The Effect of Current to Hardness, Microstructure and Toughness in Shielded Metal Arc Welding of Carbon Steel and Stainless Steel 304

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CERTIFICATION OF APPROVAL

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Approved

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CERTIFICATION OF ORIGINALITY

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

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(MUHAMMAD ZHARIF BIN ABD RAZAK)

ABSTRACT

This is a research on studying the effect of current towards mechanical properties in welding of carbon steel and stainless steel with shield metal arc welding. Mechanical properties consists of hardness, microstructure, and impact toughness. The data of the properties can be obtained from several testing procedure which are specifically designed for it. The test that going to be conducted are tensile test, hardness test, and microstructure. As from the study, the author has decided the current to start the experiment. As for this research, it will be for 2 main materials in the industry which is carbon steel and stainless steel and the result of this research will be very useful to the manufacturing industry.

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CHAPTER 1
INTRODUCTION

1.1 Background of study.

In manufacturing, welding is one of the important process. It is used widely to join metals using metals or using fillers. There are many types of welding such as Arc Welding, Metal Inert Gas Welding (MIG Welding), Oxy-acetylene welding, Tungsten Inert Gas Welding (TIG Welding), Laser Welding, and Friction Welding.

Arc welding has been widely used to produce a good joint. In this paper, the research will focus on a type of arc welding which is Shielded Metal arc Welding (SMAW) to joint two different metals which is steel and stainless steel.

1.2 Problem statement

Welding two different metals such as steel and stainless steel also can be difficult and some of the problem in welding industries is cracking and to prevent corrosion resistance. Due to **limited knowledge in effect of current towards the weld**, the task is to analyse the effect of different current towards the weld and the effects towards its impact strength, hardness and microstructure.

1.3 Objectives

The objectives of this research is as follows.

i) To investigate the mechanical properties of the welded joint part using SMAW between steel and stainless steel.

ii) To investigate the effect of current towards the weld

1.4 Scope of research

The scope of this research is mainly doing a laboratory experiments and it is focused to Shielded Metal Arc Welding (SMAW). The scope for the materials is carbon steel and stainless steel. The test that is going to be conducted is hardness test, tensile test and microstructure test.

CHAPTER 2

LITERATURE REVIEW

2.1 Type of Welding

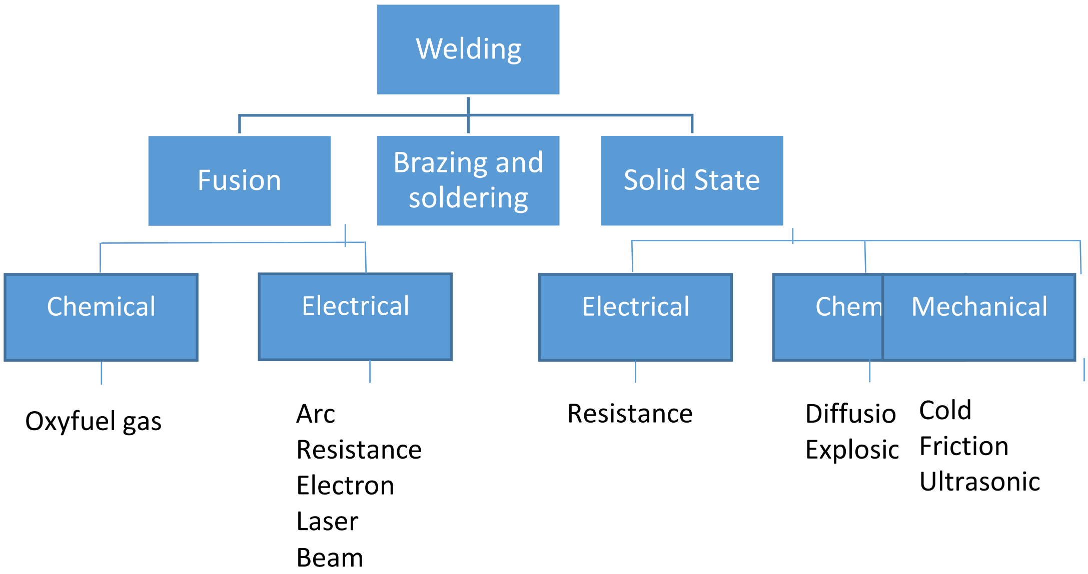

Figure 1 : Type of Welding (Kalpakjian, 2010)

