 2.4: Description from figure 2.5

No.	Types	Description	Measurement
1	G	Gauge length	50.0 $\pm$ 0.10 mm
2	W	Width	40 +3,-6
3	T	Thickness	Below than 5 mm
4	R	Radius	13 mm
5	L	Overall length minimum	200 mm
6	A	Length of reduce section	60 mm
7	B	Length of grip section	50 mm
8	C	Width off grip section, approximate	50 mm

2.6 HARDNESS PROPERTIES FOR LOW CARBON STEEL

Mechanical properties of low carbon steel materials can be determined by applying a mechanical stress. Some of the mechanical properties that are available to be determined such as hardness, strength modulus of elasticity, ductility and others.

Hardness properties of carbon steels is very important in the production of carbon steels with good performance and good quality to be applied in the use of engineering equipment to make sure the failure of the material is not likely occur. Therefore, studies on the nature of the composite hardness is one of the important factor in producing high quality for carbon steel.

2.6.1 Hardness Test

Hardness is the ability of a material to hold the loads applied from the elastic-plastic deformation until fracture (Szwedzicki 1997). The hardness test can be done by using a Vickers hardness test method. The greater hardness, the greater the resistance to marking or deformation. A hard material is also strong material but it is not very ductile. The Vickers hardness were used to identify the mechanical properties of the base material and at the weld zone (Song, 2009).

The Vickers hardness test gives the value of a substance by measuring the diameter of dent by using Vickers notch. This test is designed by a member of metallurgy, (Robert, 1921). Apart from this method, there are other test can be done to determine the material hardness properties such as Rockwell and Brinell test. Vickers test using the notch with small size that have shape like a diamond and specific force to be pressed on the experimental material from the original position with the prescribed load. Figure 2.6 below shows the Vickers hardness test method.

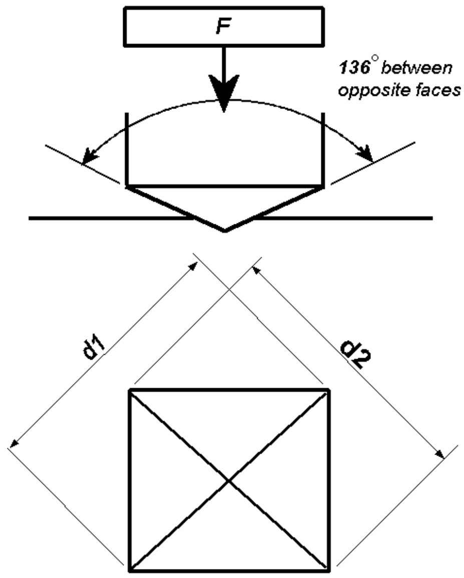

Figure 2.6: Vickers hardness test

Source: www.gordonengland.co.uk/hardness/vickers.htm

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kg force. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kg force load by the square mm area of indentation.

$$\text{Vickers hardness} = \frac{2F\sin\frac{136^{\circ}}{2}}{d^{2}}$$

Where F is the load in kgf while the d is the arithmetic of the two diagonals which is diameter 1 (d1) and diameter 2 (d2) in mm.

The advantages of the Vickers hardness test are that extremely accurate readings can be taken and just one type of indenter is used for all types of metals and surface treatments. The Vickers method is capable of testing the softest and hardest of materials, under varying loads.

Welding will causes the each region which is unaffected zone, heat affected zone and fusion zone will have different hardness value. The changes of the Vickers hardness in each region of the weld is influence by the grain for each reqion which it have variations sizes (Zhaohua, 2011). The Vickers hardness is used to measure the hardness through cross sections of indention to evaluate the material behaviour based on the different welding parameters (Cavaliere, 2006). The fusion zone will have higher hardness compare to heat affected zone and base metal zone because of different heat received by each area (Hidetoshi, 2010). The microhardness was gradually increased by the grain refinement (Song, 2009).

Table 2.5: Standard Vickers scales

Micro hardness scales	**Test force, F (N)**	**Low force hardness scales**	**Test force, F (N)**	**Macro hardness scales**	**Test force, F (N)**
HV 0.01	0.09807	HV0.2	1.961	HV5	49.03
HV0.015	0.1471	HV0.3	2.942	HV10	98.07
HV0.02	0.1961	HV0.5	4.903	HV20	196.1
HV0.025	0.2452	HV1	9.807	HV30	294.2
HV0.05	0.4903	HV2	19.61	HV50	490.3
HV0.1	0.9807	HV3	29.42	HV100	980.7

Table 2.6: Standard Reference

Standard	Refering
Bs en iso 6507-1:2005 (bs 427:Part 1:1961)	Metallic materials. Vickers hardness test. Test method
ASTM E92-82(2003)e2	Stand Test method for Vickers Hardness of Metallic Materials

Source: www.materials.co.uk/vickers.htm

2.7 WELDING

Welding is one of the most applicable connection processes which employed for fabrication in many the industry. Welding is a process in which materials of the same fundamental type of class are bought together and caused to join which it will become one through the formation of primary chemical bonds under the combined action of heat and pressure (Messler, 1993).

2.7.1 Gas Metal Arc Welding (GMAW)

The gas metal arc welding (GMAW) or metal inert gas (MIG) process employs a continuous consumable solid wire electrode and an externally supplied inert shielding gas which will causes current flow that generates thermal energy in the partially ionized gas (M.A.Wahab *et al,* 1998). The arc constantly melts the wire as it is fed to the weld puddle. The weld metal is shielded from the atmosphere by a flow of an inert gas or gas mixture.

The consumable wire electrode produces an arc with a workpiece made part of the electric circuit and provides filler to the weld joint. The wire is fed to the arc by an automatic wire feeder of which both push and pull types are employed, depending on the wire composition diameter and welding application.

Gas metal arc welding offers flexibility and versatility is readily automated, requires less manipulative skill and efficiencies. The greatest shortcoming process is that the power supplies typically required are expensive.

2.7.2 The Advantages using GMAW

The advantages for this type of welding is that the mode molten metal transfer from the consumable wire electrode can be intentionally changed and controlled through a combination of shielding gas composition, power source type, electrode type and form, arc current and voltage, and wire feed rate (Messler, 1993). The process is versatile since it can be applied for all position welding.

This welding process given a lot of advantages which are (Sacks and Bonhart, 2005):

i) The process is fast and much faster than other welding process
ii) The elimination of flux and slag reduces the cleaning time considerably
iii) Fewer starts and stops because it use continuous electrode
iv) High quality process and meets the requirement of most codes
v) Good weld appearance
vi) Good penetration, fusion and smooth weld bead can be produced
vii) Reduced distortion and warpage because the heat being concentration during welding process.

2.7.3 Factors Influencing the Metal through GMAW

There are two main factors influencing the metal transfer for the arc welding which are the arc voltage and the welding current. When the values for both factors parameters are increasing, the type of transfer is also changing (Quintino et al, 2008). The quality of welding joint is also based on enough penetration, high heating rate and right welding profile (Karadeniz et al, 2007).

2.7.4 Effect Welding Current, Arc Voltage and Welding Speed on Penetration

When the speed was fixed at certain value and the welding current is increasing, the depth of penetration also will increase. Same goes to arc voltage and welding speed value which it will cause the increasing of penetration when the value of arc voltage and welding speed is increased (Karadeniz et al, 2007). The heat input will increase when the welding time is increasing while others conditions are constants but only in linearly (Kaharaman, 2007).

The welding process is also being influenced by the material used. When the material is low carbon, the weldability also will become excellent (Guo et al,2009). The weldability of low carbon steel is excellent (Sacks and Bonhart, 2005).

2.7.5 Affect Welding process on Microstructure

After the welding, it shows that the structure is little bit different from the structure from the original material and the grains are oriented towards the heat centre. It also shows that new grains were deform in the interface. Due to thermal gradient of the welding, this new grains become larger than the original grains (Kaharaman, 2007).

Metallurgy is a process that deals with the internal structure of metals. The various changes that take places in welding metallurgy that need to be concerned in the metals during the joining process with thermal processes. It is important to understanding the avarious state of structure which is solids, liquids, gases and plasmas. As welding process take place on steel material, the atomic structure become more active and expands before it reaches melting temperature which the atoms can move freely. The grain size will have an effect on the mechanical properties of the metal (Sacks and Bonhart, 2005).

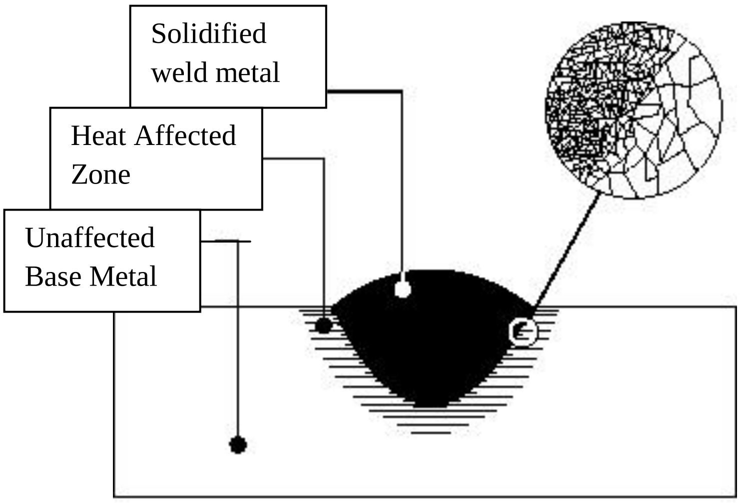

Figure 2.7: Solidification of molten weld metal

Source: www.esabna.com

In welding process, too high volume of welding current or too slow speed travel during process may cause the metal overheating in weld deposit which it may destroyed the original properties of the metal through heat given from welding. This process can be classified as overheating because the temperature exceeds its critical range and impaired the metal properties. The amount of carbon in steel will determined its hardness and also will affect the welding process. The tensile strength will increasing when the percentage of carbon in the steel material is increased but the ductility and weldability will reduces (Sacks and Bonhart, 2005).

In welding process, it will cause heat treatment process which makes the material become solid liquid interface. This process is homogenous nucleation where the precipitation occurs within a completely homogenous medium. The first stage is nucleation (new phase) that form because of it was stable and the first appears as small nuclei. At the precise transformation temperature (melting point), the solid and liquid phase is in equilibrium there is no net driving force for the transformation to occur. The liquid cooled below the transformation temperature and it become more unstable. The homogenous nuclei were created by slow moving atoms bonding together which grow of nuclei into crystals. Homogenous nucleation usually requires a considerable amount of undercooling for nucleus to be stable which it can grow into crystals to form grains and associated grain boundaries (William and Javad, 2006).

The size and shape of dendrite was depends on the cooling rate. The liquid metal existing among the dendritic structures eventually solidifies to form a completely solid structure that was called as grain structure. It will be large enough to impinge upon each other when dendritic crystals form and growth. Dendrites can often be seen in solidification voids that sometimes occur in castings or welds. During solidification, the primary dendrites/ columnar grains that grow into the molten metal from both sides of the weld pool meet which it will creates coherent network and will contract to further cooling and lead to shrinkage or cracking. Cracking happen on the center of the weld where the columnar grains meet (centerline cracks). Liquation cracking may happen on heat affected zone (HAZ) when a low melting phase may melt and depending on the surface tension may spread out as a film on the grain boundaries. The structure is weakened and stresses due to shrinkage. The equiaxed grain will be different for each places which is fusion zone, heat affected zone and unaffected base metal (James, 2005).

Through welding, it causes the temperature of the pure material to rise above its melting point. By complete melting, it create fusion zone (FZ). The fusion zone or weld metal in a pure metal or other crystalline material is portion of the weld that completely melted during welding by having heated by welding thermal cycle above the pure metal melting point. The fusion zone, it was important to the properties of the final weld it has undergone melting and solidification and it really different in structure and properties compare to the base material and heat affected zone even if welding was autogenously (Robert,2004).

2.7.6 Expansion and Contraction

Welding process may cause stressed. The heat causes the metal to expand which causes strain. Although it was expands but it is not free to move because of other welds, tacking and the design of the weldment. Stresses during fabrication are combination of expansion due to heat, contraction due to cooling and condition of restraint. Distortion in other word is shrinkage which deform after welding process. Strees will cause distortion and cracking on the metal will happen. Properties of the metal, welding process and welder technique will determine the stress and distortion (Sacks and Bonhart, 2005).

2.7.7 Welding Type of Joint

Groove weld is one of the types which it will have one or more beads deposited in a groove. This type is only suitable for butt joints. The edge of the metal can be prepared with single V type shape for the groove. This process is important to make sure the metal will weld in complete joint penetration (CJP). The proper reinforcement after welding process must not exceed more than 1/8 inch. For the width of groove, it should not more than ¼ inch greater than width of the groove face to avoid waste of time and filler metal (Sacks and Bonhart, 2005).

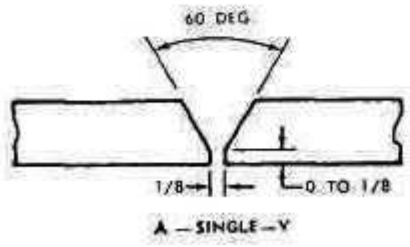

Figure 2.8: Single V type shape

Source: www.tpub.com

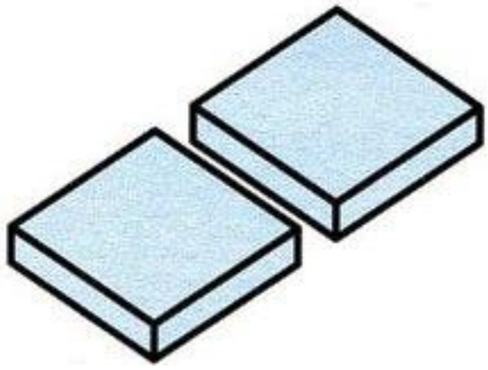

Figure 2.9: Butt joint Diagram

Source: www.millerwelds.com

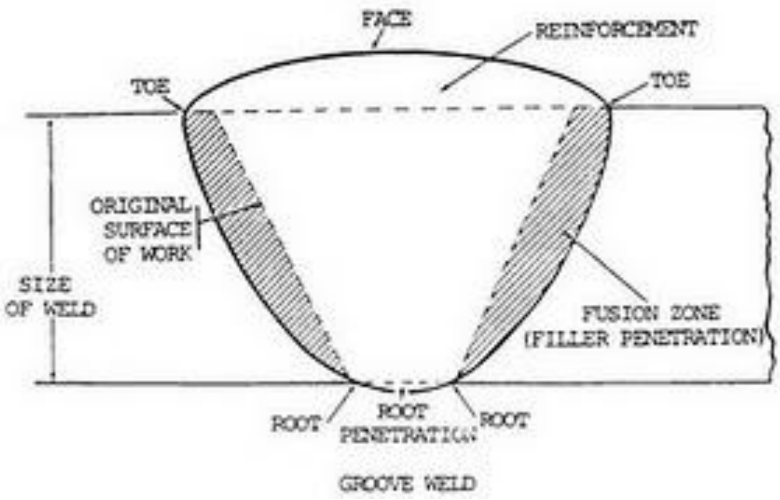

Figure 2.10: Measurement of Groove Weld

Source: www.weldingcourse.net

2.7.8 Filler Wire in GMAW

A filler wire also given a role to determined the best welding. Diameter of 0.035inch gives the best results and suitable to weld using GMAW. The welder can control the pool better compare to other sizes. The cost also less compare to filler wire with diameter 0.030inch. If the welder wish to use 0.030 inch size, the wire feed speed must be increase to obtain the same result as using 0.035inch size diameter. The table below shows GMAW filler metals for carbon steel (Sacks and Bonhart, 2005).

Table 2.7: GMAW filler metal for carbon steel

Base metal type	**Material type**	**Electrode Classification**	**AWS filler metal specification**	**Electrode diameter, inch**	**Amperes**
Carbon steels	Hot rolled or cold-drawn plain carbon steels	ER70S-3 or ER70S-1, ER70S-2, ER70S-4, ER70S-5, ER70S-6	A5.18	0.020 0.025 0.030 0.035 0.045 0.052 1/16 5/64 3/32 1/8	40-200 60-280 125-380 160-450 275-475

Source: (Sacks and Bonhart, 2005).

Filler wire classification can be determined based on the code. Each code have its own meaning. For example as the code below show code for wire filler for GMAW solid electrode (ASTM).

E R 70 S – X HZ

E= Can be used as an Electrode

R= Can be used as a Filler Rod

70= Minimum Tensile Strength in 1000-p.s.i increments

S= Indicate a Solid Electrode

X= Indicates Chemical Composition and Operating Characteristics

HZ= Optional Supplemental Hydrogen Designator

2.7.9 WELDING DEFECTS

Welding defects or imperfections often happen during welding process. The defects can greatly affect weld performance and longevity. Many of these defects happen because of: poor process conditions, error cause by operator, wrong technique while doing welding, incorrect consumable and bad weld grooves.

The material to be welded should be inspected thoroughly for surface defects and the presence of contaminating materials. The material should be checked for size, edge, and angle of bevel. The material edges and faces should be free from laminations, blister, nicks and seams. Heavy scale, oxide layer, grease, paint and oil also need to be removing. Make sure the material is a type suitable for welding (Sacks and Bonhart, 2005).

2.7.9.1 POROSITY

Porosity is the presence of pockets that do not contain any solid material. It differs from slag inclusions in that the pockets contain gas rather than solid. The gases forming the voids are derived from:

i) Gas released by the cooling weld metal because of its reduced solubility as the temperature drops
ii) Gases forming by chemical reactions in the weld

Excessive porosity in welds has a serious effect on the mechanical properties of the joint. Certain codes permit a specified maximum amount of porosity. Pockets may be found scattered uniformly throughout the entire weld, isolated in small groups or concentrated at the root. Porosity is best preventing by avoiding:

i) Overheating and underheating of the weld
ii) Excess moisture in the covered electrode
iii) Contaminated base metal or consumables
iv) Too high current setting

v) Too long an arc

A metal temperature that is too high increase unnecessarily the amount of gas dissolved in the molten metal. This excess gas is available for release the solution upon cooling. If the welding current and/or arc the length is excessive, the deoxidizing elements of the electrode coating are used up during welding so that there are not enough of them left to combine with the gases in the molten metal during cooling. Underheating does not permit the weld pool to be molten long enough to allow the trapped gases to escape. Reducing all sources of contamination to a minimum will greatly reduce possible gasifiers and help eliminate hydrogen pickup. Shielded gas must be pure, delivered at the proper flow rate and protected from being blown away (Sacks and Bonhart, 2005).

2.7.9.2 CRACK

Cracks are linear rupture of metal under stress. When they are large, they can be seen easily but they are often very narrow separations. Cracks may occur in the weld metal, in the plate next to the weld or in the heat affected zone (HAZ). Cracking results from localized stress that exceeds the ultimate strength of the material. Little deformation is apparent because cracks relieve stress when they occur during or as a result of welding (Sacks and Bonhart, 2005). There are three major classes of cracking: hot cracking, cold cracking and microfissuring.

Hot cracking: occurs at elevated temperature during cooling shortly after the weld has been deposited and has started to solidify. Slight stress caises very small cracks that can be detected only with some of the non-destructive test techniques such as radiographic and liquid penetrant inspection. Most welding cracks are hot cracks.

Cold cracking: cracking at or near room temperature. These cracks may occur hours or days after cooling. It usually starts in the base metal in the HAZ. May appear as underbead cracks parallel to the weld or as toe cracks at the edge of the weld. Occurring more often in steels than other metals.

Microfissure: can be either hot or cold cracks. Too small to be seen with the naked eyes and are not detectable at magnifications below 10 power. Usually do not reduce the service life of the fabrication.

2.7.9.3 INCLUSIONS

Generated by extraneous materials such as slag, flux, tungsten or oxide inclusion. Usually elongated or globular in shape. May be caused by contamination of the weld metals by foreign bodies. Slag inclusions are generally happen in arc welding, made up of electrode coating materials or fluxes. During the deposition and solidification of the weld metal, the air and the electrode coating materials or the gases produced by arc flames. Some of the products of these reactions are metallic compounds that re only slightly soluble in the molten weld metal The oxide may be forced down the surface by the stirring action of the arc or it may flow ahead of the arc, causing the metal to be deposited over oxide.

These defects are often associated with undercut, incomplete penetration and lack of fusion in welds. Insufficient cleaning between multi-pass welds and incorrect and electrode manipulation can leave slag and unused sections along the weld joint (Sacks and Bonhart, 2005). Most inclusions can be prevented by:

i) Preparing the groove and weld properly before each bead is deposited
ii) Taking care to avoid leaving any contours that will be difficult to penetrate fully with the arc
iii) Making sure that all slag has been cleansed from the surface of the previous bead
iv) Slag inclusions not only reduce cross sectional area strength of the joint but may serve as an initiation point for serious cracking. These defects can only be repaired by grinding down or gouging out and re-welding.

2.7.9.4 UNDERCUT

Undercut is one of most serious defect in welding process. It is burning away of the base metal at the toe of the weld or essentially unfilled grooved along the edge of the edge. The defects are often associated with incorrect electrode angles, incorrect weaving technique, excessive current and travel speed. In the addition to poor welding technique and the type of electrode required, undercutting may be caused by:

i) Current adjustment that is too high
ii) Arc length that is too long
iii) Failure to fill up the crater completely with weld metal. This permits the arc to range over surface that are not to be covered with weld metal

Undercut at the surface of a joint should be not being permitted since it materially reduces the strength of the joint. To prevent any serious effect upon completed joint, it must be corrected before depositing the next bead. A well rounded chipping tool is used to remove the sharp recess that might otherwise trap slag. If the undercutting is slight and the welder is careful in applying the next bead, it may not be necessary to chip (Sacks and Bonhart, 2005).

2.7.9.5 OVERLAP

Overlap also known as incomplete fusion. Weld metal protrusion beyond the weld toe or weld root. This kind of defects is largely the result of improper gun handling, low heat and improper speed of travel. It is important that the arc be directed at the base metal and the leading edge or the pool. Overlap can be repaired by grinding off the excess weld metal and surface grinding smoothly to the base metal (Baughurst and Voznaks). To prevent this defect, give careful consideration to the following:

i) Direct the arc so that it covers all areas of the joint. The arc, not the pool do the fusing
ii) Keep the electrode at the leading edge of the pool
iii) Reduce the size of the pool as necessary by adjusting the travel speed

iv) Check current values carefully. Keep a short electrode extension

2.8 MASS SPECTROMETER

Spectrometer is one of machine used in determine and identify the chemical compositions of metal or molecule sample. It is an analytical method that measures the charged particle mass-to-charge ratio. In determining sample, a mass spectrometer changes molecules of sample to ions so that they can be moved and manipulated by magnetic fields and electrical field.

The three important components of spectrometer consist:

i) The ion source: convert gas phase molecules of sample into ions through, for example, electrospray ionization that let the ions turn into gas phase.
ii) The mass analyzer: sort and analyse each ions by the mass and charge by electromagnetic fields
iii) The detector: the ions that have been separated are then measured by the value of quantity indicators. From it, they will provided and the results will be shown on a chart
iv) The spectrometer has practical usage in quantities and qualitative. The machine can also be used in other study in determining physical, chemical or biological properties of any variety of compounds (Chace and Sparkman, 2005).

2.9 COMPUTER NUMERICAL CONTROL (CNC) MILLING MACHINE

Machine that capable to perform a variety of cutting operation which one of the most versatile and useful machine tools. The first milling machine was built in 1820 by Eli Whitney in between 1765-1825. CNC is a system that capable to satisfy the increasing industrial demand for machining complex shape parts and it was an important goal in the field. To design the tensile shape for tensile test at the material, CNC milling machine need to be used since it can complete the job in period time compare to others machine. The surface finishes are also good and can obtain good contour accuracy because it can achieve high level of reliability.

The performance for this milling machine is the cutting process which cut at the required accuracy and time efficient. The disadvantages by using this machine is it can cause breakage to the cutting tool, damage the machine tool or causes the production scrap since it inability to leave the working machine tool unattended. (Mariana and Huw, 2005).

This machine directly needed a program to running. The program can be create by using drawing that have been draw using software such as AutoCAD, Hewlett Packard 9000/32, SolidWork, MasterCAM and others (Douglas and Carrier, 1989). Computer aided design (CAD)/CAM system will generated the voluminous part programs of these motions which it will drive the cutting tool through a set of point approximating the complex paths. The user specifies the desired surface shape, the tool radius and the required cutting conditions (Sotiris and Andreas, 2007). The tool movement consist of the working and feeding motions. The material will be take a place by cutting into several part based on machining process with optimum sequence only for simple products (Kovacic et al, 2005).

2.10 OPTICAL MEASUREMENT MACHINE

Optical measurement machine is used to examine the weld cross section view (Wouters, 2005). From this machine, the view of all zone can de view more clear which are fusion zone area, heat affected area and unaffected area. The different of each specimen can be seen and thus helping in making the result. The optimum range of gap between two part of material that going to be weld will give a maximum weld strength to the specimen (Wouters, 2005). If there is no gap or not in optimum gap is used, crack defect will happen and thus reduce the strength of joint.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the test carried out based on previous studies. It includes a description of the preparation for experiments, tests of mechanical testing of materials such as tensile test and hardness test and the microstructure of experimental materials. Layout of the test carried out has been summarized in a flow chart of the study and performed the tests was being described in more detail in the next title.

3.2 METHODOLOGY FLOW CHART

Figure 3.1 show the flow chart for the whole research that has been running. Further information and the method used is described in the next subheading.

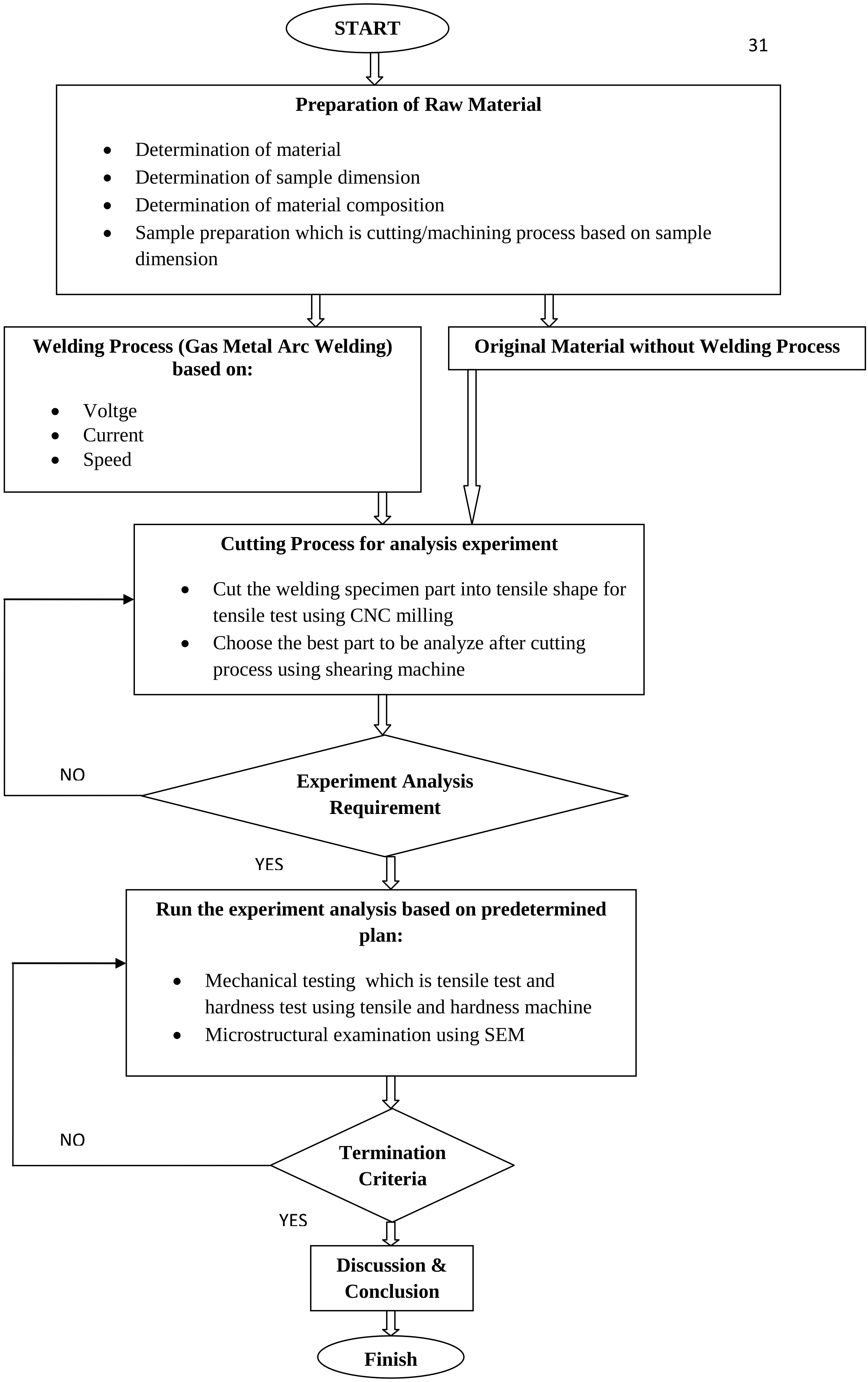

Figure 3.1: Flow chart for experimental procedure

3.3 PREPARATION OF EXPERIMENTAL MATERIALS

In this study, the steel used is low carbon steel 1010. The original size of sheet metal material has been cut into 32 specimens where each specimen has a dimension 75 mm x 50 mm x 3mm including the specimen without welding process which is 1 specimen that have a dimension 300mm x 50mm x 3mm. The thickness was 3 mm dimension.

3.4 COMPOSITION ANALYSIS

The sample of sheet metal was analyzed to determine the metal composition. Composition analysis is used to analyze the internal content of specimen. Before testing the specimen, the material must be prepared first by grinding the material surface using flat grinding machine to remove oxide layer, scale, oil and other residue on top of sample. The surface of sample must be flat in shape. Then the surface needs to being checked to prevent any presence of porosity, slag, inclusion and others. The instrument used for this process is Foundry Master Oxford Instrument as shown in Figure 3.2.

Figure 3.2: Foundry Master Oxford Instrument

The mass spectrometer machine has been checked for properly calibrate to measure the carbon content in the material using sparking process. Carbon contain in the specimen has been checked. The specimen surface must be clean first with the alcohol solution before progress to next process to remove the dust or others dirt. After that, put the specimen on spark table so that sparking process can be done.sparking process will cause burn on the surface metal. This process is to create a smoke air and the detector detects the composition based on the smoke created. Make sure there is no too much air leakage, so that the result can be determine correctly. Continue the process for several times, at least 3 times, to get average results and the result in stable condition. Check area for preburn times during sparking process. Table 3.1 shown the chemical composition of carbon steel

Table 3.1: Chemical composition of low carbon steel

Fe	C	Si	Mn	P	S	Cr	Mo	Ni
99.4	0.0847	<0.005	0.195	0.0056	0.003	0.0501	0.0142	0.0363

Al	Co	Cu	Nb	Ti	V	W
0.0227	<0.001	0.0804	<0.0020	<0.0020	<0.0020	<0.0150

3.5 SHEARING MACHINE FOR CUTTING PROCESS

Sample material with thickness 3mm has been cut using shearing machine with dimensions 75mm x 50mm. The instrument used for cutting process is NC Guillatine Hydraulic Shearing LVD (MVS-C) as shown in Figure 3.3.

Figure 3.3: NC Guillatine Hydraulic Shearing LVD (MVS-C)

This machine is used to cutting the metal into smaller part. To start the process, the button must be switch on at machine and make sure the hydraulic lever is open. Insert the length value based on the dimensions given. Press start button. Set lever thickness, clearances and angle according to the material thickness and type of it. If this process is not done, the material dimension was not accurate because this is one of the important setting processes. Figure 3.4 and figure 3.5 below showed the dimensions for sample preparation.