As can be seen in the table above, welding are generally classified into three basic categories:

- Fusion Welding
- Solid-state Welding
- Brazing and Soldering

Fusion welding can be defines as the melting together and coaslescing of materials by means of heat, usually supplied by chemicals or electrical means; filler metals may or may not be used. In solid-state welding, joining takes place without fusion; consequently, there is no liquid (molten) phase in the joint. The basic processes in this category are diffusion bonding and cold, ultrasonic, friction, resistance, and explosion welding. Brazing uses filler metals and involves lower temperatures than welding. Soldering uses similar filler metals (solders) and involves even lower temperatures. (1)

2.1.1 Oxyfuel gas welding

Oxyfuel gas welding is the type of chemical welding in fusion welding. Oxyfuel-gas welding (OFW) is a general terminology used to describe any welding process that uses a fuel gas combined with oxygen to generates a flame. The flame is the source of the heat that is used to melt the metals at the joint. The most common gas welding process uses acetylene; the process is known as oxyacetylene-gas welding (OAW) and it is used for structural metal fabrication and repair work.

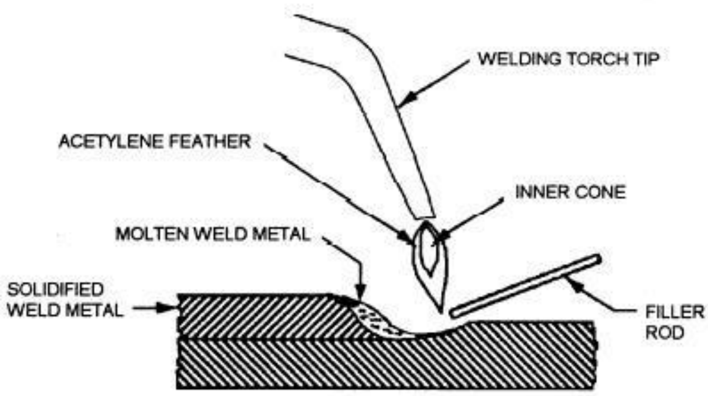

Figure 2: Oxyfuel gas welding (Kalpakjian, 2010)

2.1.2 Arc Welding Process

Arc welding process in mainly divided into 2 categories which is:

- Non-consumable electrodes
- Consumable electrodes

2.1.2.1 Non Consumables Electrode

In nonconsumable-electrode welding processes, the electrode is typically a tungsten electrode. Because of the high temperatures involved, an externally supplied shielding gas is necessary to prevent oxidation of the weld zone. Typically, DC (direct current) is used, and its polarity (the direction of current flow) is important. The selection of current levels depends on such factors as the type of electrode, metals to be welded, and depth and width of the weld zone.

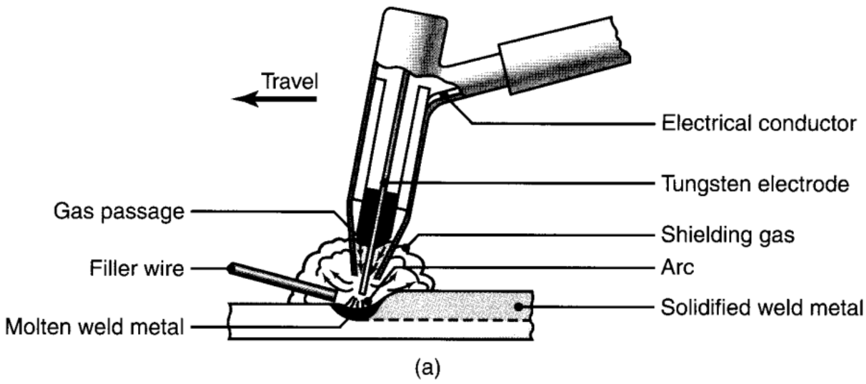

Figure 3: Tungsten Arc Welding Process Schematic drawing (Kalpakjian, 2010)