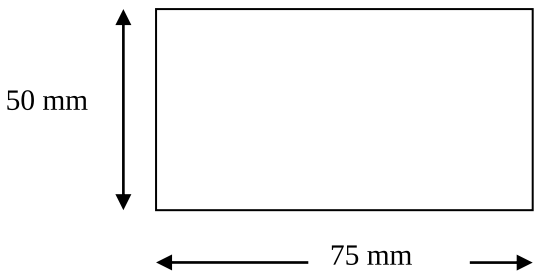

Figure 3.4: Dimension size for specimen before welding process

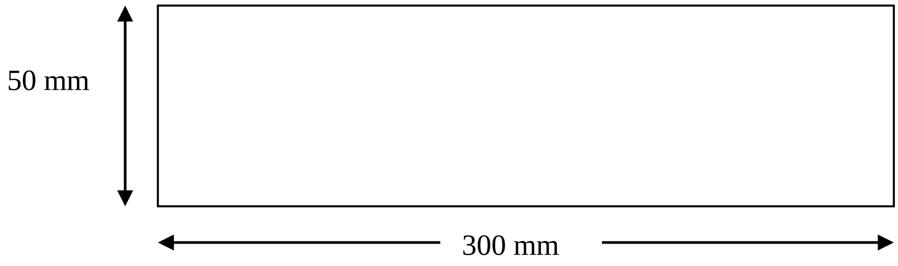

Figure 3.5: Dimension size for specimen without welding process

3.6 WELDING PROCESS (GAS METAL ARC WELDING)

Welding process is a process to combine two part of same metal. For Gas Metal Arc Welding (GMAW) welding, it is essential to carefully clean the joint surfaces and use clean filler metal in order to avoid weld defects. Figure 3.6 shown the GMAW machine type Dr Well DM-500EF while Figure 3.7 shown the speed control table.

Figure 3.6: GMAW machine type Dr Well DM-500EF

Figure 3.7: Speed control table

Mild steel filler metal type ER70S-4 has been used in this weld process because the diameter of the filler is suitable for the thickness of the sheet (Sack and Bonhart, 2005). This type of welding is used a continuous solid wire consumable electrode for filler metal and an externally supplied gas or gas mixture for shielding. The shielding gas was protected the molten metal from reacting with constituents of the atmosphere. All 32 specimens has been weld and become 16 specimens. The welding parameter has been change in welding process based on table 3.2 shown below using probability method.

Table 3.2: Welding parameter

No	Speed	Voltage	Current
1.	Low	Low	Low
2.	Low	Low	High
3.	Low	High	Low
4.	Low	High	High
5.	High	Low	Low
6.	High	Low	High
7.	High	High	Low
8.	High	High	High

Table 3.3: Value for each parameter

	Speed, mm/s	Voltage, V	Current, A
Low	9	21	115
High	10	23	125

3.7 CNC MILLING TENSILE SHAPE CUTTING

Computer Numerical Control (CNC) Milling is a machine that have multiple used such as cutting, shaping, drilling, finishing and others. This machine has been used for machining the specimens into tensile shape according to standard of ASTM. The machine used to cut the specimens is called HASS TM2 CNC Milling machine as shown in Figure 3.8 below.

Figure 3.8: HASS TM2 CNC Milling machine

Before machining the specimen, the shape has been drawn in Master CAM X3 software based on ASTM standard dimension. The software being converted the drawing shape into computer coding for CNC milling machine which is called G-code. The coding has been transfer into CNC milling machine. The figure 3.9 showed the dimensions for tensile test shaping process according to ASTM standard E8 based on the figure.

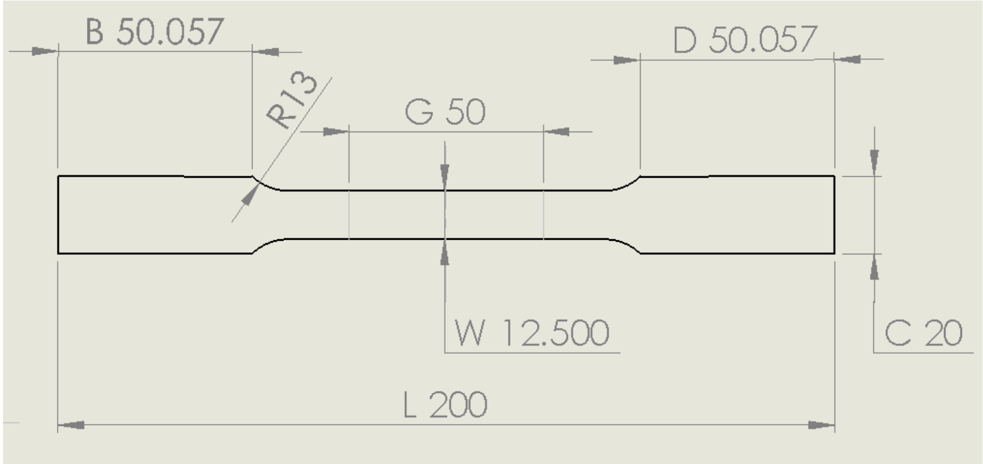

Figure 3.9: Dimension in accordance ASTM standard of E8

3.8 SECTIONING CUT-OFF MACHINE

Sectioning cut-off machine were used to cut the specimens after welding process to get a small pieces for analysis part. This machine has coolant to prevent the specimens from being influenced by the heat which come from the cutting process. Figure 3.10 shown the sectioning cut-off machine type MSX200M

Figure 3.10: Sectioning cut-off machine type MSX200M

3.9 TENSILE TEST

Tensile tests were conducted on experimental material in the form shown in Figure 3.11.This test is intended to obtain the mechanical properties of experimental materials such as yield strength, tensile strength, the modulus of elasticity, and ultimate tensile strength of the experimental material. The instrument used for tensile tests is Universal Testing Machine Instron 3369 screening as shown in Figure 3.8.

Figure 3.11: Universal Testing Machine Instron 3369

There are nine specimens that has been test where eight from nine of it has different parameters to be weld each while and one specimen as received specimen. All specimens have been being conducted with constant and same strain for tensile test experiment. The cross hair speed rate used in this test is 2.4mm / min. The speed rate is selected by following the previous research.

Experimental material has been placed on the gripper machine. The sample position must be parallel to the axis of machine gripper. Gripper grips the experimental materials must be tight so that no slippage occurs during the tensile tests carried out.

3.9.1 Analysis of Tensile Test

Analysis of tensile test was conducted after the data for the tensile test results obtained. Graph of engineering stress versus engineering strain can be obtained by plotting the data using Microsoft Office Excel 2007.

Stress versus strain graph plotted to get the value of the yield strength, maximum tensile strength and modulus of elasticity. Graph of stress versus strain for each specimens are also being plotted to show the maximum stress to the material. Figure 3.12 shown the gripping specimen at Instron Universal Testing Machine.

Figure 3.12: Process of specimen gripping

3.10 METALLURGY PROCESS

Process for checking metallurgy has been done after welding process to check grain structure of weldment sample. The sample has been through mounting, grinding, polishing and etching to determine and reveal microstructure of the weldment sample. Then it will be reviewed under a microscope with different magnification.

Mounting of specimens is needed to allow them to be handled easily. Then the specimens were placed inside the mounting cup. The correct amounts of two components which is powder transparent and cold-curing resin liquid had been weighted carefully with same weight. The two components are then mixed thoroughly and poured over the specimens. The specimens were placed inside the cold mounting machine for approximately 20 minutes.

Surface damaged of specimens after cutting process had been removed by grinding and polishing. The specimens were grinded using 240, 320, 400 and 800 SiC, starting with the lower number of grinding paper, paper disc and lubricated using water as shown in Figure 3.13. Finally, the specimens had been polished using polish machines with three different type of lubricant which is 6 µ, 3 µ and 0.05 µ PC diamond. Grinding and polishing process is to refine the material surface from rough into smooth surface for microstructure viewed. Figure 3.14 shows the polishing process with different lubricant.

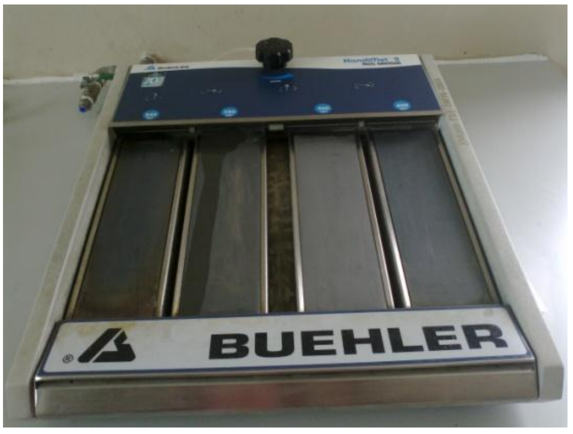

Figure 3.13: Grinding process

Figure 3.14: Polishing machine with PC diamond lubricant

Figure 3.15: Etching solution

Microstructure of the stainless steel specimens had been revealed by etching process. Low carbon steel has been etching by mixing of 100 ml Ethanol ($C^{2}H^{4}$OH), and 1-10 ml nitric acid (HNO_3) for 3-10 seconds. Figure 3.15 etchant for carbon steel solution that already being mixed. Process being conducted in fume hood for safety precaution.

A microstructural observation is to see the grains structure formed after the welding process. To determine the grain structure on the heat affected zone (HAZ) on the specimen based on the different parameter being used which is speed, current and voltage.

Experimental material microstructure seen under an optical metallurgical microscope Meiji Techno brand, model IM7200. Figure 3.16 shows the optical microscope used in this test to viewed the microstructure of experimental materials.

Figure 3.16: Optical Microscope

The microstructure is revealed by using 100x magnification up to 20x on some of the experimental material. All specimens are stored in desiccator cabinet to prevent from corrosion.

3.11 HARDNESS TEST

Hardness test is to obtain the true hardness value for each experiment after the application of percentage of different strains. Hardness refers to the characteristics of materials that provide polarity of each type of shape change when force is applied. Materials with high hardness have been produced material that is resistant to scratches and wear.

There are various types of hardness tests can be applied but for this study, the Vickers hardness test is selected to be used to obtain the true value of the hardness testing of materials. This test uses a diamond notch that has high hardness and shape notch diamond is a pyramid shape square with 136˚ angle between the opposite surfaces. Equipment used is a measure of the hardness machine Vickers Hardness Tester MMT-X7 Matsuzawa types as shown in Figure 3.17.

Figure 3.17: Vickers Hardness Tester MMT-X7 Matsuzawa

Before the hardness test run, the variables on the Vickers hardness test machine first has been entered such as the load, period of load, and reading methods. Table 3.5 shows the values of variables used in hardness test to carry out.

Table 3.5: Variables value for Vickers hardness test

Variables	**Value**
Load	500gf
Period of load	10 seconds

A total of nine experimental materials need to be done in this test to determine the different in hardness before and after welding process at each area zone. One specimen was not being weld and the others are specimens that have been weld based on the parameter that already set before this.

Hardness test on each test material has been taken 3 times on each region which are fusion, heat affected and unaffected zone. Figure 3.15 show the illustration of the distance of points on the surface of indentation experiments.

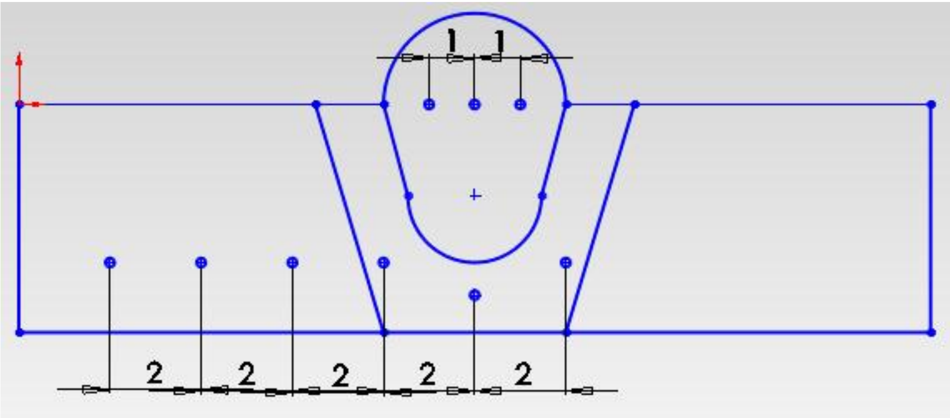

Figure 3.18: Illustration of the distance of points on the surface of indentation experiments

3.12 OPTICAL MEASUREMENT VIEW

Optical measurement machine has been used to analyze the weld cross section view for each region including unaffected zone. This process is to examine how was the depth of penetration. Each region which is fusion, heat affected and base metal zone area was having different hardness.

Equipment that used to view the welded part of the specimen especially on penetration on fusion zone was Mahr MM 320 types as shown in Figure 3.16.

Figure 3.19: Optical Measrurement Machine Mahr MM 320 type

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Sample Characterization

The microstructure of the specimen had been revealed under Inverted Microscope IM7200 series before others part process taking place. Low carbon steel had been etched by natal solution for 5-10 seconds.

The following figure shows the microstructure of low carbon steel after the etching process using Inverted Microscope at magnifications 100x. Eight welding samples and one specimen without welding process had been prepared using different parameters which are speed of welding, voltage and current. The table 4.1 shows eight specimens for welding process using different parameters.

Table 4.1: Number of specimens for welding with parameters

Specimens	Speed, mm/s	Voltage, V	Current, A
1	9	21	115
2	9	21	125
3	9	23	115
4	9	23	125
5	10	21	115
6	10	21	125
7	10	23	115
8	10	23	125

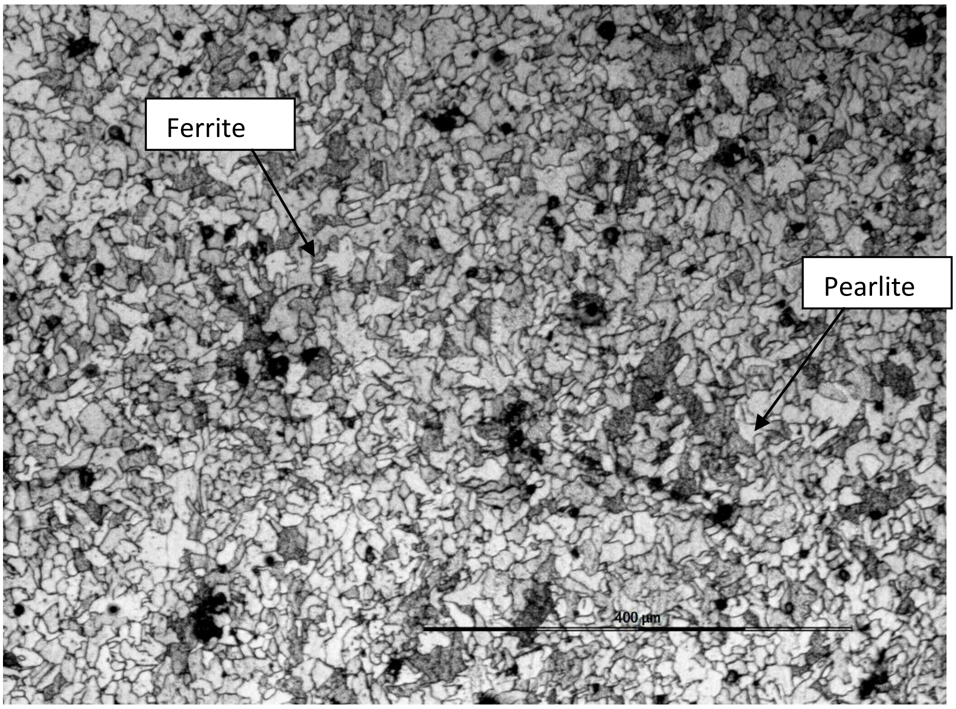

Figure 4.1: Microstructure as received sample between weldment and heat affected zone at magnification 100x

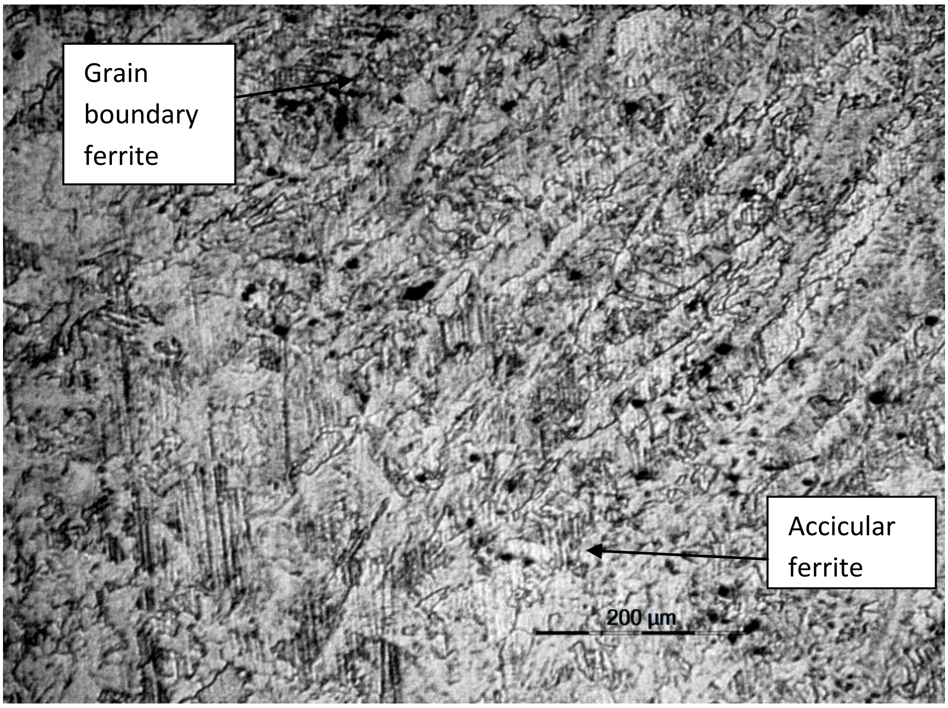

Figure 4.2: Microstructure between weldment and heat affected zone for specimen 1 at magnification 100x

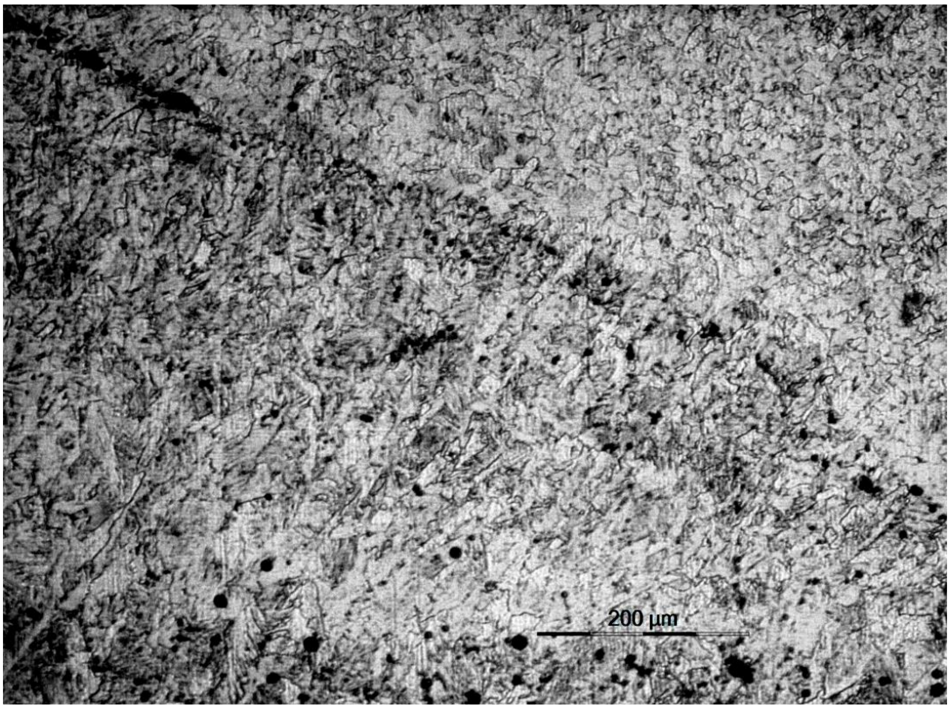

Figure 4.3: Microstructure of between weldment and heat affected zone for specimen 2 at magnification 100x

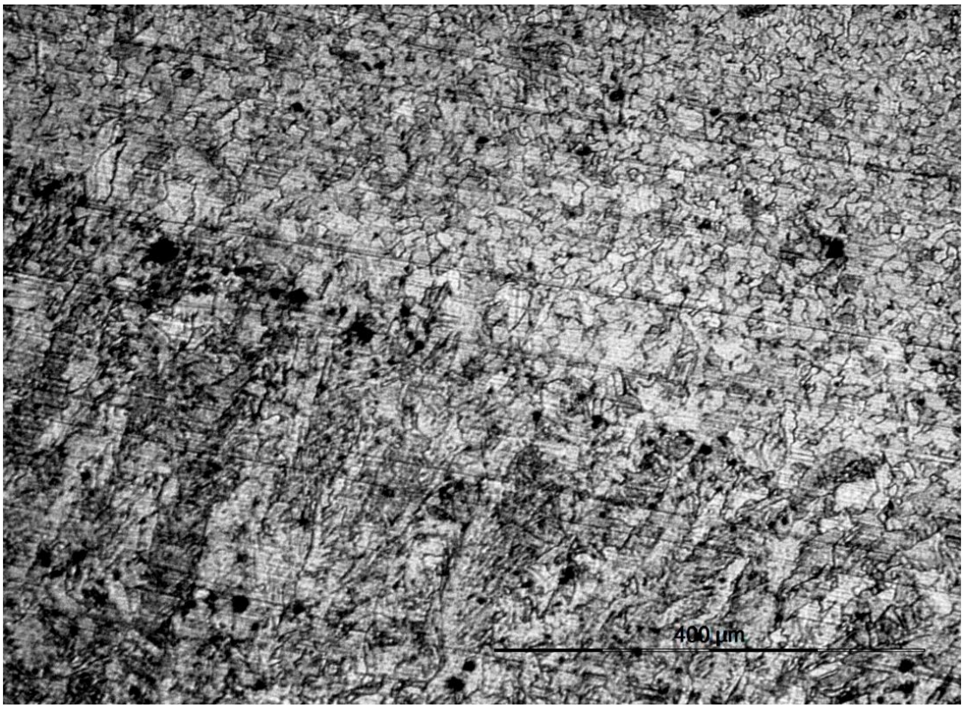

Figure 4.4: Microstructure between weldment and heat affected zone for specimen 3 at magnification 100x

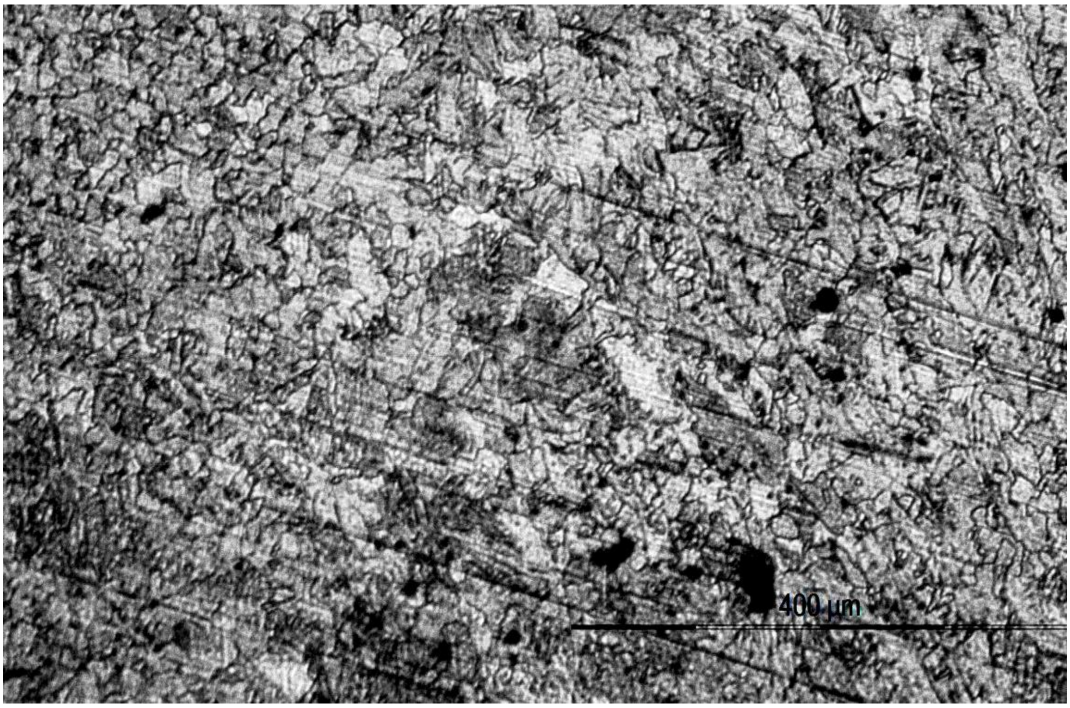

Figure 4.5: Microstructure between weldment and heat affected zone for specimen 4 at magnification 100x

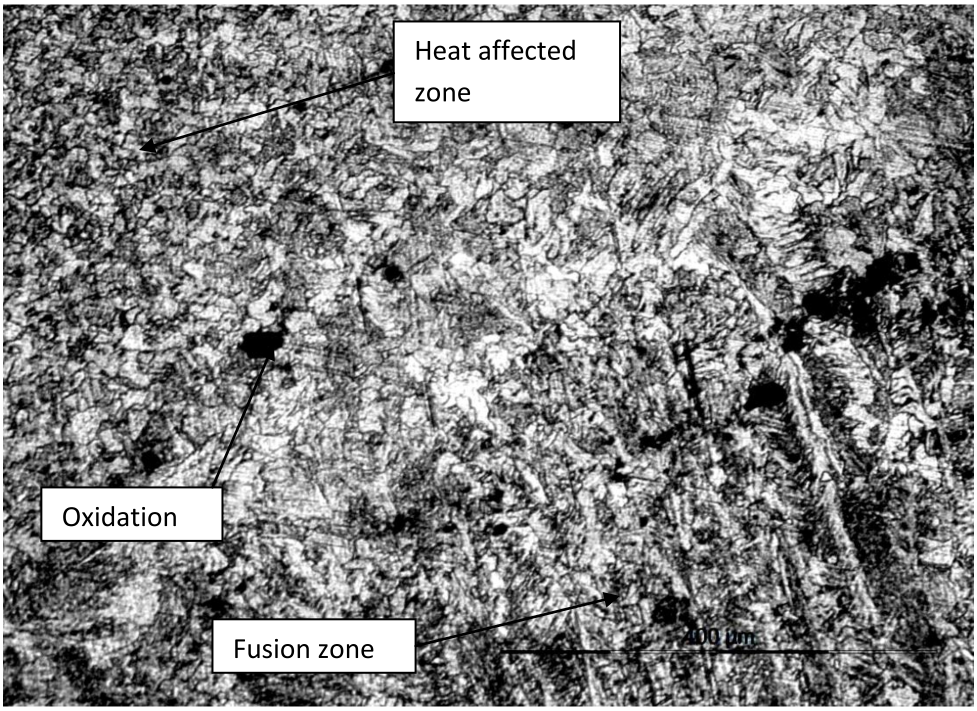

Figure 4.6: Microstructure between weldment and heat affected zone for specimen 5 at magnification 100x

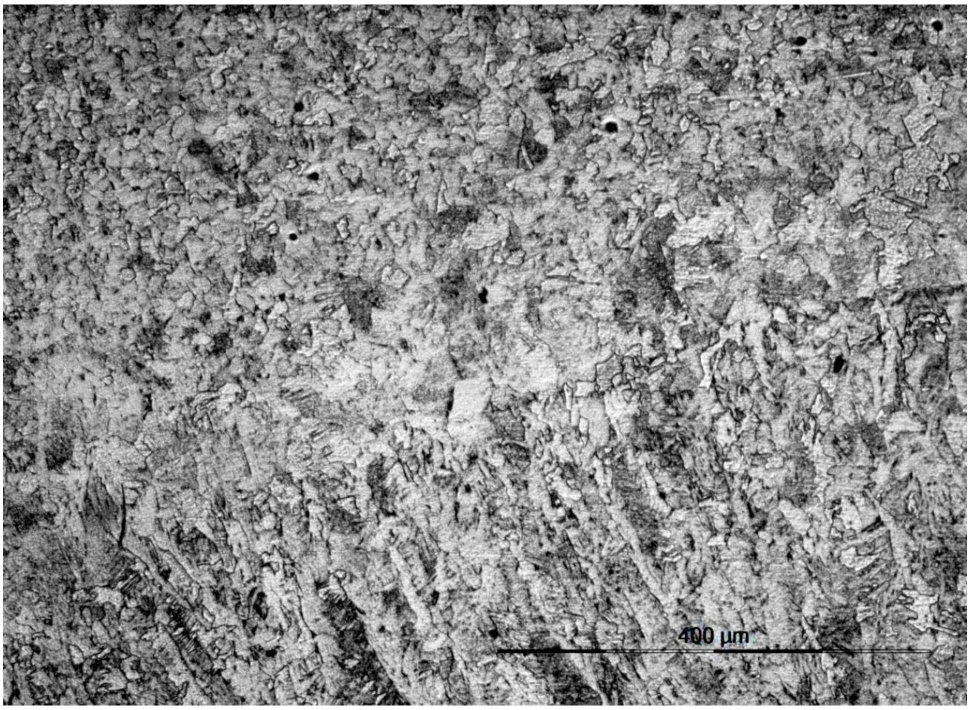

Figure 4.7: Microstructure between weldment and heat affected zone for specimen 6 at magnification 100x

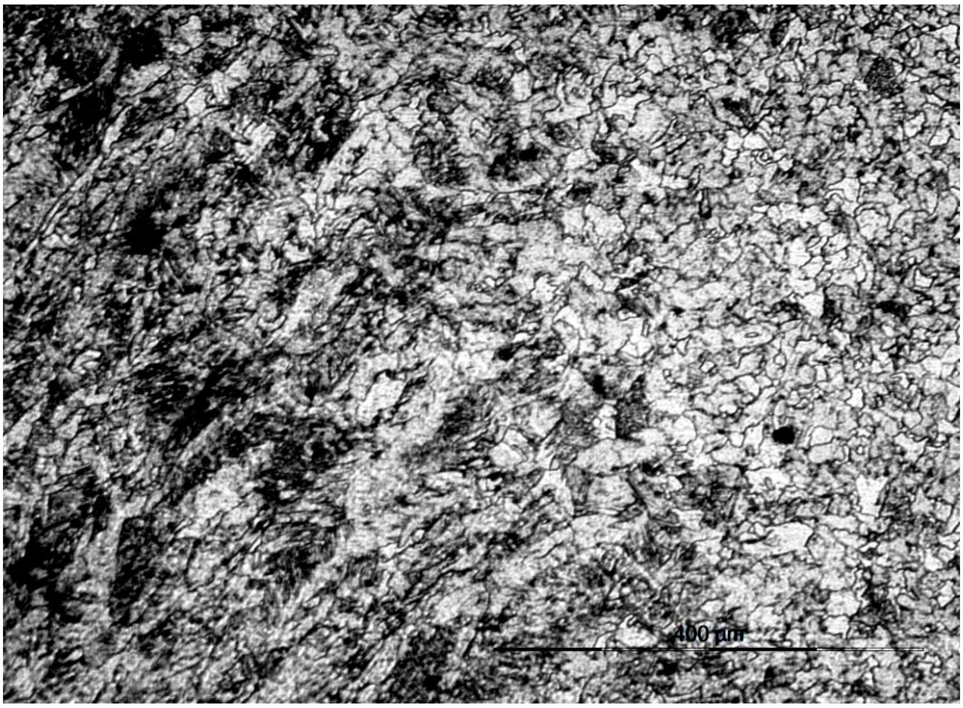

Figure 4.8: Microstructure between weldment and heat affected zone for specimen 7 at magnification 100x