2.1.2.2 Consumables Electrode

Shielded Metal-arc Welding

In this project, the author will focus on this part of welding. Shielded metal-arc welding (SMAW) is one of the oldest, simplest, and most versatile joining processes. About 50% of all industrial and maintenance welding currently is performed by this process. The electric arc is generated by touching the tip of a coated electrode against the workpiece and withdrawing it quickly to a distance sufficient to maintain the arc. The electrodes are in the shapes of thin, long rods (hence, this process also is known as stick welding) that are held manually.

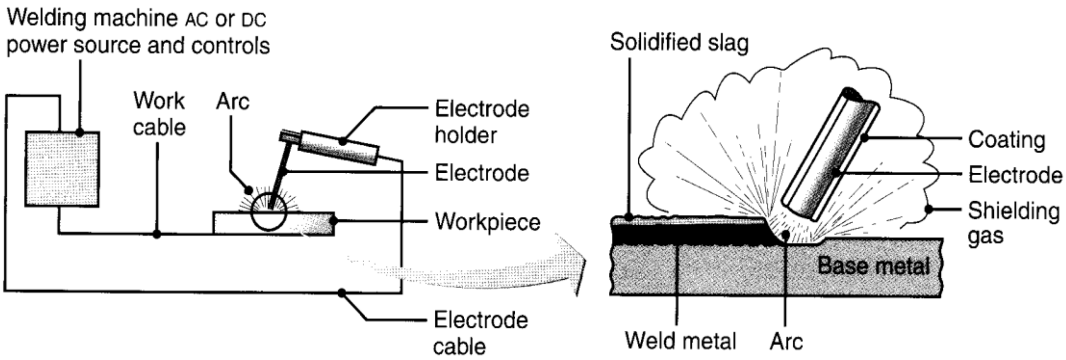

Figure 4: Schematic illustration of the shielded metal-arc welding process. (Kalpakjian, 2010)

The SMAW process has the advantages of being relatively simple, versatile, and does not require a huge variety of electrodes. The equipment consists of a power supply, cables, and an electrode holder. The SMAW process commonly is used in general construction, shipbuilding, pipelines, and maintenance work.

2.2 The Weld joint, Quality, and Testing

Three distinct zones can be identified in a typical weld joint, as shown in Fig.

i) Base metal
ii) Heat-affected zone
iii) Weld metal.

The metallurgy and properties of the second and third zones depend strongly on the type of metals joined, the particular joining process, the filler metals used (if any), and welding process variables. A joint produced without a filler metal is called autogenous, and its weld zone is composed of the resolidified base metal. A joint made with a filler metal has a central zone called the weld metal and is composed of a mixture of the base and the filler metals.

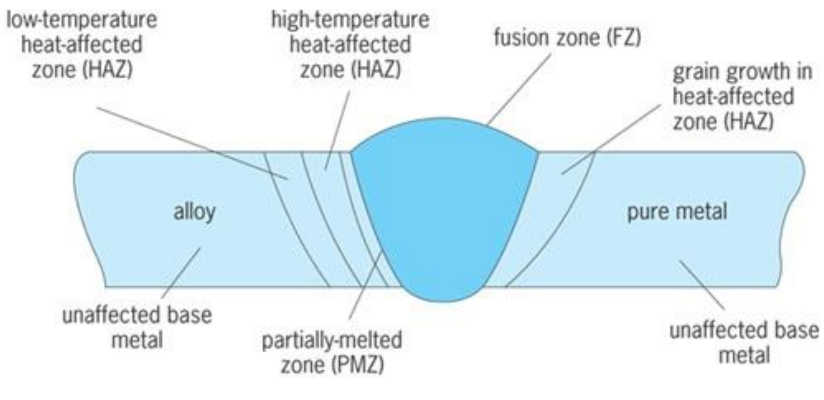

Figure 5: Distinct zones of Weld Joints (Kalpakjian, 2010)