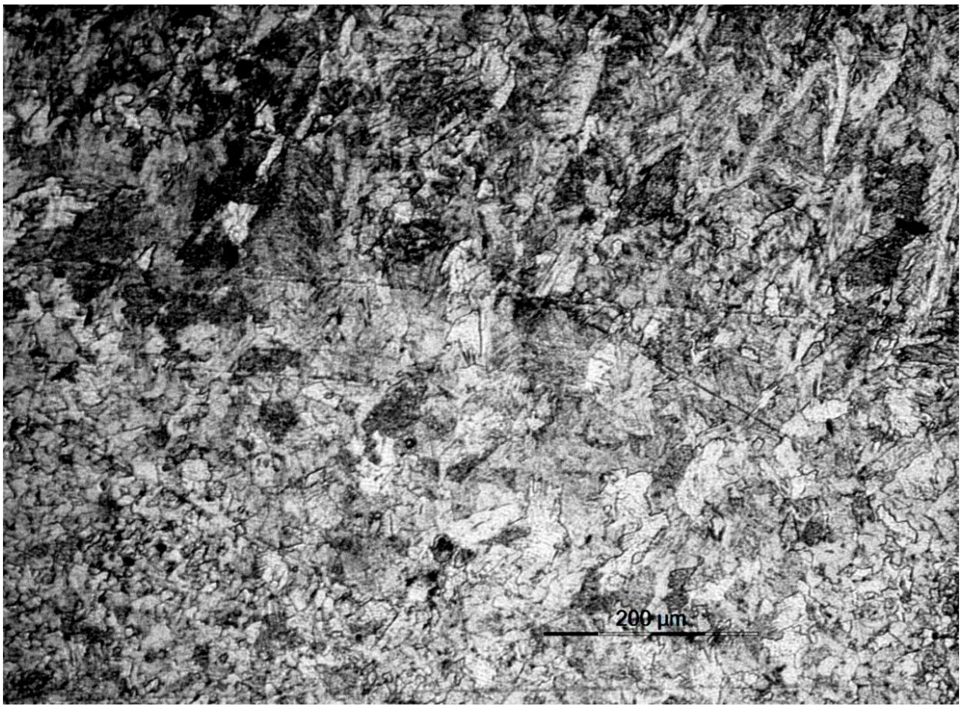

Figure 4.9: Microstructure between weldment and heat affected zone for specimen 8 at magnification 100x

The microstructure had been revealed at magnification 100x. Based on the microstructure result, each of the regions has a different shape of a grain except base metal which did not change from the original shape of grain. It was proven by where after the welding process, it shows that the structure of microstructure is different from the microstructure of original material and the grains are oriented towards the heat centre which is weldment area and heat affected area (Kaharaman, 2007). It also shows that new grains were deformed in the interface. Due to thermal gradient of the welding, this new grains become larger than the base metal grains. (Sack and Bonhart, 2006) said that the grain size will have an effect on the mechanical properties of the metal either ductile of brittle. This will influence the mechanical properties of the original material rapidly because the materials have been given a heat process which comes from the welding process. The material after welding becomes solid liquid phase. Based on figure 4.1 shown the type of phases contains which are ferrite and pearlite. Ferrite phase is an interstitial solid solution of carbon in the body centered cubic (BCC) iron crystal lattice. Pearlite is a lamellar constituent of steel consisting of alternate layers of ferrite (alpha-iron) and cementite (iron Carbide Fe_3C). This produces a tough structure and is responsible for the mechanical properties of unhardened steel. Figure 4.2 shown the type of grains created in weldment area which are grain boundary ferrite and accicular ferrite. These both of grain type have a different shape of grain created. Acicular ferrite is shaped and pointed like a needle shaped crystals while grain boundary ferrite is a grain shape created in weldment area.

Most all of the specimens have oxidation elements that not good for the material properties which reduce the strength. This is because of the arc length is excessive that create the deoxidizing elements of the electrode coating that used up during welding which there are not enough of it to combine with the gases in the molten metal during cooling (Sacks and Bonhart, 2005). This defect is called porosity where it is the presence of the pockets that do not contain any solid material (Sacks and Bonhart, 2005).

The microstructure at fusion zone show the dendrite shape and the shape has become different when it goes to heat affected zone which it become to columnar shape before it be an equiaxed grain shape. All specimens almost have the same result in the dendrite shape because of the specimen being cool at same condition which slowly cooled to room temperature. The welding process causing the filler melting and heating the two parts of the specimen. This causes the original materials which contain ferrite and cementite structure was heated into liquid before slowly cooled back into the cementite and ferrite structure. This being proved where low carbon steel that being heated will return back to cementite and ferrite structure through slow cooling process (Kalpakjian, 2006)

All specimens that have been welded base on different parameters can be concluded that it almost has a same shape based on the same area which are base metal, heat affected zone and fusion zone. Result of the microstructure created is dendrite shape at fusion zone, columnar between fusion and heat affected zone and equiaxed grains at heat affected zone. The structure of dendrite was look like tree shapes while the columnar structure more to grains but are long, thin and coarse because of the metal was solidified slowly. The equiaxed structure is a little bit different from columnar where the grain shape more circle and did not thin or long. This is happen due to different time of cooling rate (Kalpakjian, 2006).

4.2 Optical Measurement View

A polished portion of eight specimens that have been welded with different parameter is examined using optical microscopy measurement to analyze the penetration part. The fusion zone and heat affected zone will be shown.

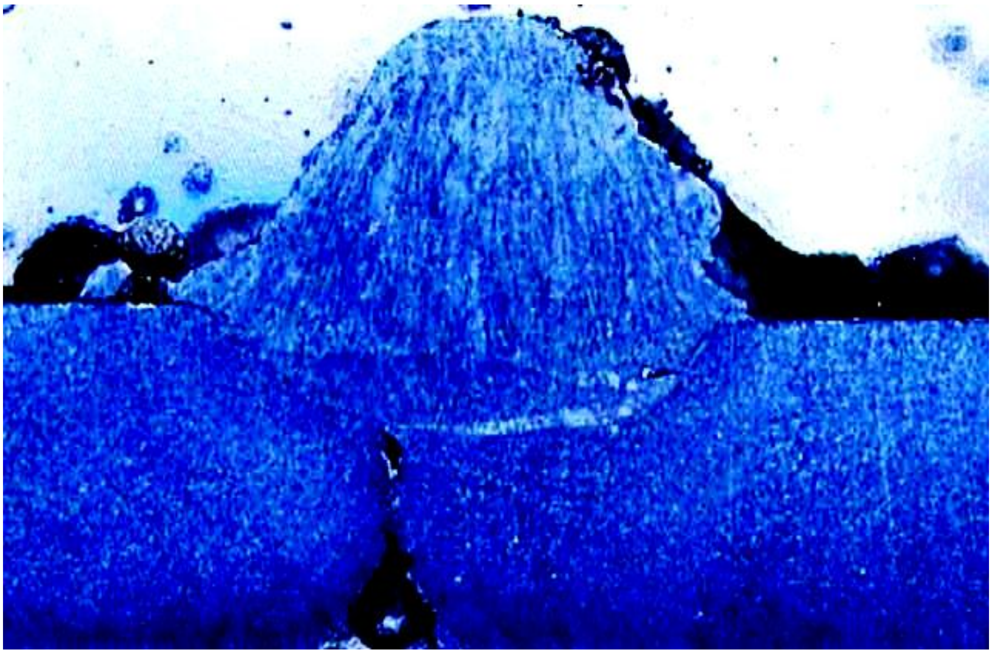

Figure 4.10: Optical measurement view for specimen 1

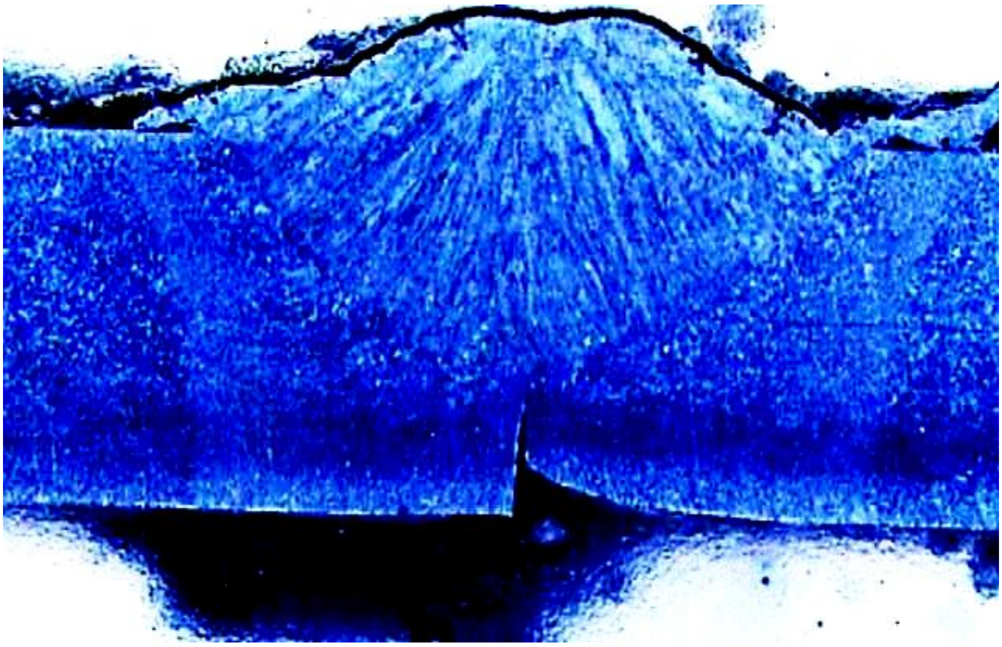

Figure 4.11: Optical measurement view for specimen 2

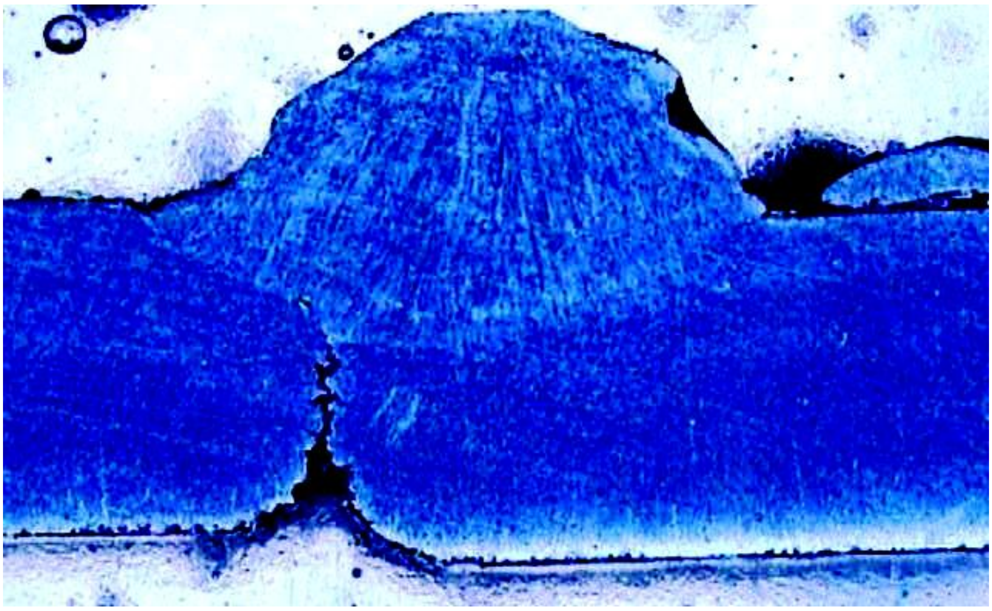

Figure 4.12: Optical measurement view for specimen 3

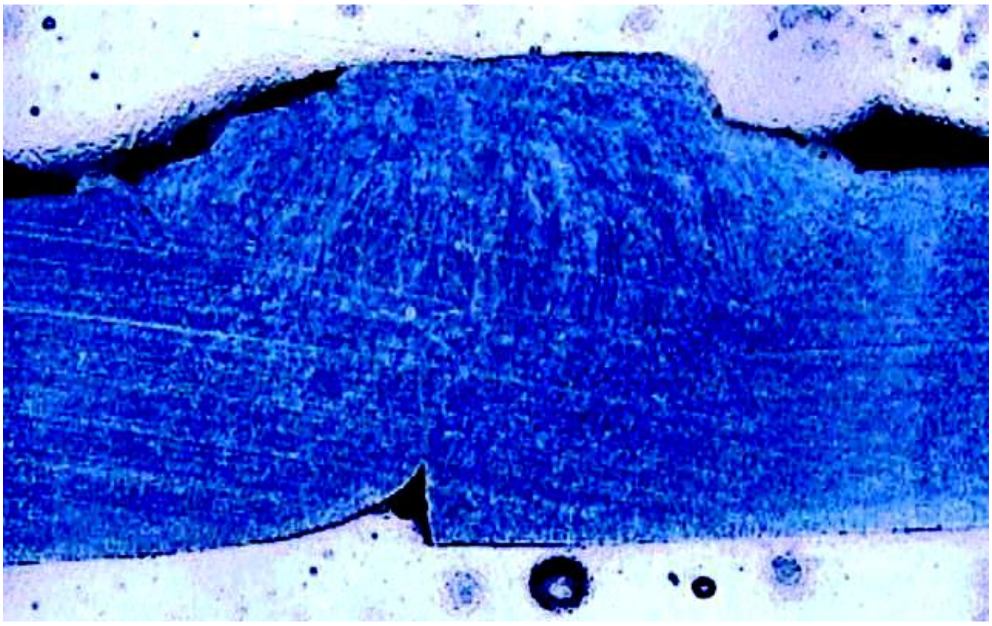

Figure 4.13: Optical measurement view for specimen 4

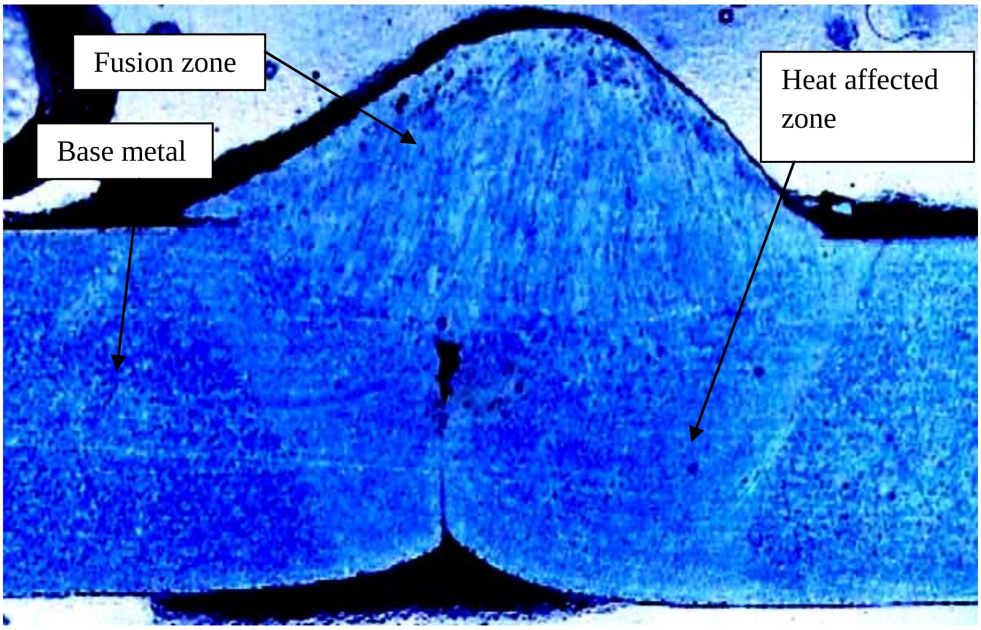

Figure 4.14: Optical measurement view for specimen 5

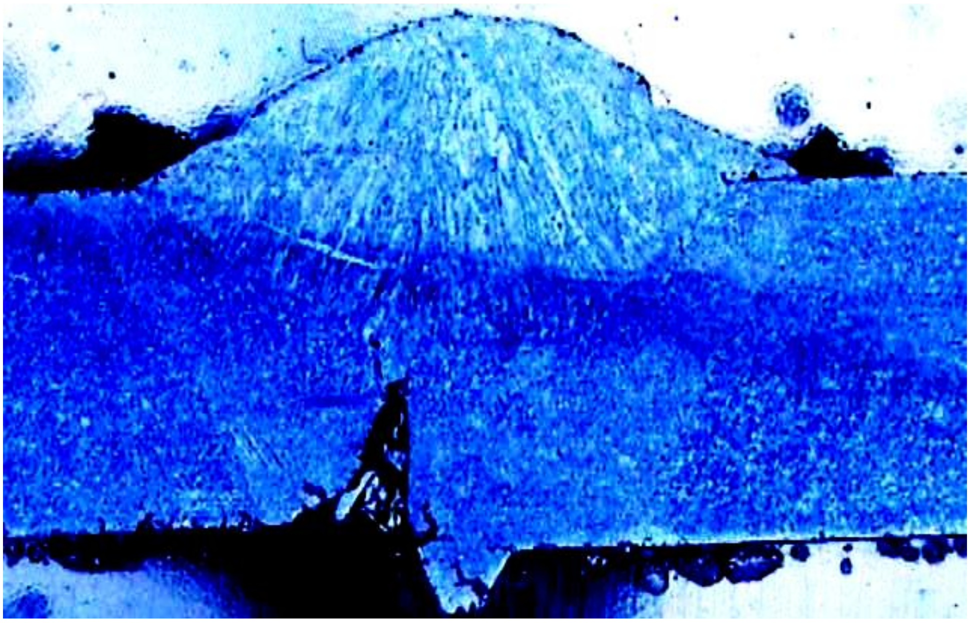

Figure 4.15: Optical measurement view for specimen 6

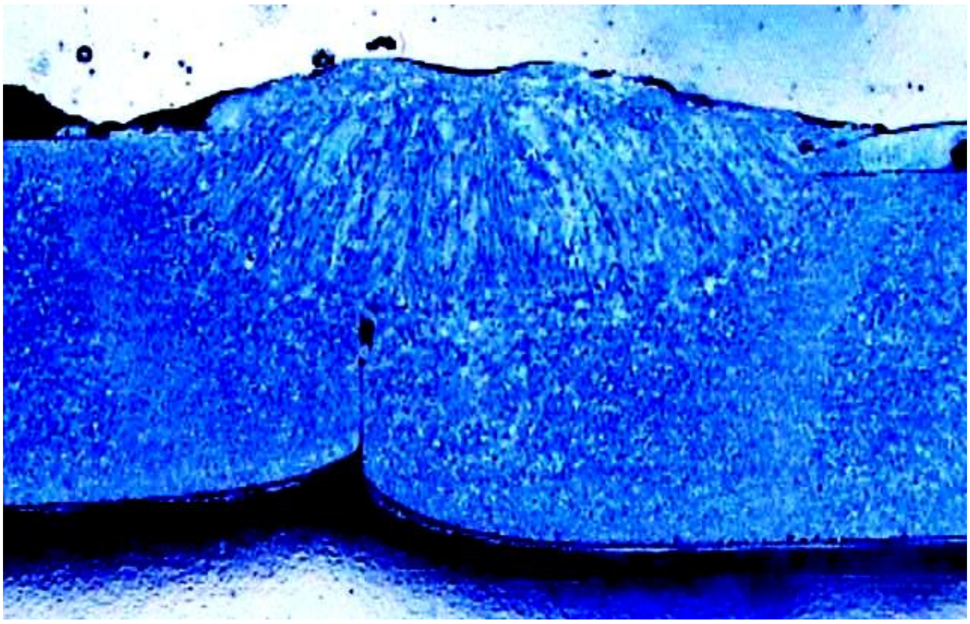

Figure 4.16: Optical measurement view for specimen 7

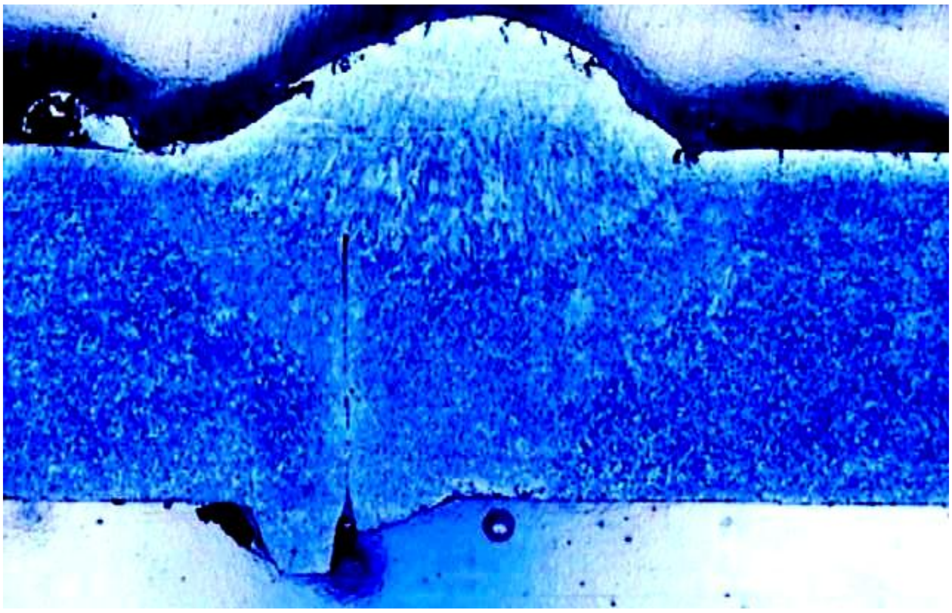

Figure 4.17: Optical measurement view for specimen 8

The optical measurement view is used to determine the depth of penetration for each of the specimens to support the tensile test result. The heat input produced was influenced the depth of penetration and thus influenced the strength during tensile test process. The more depth penetration is created, the more strength it can hold (Wouters, 2005). All of the specimens having the same defect which is did not enough penetration and this causes the strength is not too high to be hold.

4.3 Vickers Hardness Test

Table 4.2: Result Vickers Hardness test for each welded specimens

Specimens	Zone Area	Test 1	Test 2	Test 3	Average Data Test
Control Specimen	Base Metal	109.7	110.3	108.3	109.4
1	Base Metal	104.2	105.6	105.7	105.2
	Heat Affected	111.4	119.3	112.5	114.4
	Fusion	136.7	139.6	136.0	137.4
2	Base metal	101.9	108.1	119.5	109.8
	Heat Affected	111.2	115.2	115.3	113.9
	Fusion	144.2	150.8	150.0	148.3
3	Base metal	100.8	106.2	110.6	105.9

Table 4.2 continue

	Heat Affected	108.7	110.2	108.6	109.2
	Fusion	137.2	146.4	137.8	140.5
4	Base metal	108.9	111.0	116.8	112.2
	Heat Affected	111.7	121.8	117.9	117.1
	Fusion	138.4	148.2	144.8	143.8
5	Base metal	104.6	106.5	107.7	106.3
	Heat Affected	115.1	119.0	120.2	118.1
	Fusion	156.5	160.7	158.3	158.5
6	Base metal	82.8	83.3	96.1	87.4
	Heat Affected	115.1	120.1	117.1	117.4
	Fusion	150.9	169.4	162.7	161.0
7	Base metal	106.6	113.5	118.3	112.8
	Heat Affected	123.3	117.0	119.6	120.0
	Fusion	132.9	145.9	139.6	139.5
8	Base metal	107.4	109.3	111.6	109.4
	Heat Affected	117.4	119.4	118.5	118.4
	Fusion	146.6	156.6	148.9	150.7

Table 4.3: Result hardness increment for welded specimens at fusion zone

Specimens	**Zone Area**	**Data Test**	**Percentage Increments, (%)**
1		137.4	20.3
2		148.3	26.2
3		140.5	22.1
4	Fusion	143.8	23.9
5		158.5	31.0
6		161.0	32.0
7		139.5	21.6
8		150.7	27.4

It is important to undergo with a hardness process to analyze the ability of material and to determine between brittle and ductile type. According to (Szwedzicki, 1997) that the hardness test is important to know the ability of a material to hold the loads applied from the elastic-plastic deformation until fracture. This test is to identify the mechanical properties of the base metal, affected zone and weld zone (Cavaliere, 2006). From the result above, it shows that all specimens that having through welding process been having almost the same result. The welded fusion zone is more hard followed by heat affected zone and last is the unaffected zone area. It was proved by (Zhaohua, 2011) where each region of the weld is the influence of the grain for each region which it have varying sizes and influence the hardness value where it is different for each region. Specimen 6 has the hardest result at fusion zone while specimen 1 is the lowest. Hidetoshi also proved that fusion zone will have higher hardness compare with heat affected zone and unaffected zone area. This is because due to different heat input given for specimen 6 and specimen 1 where specimen 6 receive more heat compare to specimen 1. It is proved where heat input was effect the hardness that is based on the parameter setup (Karadeniz, 2007). In overall, this result is significant since it also being proved by Szwedzicki in 1997 where the hardness will be harder at fusion zone following with heat affected zone and last is base metal. This happen because of heat input received by each of the area is different. The fusion zone received the highest heat while base metal is the lowest heat received.

4.4 Tensile Test

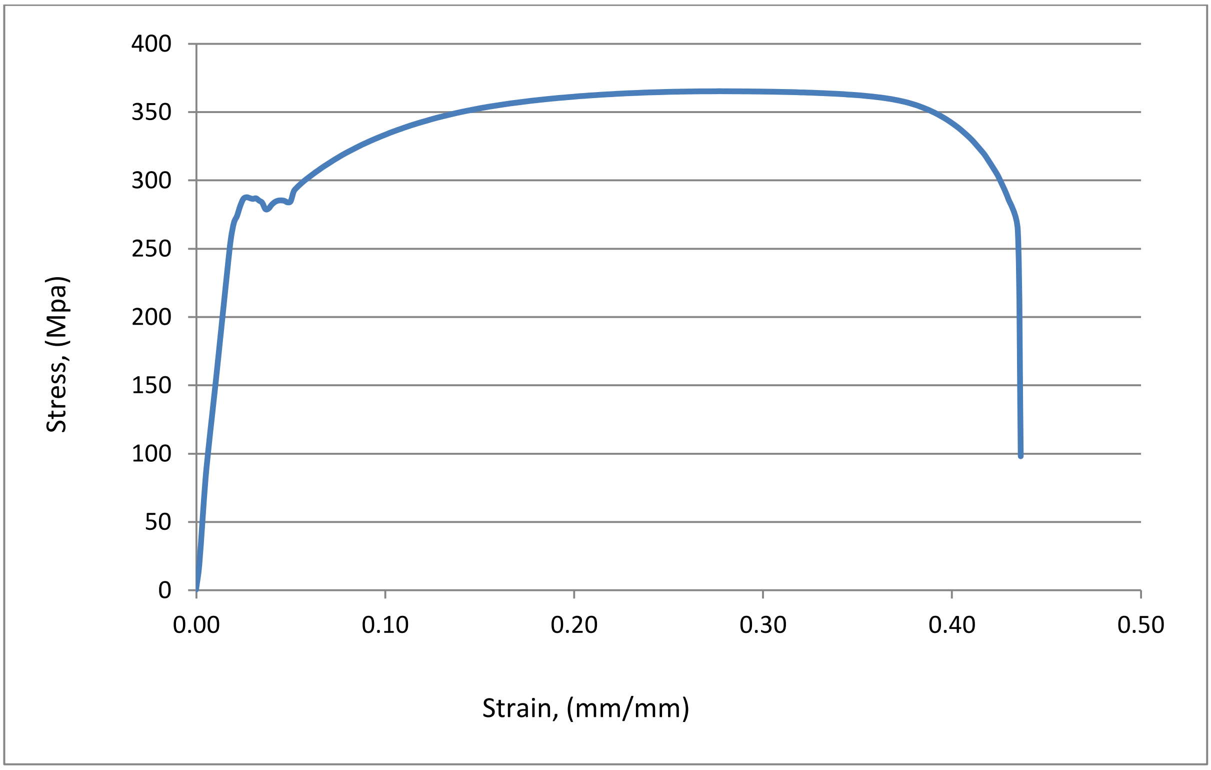

Figure 4.18: Tensile test result as received specimen

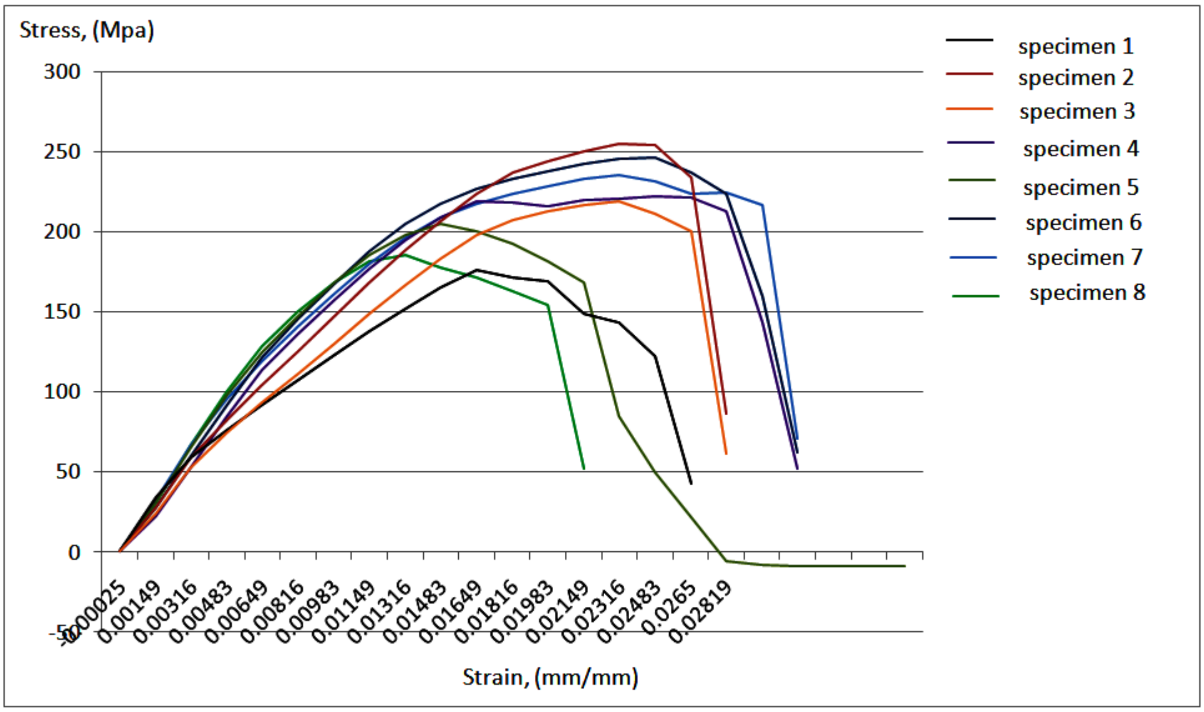

Figure 4.19: Tensile test result for all welded specimen

Table 4.4: Tensile test result for each specimen after welding process

Specimen	Modulus elasticity E (GPa)	Yield strength, σ_y (MPa)	Ultimate tensile strength σ_{UTS} (MPa)	Strain (mm/mm)
Parent	5.0	279	365	0.2765
1	14.7	-	180	0.017
2	16.3	-	261	0.023
3	15.1	-	224	0.023
4	20.2	-	209	0.015
5	18.7	-	227	0.025
6	19.2		252	0.025
7	19.1	-	241	0.023
8	21.5	-	190	0.013

Figure 4.18 and 4.19 shows the result for tensile test for eight specimens after welding which have different parameter setup. Based on the result, it shows that all graph almost having the same travel of graph although it has different results for ultimate tensile strength, stress, strain and break point except a few graph which is graphical for specimen 4 is different. The shape of the graph for all eight specimens is

different from the original specimen in a tensile test. This means that the specimen after welding having a change in yield strength and strength. This because of given a heat process to the material will cause it to change in yield strength, ultimate tensile strength and the stress (Wahab, 1998).