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Heat-affected Zone.

The heat-affected zone (HAZ) is within the base metal itself. It has a microstructure different from that of the base metal prior to welding, because it has been temporarily subjected to elevated temperatures during welding. The portions of the base metal do not undergo any microstructural changes during welding as they are far enough away from the heat source and far lower temperature to which they are subjected.

The properties and microstructure of the HAZ depend on:

(a) The rate of heat input and cooling and

(b) The temperature to which this zone was raised. In addition to metallurgical factors (such as the original grain size, grain orientation, and degree of prior cold work), physical properties influence the size and characteristics of the HAZ.

The microstructures of weld metal (WM) and parent metal (PM) is known that it undergoes considerable changes because of the heating and cooling cycle of a welding process, e.g. as discussed in Gunaraj and Murugan (2002) [6]. To reveal the heat-affected zone (HAZ) around a weld, hardness measurement, metallographic and electrochemical etching techniques have been commonly used. For instance, Huang et al. (2005) [7] investigated the HAZ in an Inconel 718 sheet using those aforementioned methods. It has been found that the hardness measurement is simple and effective as it clearly shows the hardness variations around the weld and HAZ. A welding process usually reduces the hardness, and impairs the strength and fatigue behaviour of a welded structure.

2.3 Testing of Welds

As in all manufacturing processes, the quality of a Welded joint is established by testing several standardized tests and test procedures that have been established. They are available from many organizations, such as the American Society for Testing and Materials (ASTM), the American Welding Society (AWS), the

American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), and various federal agencies. Welded joints may be tested in laboratory either destructively or non-destructively. Each technique has certain capabilities and limitations, as well as sensitivity, reliability, and requirements for special equipment and operator skill. [1]

The testing technique can be categorized into:

i) Destructive

ii) Non-destructive

2.3.1 Destructive

- *Tension test*: Longitudinal and transverse tension tests are performed on specimens removed from actual welded joints and from the Weld-metal area. Stress-strain curves are then obtained. These curves indicate the yield strength, Y, ultimate tensile strength, UTS, and ductility of the Welded joint (elongation and reduction of area) in different locations and directions.

- *Tension-shear test*: The specimens in the tension-shear test are prepared to simulate conditions to which actual Welded joints are subjected. These specimens are subjected to tension so that the shear strength of the weld metal and the location of fracture can be determined.

- *Bend test*: Several bend tests have been developed to determine the ductility and strength of welded joints. In one common test, the welded specimen is bent around a fixture in another test, the specimens are tested in three-point transverse bending. These tests help to determine the relative ductility and strength of welded joints.

- *Fracture toughness test*: Fracture toughness tests commonly utilize the impact-testing techniques described in Section 2.9. Charpy V-notch specimens are first prepared and then tested for toughness. Another toughness test is the dropweight test, in which the energy is supplied by a falling weight.

- *Corrosion and creep tests*: In addition to undergoing mechanical tests, welded joints also may be tested for their resistance to corrosion and creep. Because of the difference in the composition and microstructure of the materials in the weld zone, preferential corrosion may take place in the zone. Creep tests are important in determining the behavior of welded joints and structures subjected to elevated temperatures.