Specimen 5 shows the different result compare to other seven specimens because the result did not show the break point. This is because of influence by the lack of penetration welding. As a result from welding specimen, the specimen 5 penetration is less compared to other specimen and this will cause the welded part easy to break. When the tensile test is running, the machine cannot detect the specimen disconnection due to this reason. This has happened because the parameter speed is high while the voltage and current at low. This causes the specimen did not have much time to penetrate which causing it becomes lack of penetration. One of the other factors is the gap and groove. Gap influence the penetration factor and same goes with the groove. This is proved by (Karadeniz, 2007) where the quality of the weld is based on enough penetration, high heating and right welding profile or not. Wouters also said that the optimum range of gap between two parts of material that are going to be weld will give the maximum weld strength to the specimen. This 3 factor is the major factor to be considered to have a good quality and high strength of the weld. This problem was one of the defects which are inclusions defect. These defects are often associated with undercut because of incomplete penetration and lack of fusion in welds (Sack and Bonhart, 2005). To prevent this from happening, the specimen must be welded in grave condition or have a gap between two parts of the material to be welded.

Based on all result tensile for each specimen, it shows that specimens 2 having the highest ultimate tensile strength which is 261MPa while specimen 1 having the lowest ultimate tensile strength which is 180MPa. Specimen 2 having this result because of a few aspects that influence the result. The aspects are based on the penetration on the specimen. Figure 4.11 shown the penetration for specimen 2 having more depth of penetration compared to other specimens based on the optical measurement view. According to (Messler, 2004), this will make the path to be joint become one through the formation of primary chemical bonds under the combined action of heat and pressure thus affect the quality of welding. The depth of penetration was influenced by the parameters of speed, voltage and current where the speed is of low value while voltage and current in high value. This will give enough time for the party to be joint being enough heating during the welding process thus given more strength to the specimen especially in the fusion zone area. Although the specimen 2 did not have the highest result of the Vickers hardness test at each region, the penetration given more effect to give the highest result on tensile test. The depth is important to the strength to provide a strong strength to the joint part. The highest value of hardness will show the material more brittle which mean the material can easily break or crack. This was proved by (Cavaliere, 2006) with the same meaning of statement. The specimens experienced plasticity deformation where elongation and deformation for each specimen material was not so obvious. This is because the material dislocation is limited due to welding process causing it to be more brittle in the center and easily to disconnect during a tensile test. The strength of material increasing but the ductility will decrease because of hardness material is increased.

Specimen 1 shows the lowest ultimate tensile strength due to the same factor. Based on figure 4.10, the optical measurement view shows that the depth of penetration was less compared to other specimens. This will cause it to have less strength due to bond under the combined action of heat. Specimen 1 was having at low speed, low current and low voltage and based from this parameter, it shows that the heat will be not enough and causes the material did not reach high melting point enough to make sure the welded material is strong enough. Based on specimen 1 on table 4.2 for the Vickers hardness test show that the result was the lowest hardness Vickers compared to other specimens which the infected zone having 105.2HV, heat affected zone is 114.4HV while fusion zone is 137.4HV. This result shows that the hardness is not too strong which it’s more too ductile compared to others specimen. That’s why the result of ultimate tensile strength for specimen 1 was the lowest result. The more heat input given will cause the material to become ductile and cause the hardness more hard (Kaharman, 2007).

The received material was ductile material where it's having elastic deformation before plasticity deformation. According to (Sack and Bonhart, 2005), the ductile material having a stretch by load and finally fracture before the material fail or fracture where the cross section area of the material become decreased. Microstructure for original specimen from figure 4.1 show that the grain size was smaller compared to specimen that having through a welded process that larger grain which proved that the material is more ductile. It also proved by (Calcagnatto,2010) where the original specimen having high yield strength, tensile strength and also high absorption force.

All specimens except original specimen, specimen 1 and specimen 2 was having almost the same travel of the graph for tensile test but different in value for ultimate tensile strength, stress, strain, and the break point. The yield strength result cannot be read or achieved by the machine due to the small value because the specimen test for each specimen cannot hold too long before the break. This is because of the same reason which all welded specimens having a lack of penetration and cause it easily to break.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

Overall, the objectives of this study were achieved through the tests that were carried out with an ultimate tensile strength value, the stress and strain value, and hardness values for each of the experimental material specimens after the welding process. Several conclusions can be made through this study is the microstructure grains of the original material will deform thus make it harder and brittle especially in the fusion zone. The cross section view of welded specimen optical measurement shows the penetrated of the fusion part which the deepest depth of penetration will increase the strength of the joint. Through the hardness process, the fusion given the hardest value following with the heat affected zone and the last is unaffected zone. The hardest will cause it to be more brittle but having a high strength material. Based on tensile test for each of the welded specimens, it can be concluded that the specimen becomes more easily disconnect or break because of lacking penetration. The average of ultimate tensile strength of welding specimen is 223 MPa which is low compare to as receive specimen. This is means the welded specimen is less strength compared to with a receive specimen because of fusion zone is more brittle which caused it a high strength but lack of penetration. The suitable can be chosen as the best parameter to be welded base on this research is a parameter for specimen 2 which it has low speed and low voltage but high current.

5.2 Recommendations

A list of recommendations for this research area:

(i) Conducting a research on the analysis of the welding part which there is a gap or groove between two parts of the material to be joined.

(ii) Conduct a welding research with different grade of steel material that's going to be welded.

(iii) Study and analyze the effect of welding process by using other parameters which are used varies angle of torch, welding pass, feed rate and type of joint.

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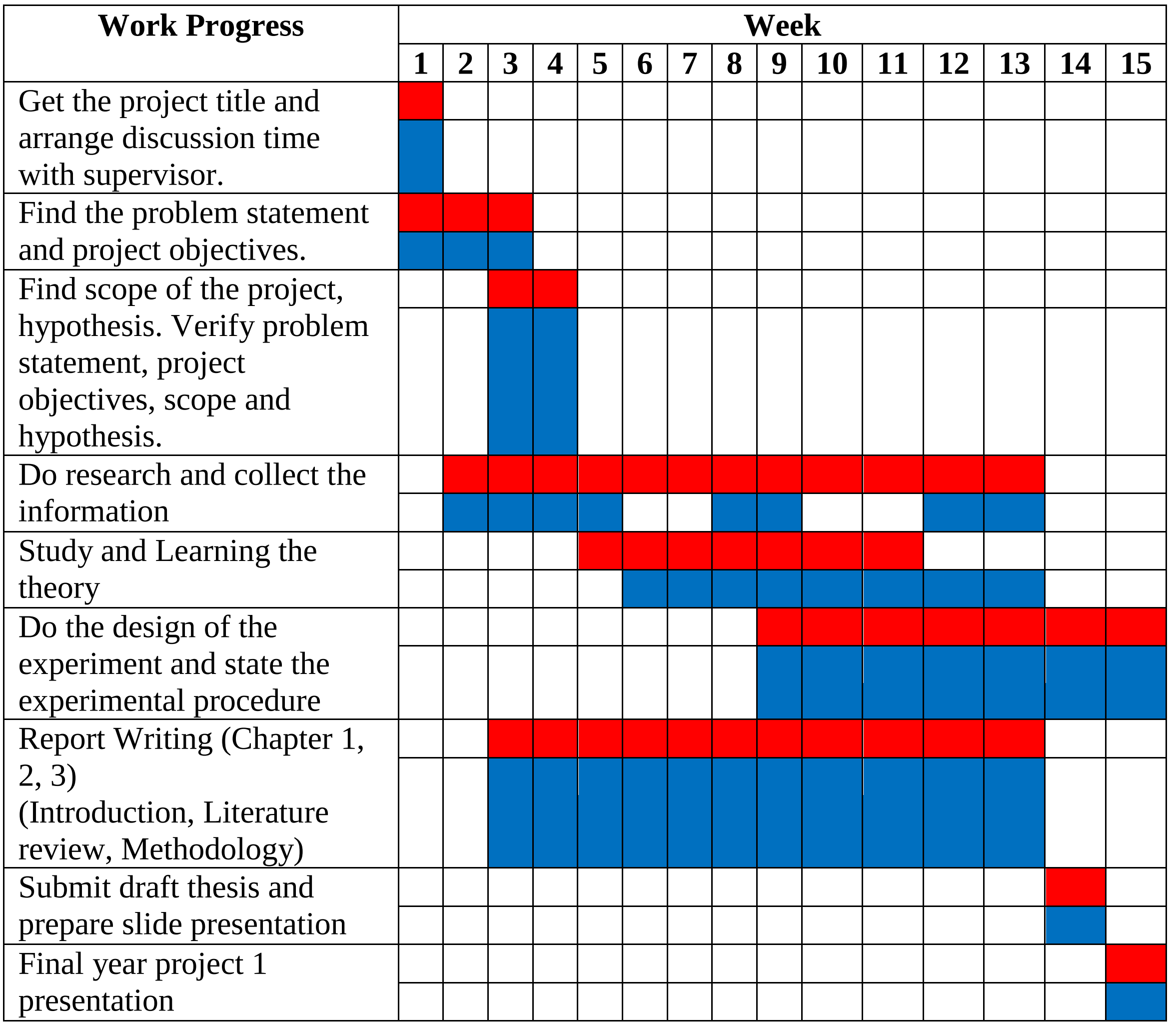
APPENDIX A

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 1

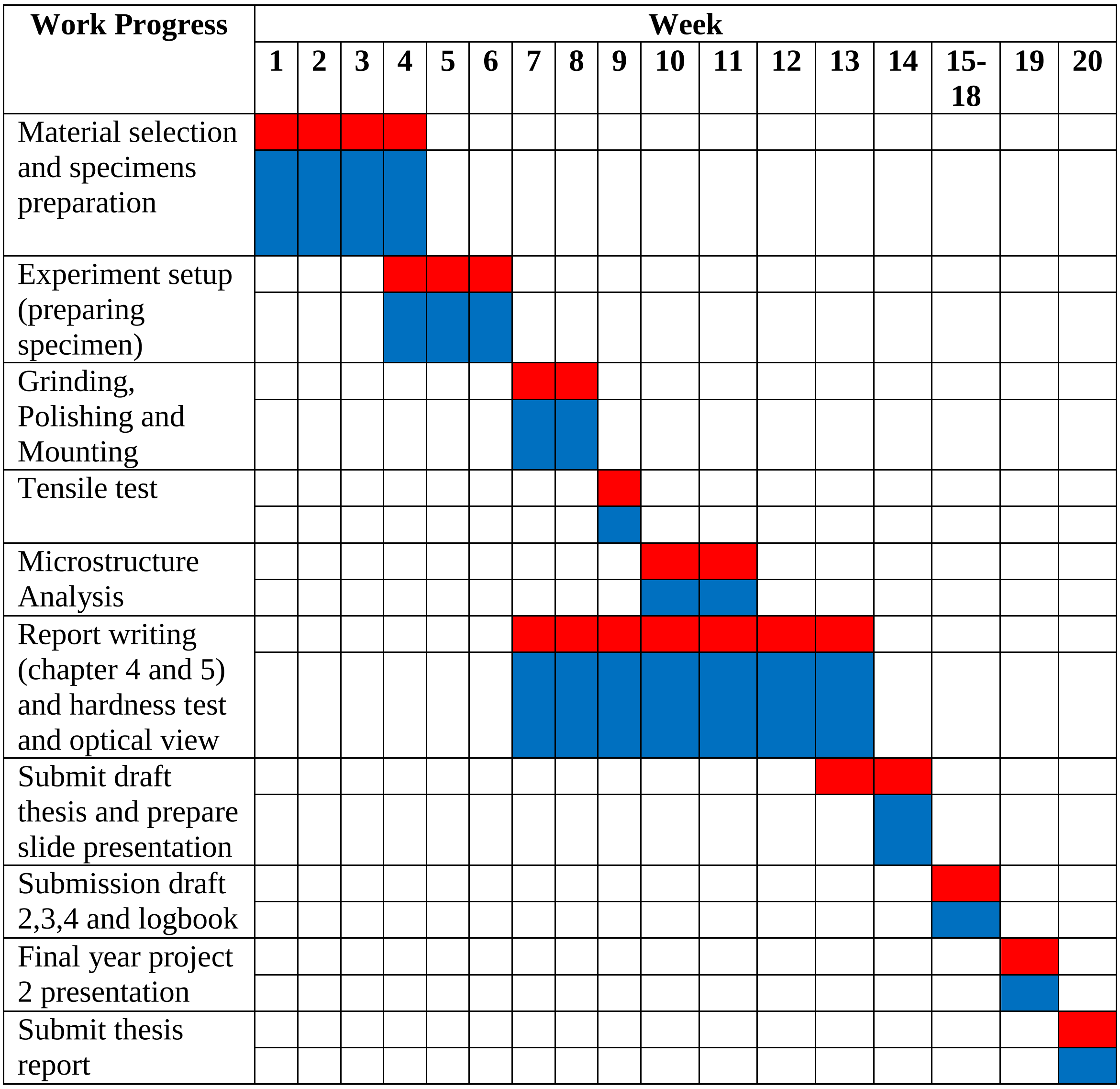


Remark:

Planning progress

Actual progress

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 2



Remark:

Planning progress

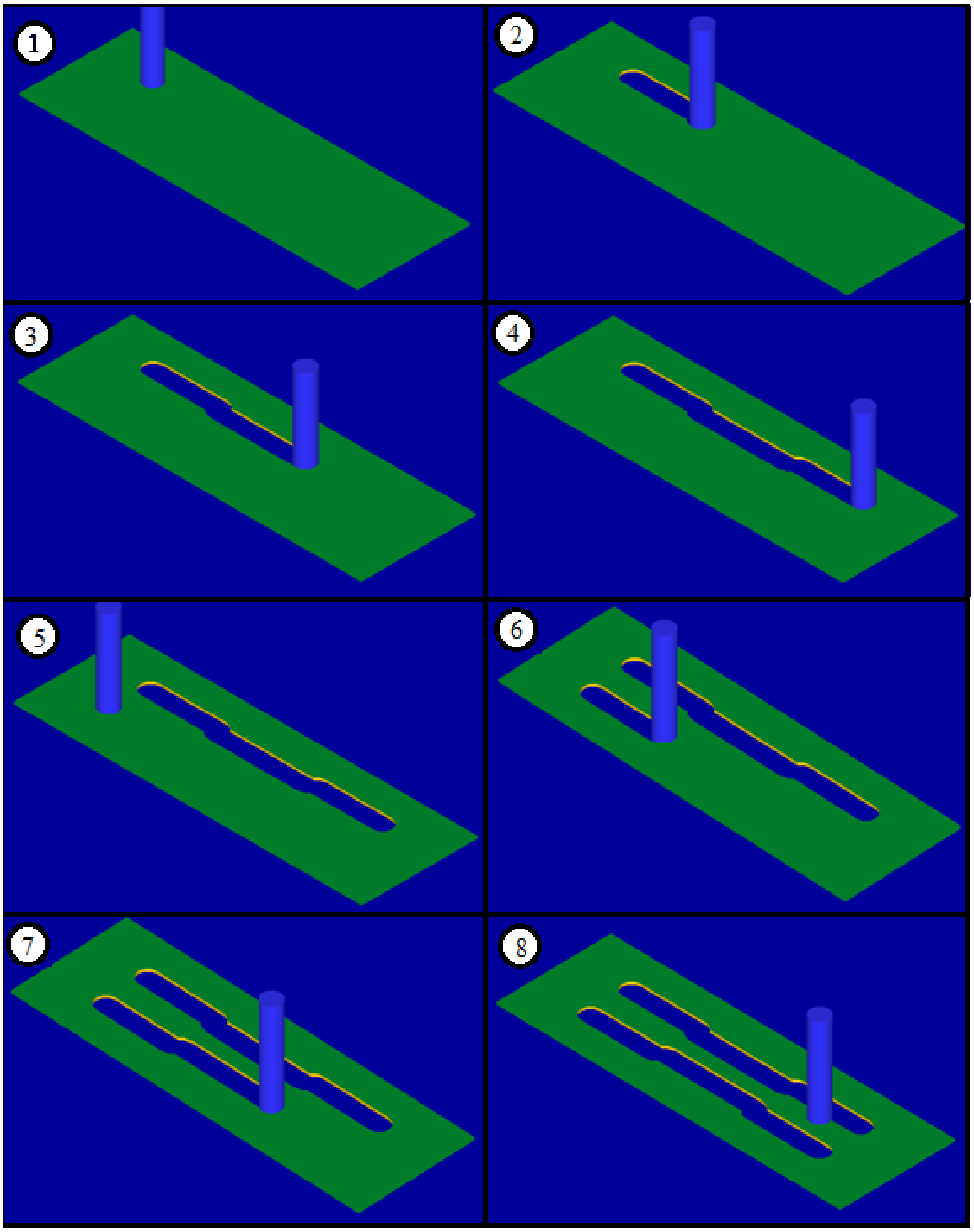
Actual progress

APPENDIX B

CNC Milling Process G-CODE using Programme

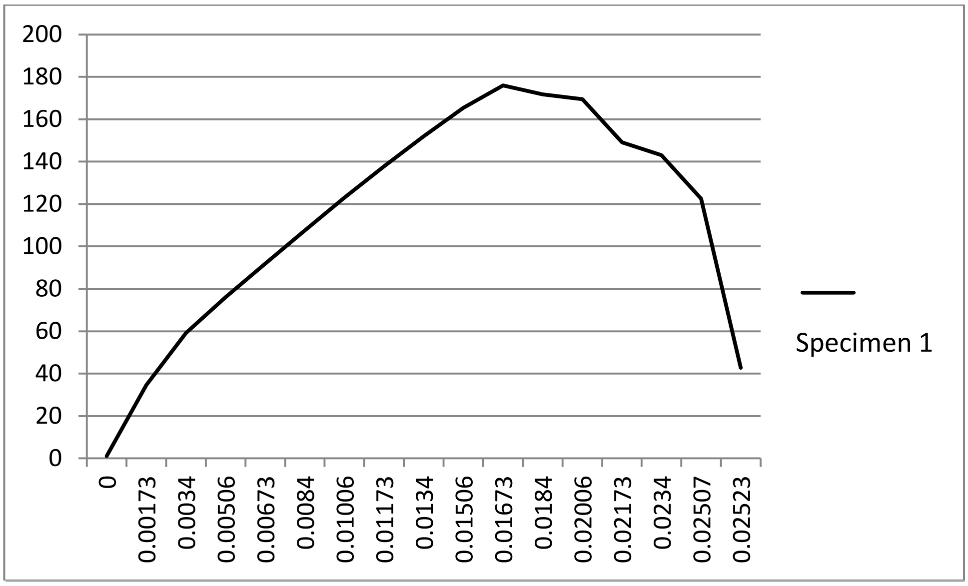
```
O0000(G CODE T BONE ST 3)
(DATE=DD-MM-YY - 26-01-12 TIME=HH:MM - 11:08)
(MCX FILE - F:\T-BONE PSM\T-BONE STAINLESS STEEL.MCX-5)
(NC FILE - C:\USERS\PTMK\DESKTOP\T-BONE PSM\G CODE T BONE ST 3.NC)
(MATERIAL - STAINLESS STEEL)
( T1 |     16. FLAT ENDMILL | H1 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
N104 T1 M6
N106 G0 G90 G54 X-100. Y18. A0. S900 M3
N108 G43 H1 Z25. M8
N110 Z5.
N112 G1 Z-2.5 F10.
N114 X-42.85 F40.
N116 X-40.513 Y15.692
N118 G3 X-37. Y14.25 R5.
N120 G1 X37.
N122 G3 X40.513 Y15.692 R5.
N124 G1 X42.85 Y18.
N126 X100.
N128 G0 Z25.
N130 X-100. Y-18.
N132 Z5.
N134 G1 Z-2.5 F10.
N136 X-42.85 F40.
N138 X-40.513 Y-15.692
N140 G2 X-37. Y-14.25 R5.
N142 G1 X37.
N144 G2 X40.513 Y-15.692 R5.
N146 G1 X42.85 Y-18.
N148 X100.
N150 G0 Z25.
N152 M5
N154 G91 G28 Z0. M9
N156 G28 X0. Y0. A0.
N158 M30
```

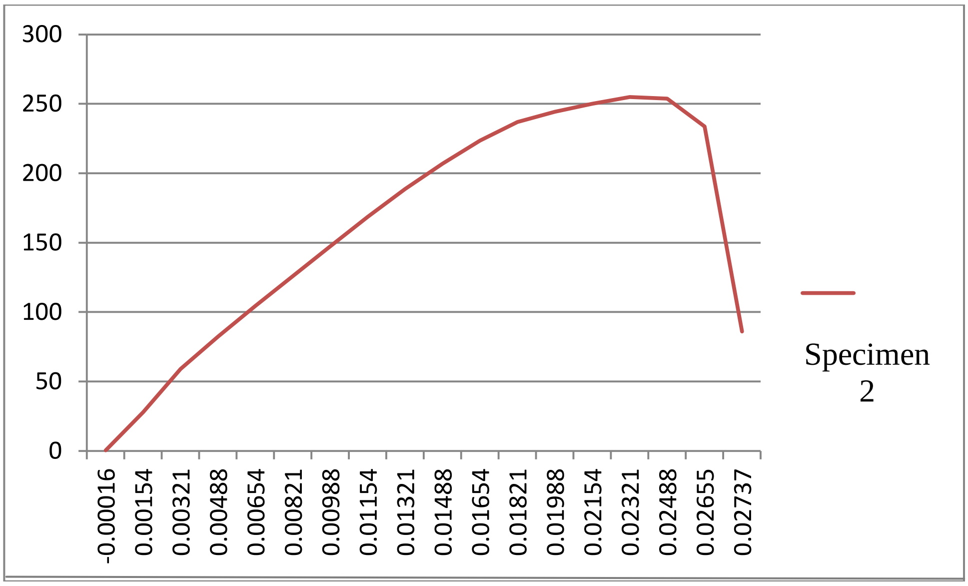
CNC Milling Process Simulation using Mastercam's

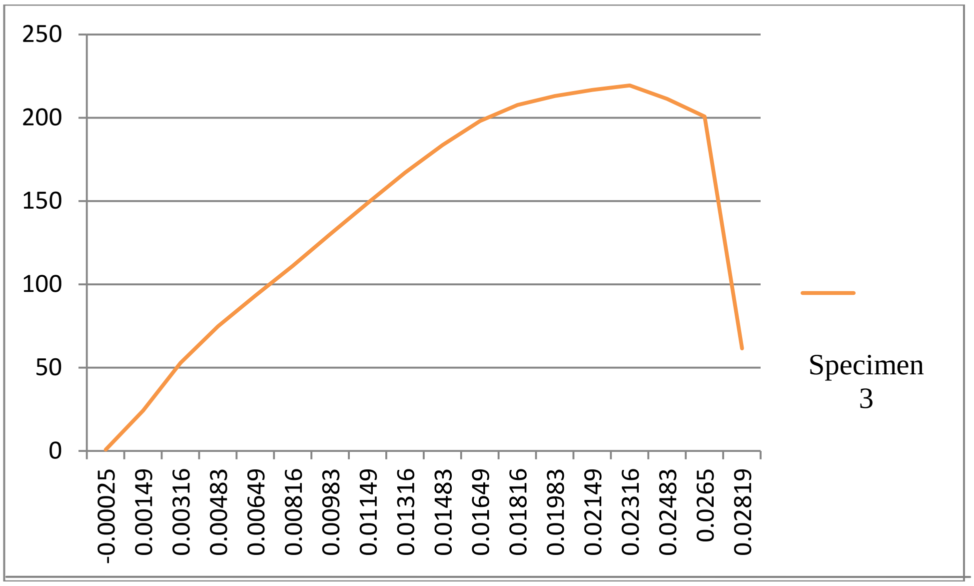


APPENDIX C

Tensile test result for each welded specimens



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200
150
100
50
0
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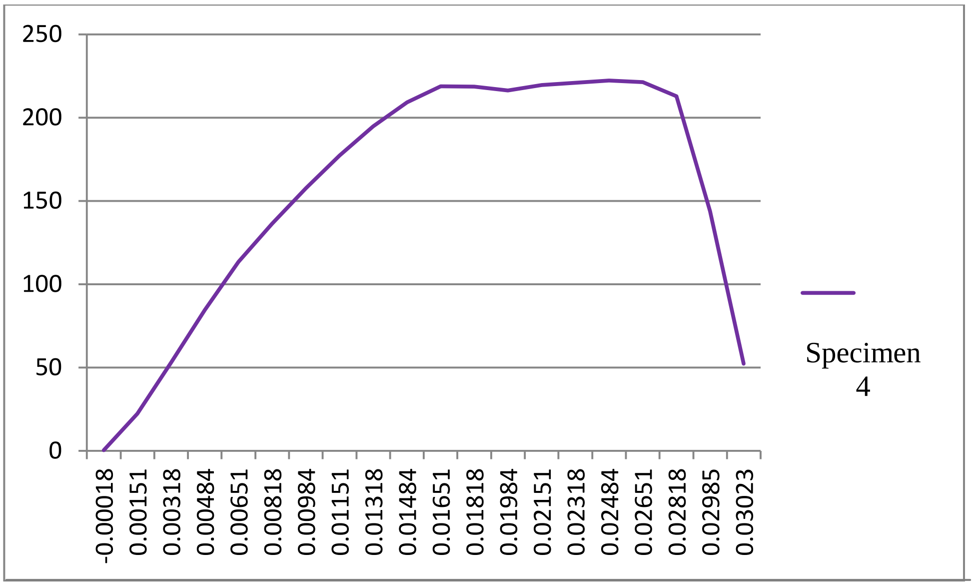
0.00149
0.00316
0.00483
0.00649
0.00816
0.00983
0.01149
0.01316
0.01483
0.01649
0.01816
0.01983
0.02149
0.02316
0.02483
0.0265
0.02819
Specimen 3


250
200
150
100
50
0
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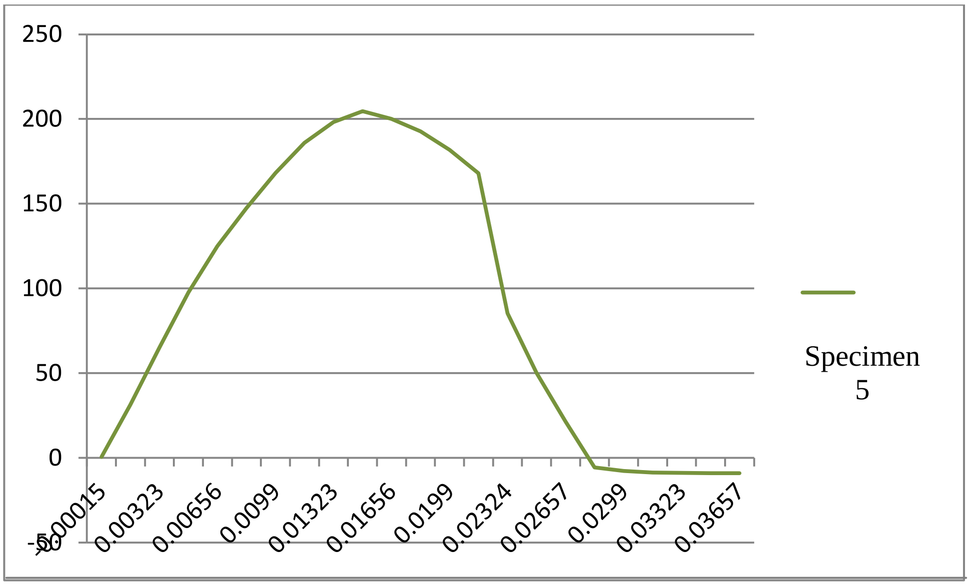
0.00151
0.00318
0.00484
0.00651
0.00818
0.00984
0.01151
0.01318
0.01484
0.01651
0.01818
0.01984
0.02151
0.02318
0.02484
0.02651
0.02818
0.02985
0.03023
Specimen 4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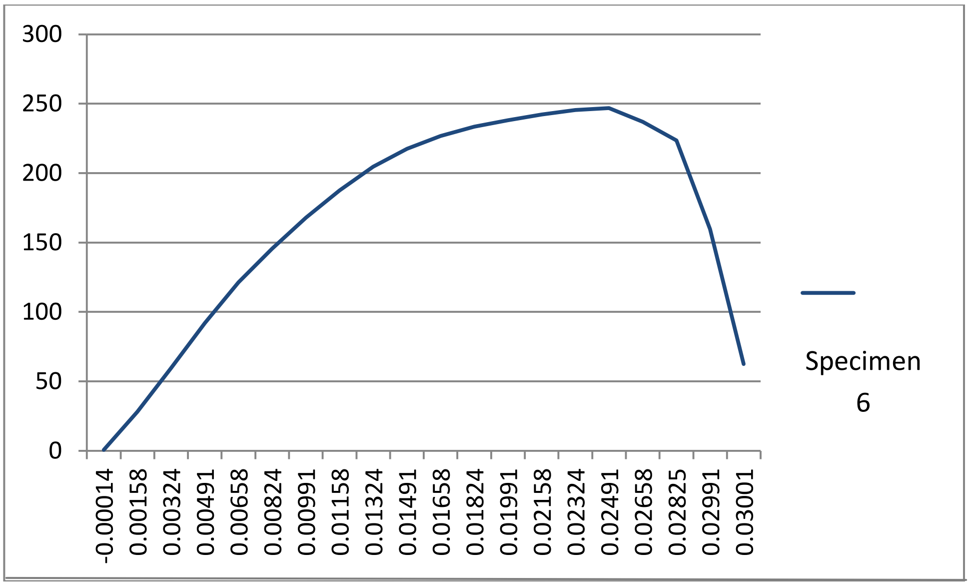
200
150
100
50
0
-50
-0.00015
0.00323
0.00656
0.0099
0.01323
0.01656
0.0199
0.02324
0.02657
0.0299
0.03323
0.03657
Specimen 5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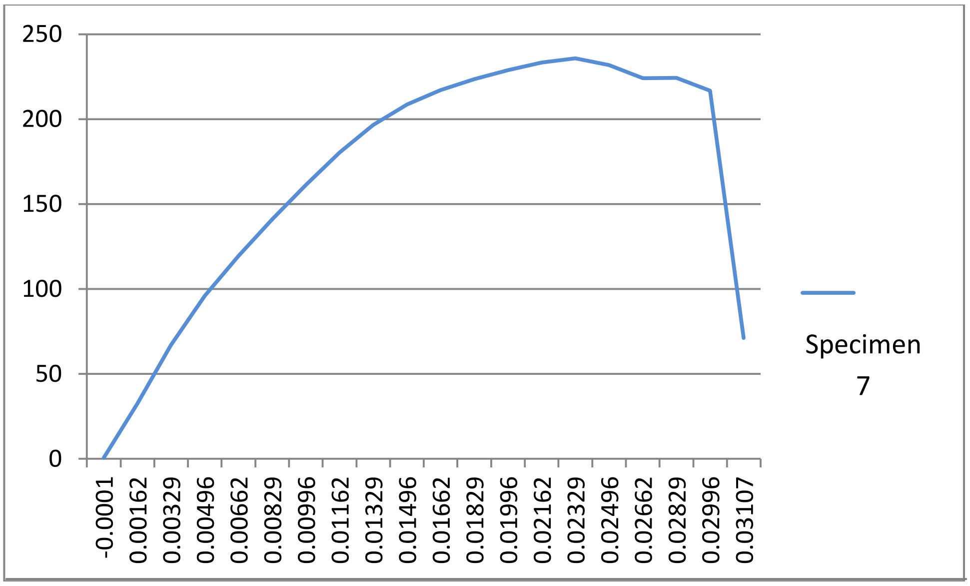
250
200
150
100
50
0
-0.00014
0.00158
0.00324
0.00491
0.00658
0.00824
0.00991
0.01158
0.01324
0.01491
0.01658
0.01824
0.01991
0.02158
0.02324
0.02491
0.02658
0.02825
0.02991
0.03001
Specimen 6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200
150
100
50
0
-0.0001
0.00162
0.00329
0.00496
0.00662
0.00829
0.00996
0.01162
0.01329
0.01496
0.01662
0.01829
0.01996
0.02162
0.02329
0.02496
0.02662
0.02829
0.02996
0.03107
Specimen 7


200
180
160
140
120
100
80
60
40
20
0
-0.00021
0.00151
0.00318
0.00485
0.00651
0.00818
0.00985
0.01151
0.01318
0.01485
0.01651
0.01818
0.01985
0.02102
Specimen 8