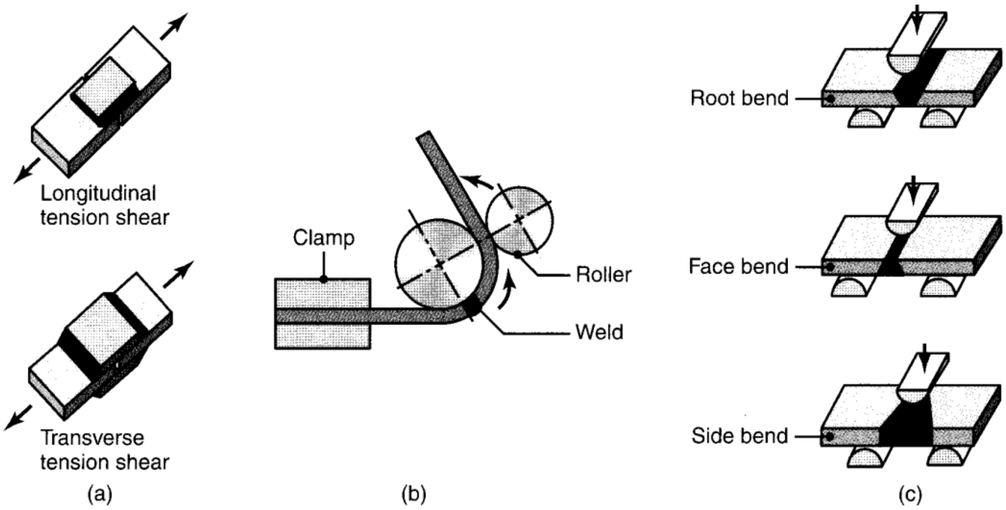


Figure 6: Several destructive test (Kalpakjian, 2010)

2.3.2 Nondestructive Testing Techniques.

Welded structures often have to be tested nondestructively, particularly for critical applications in which weld failure can be catastrophic, such as in pressure vessels, load-bearing structural members, and power plants. Nondestructive testing techniques for welded joints generally consist of the following methods:

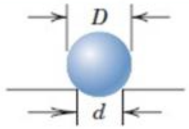
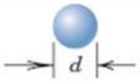
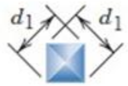
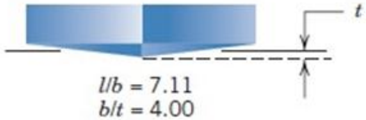
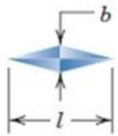
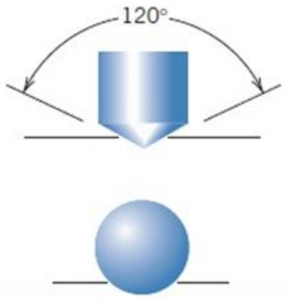
- Visual
- Radiographic (X-rays)
- Magnetic-particle
- Liquid-penetrant
- Ultrasonic.

Testing for hardness distribution in the weld zone may be a useful indicator of weld strength and microstructural changes. There is some standards of hardness test that can be used in this research. By definition, hardness, which is a measure of a material’s resistance to localized plastic deformation (e.g., a small dent or a scratch). (William D. Callister, Jr., 2007)[2]

Hardness tests are performed more frequently than any other mechanical test for several reasons:

1. They are simple and inexpensive - ordinarily no special specimen need be prepared, and the testing apparatus is relatively inexpensive.
2. The test is non-destructive - the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.
3. Other mechanical properties often may be estimated from hardness data, such as tensile strength.

Some of the hardness test can be summarized in the table below:

Test	Indenter	Shape of Indentation: Side View	Shape of Indentation: Top View	Load	Formula for Hardness Number[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$HK = 14.2P/l^2$
Rockwell and Superficial Rockwell	Diamond cone; $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in. diameter steel spheres			60 kg, 100 kg, 150 kg — Rockwell 15 kg, 30 kg, 45 kg — Superficial Rockwell	

[a] For the hardness formulas given, P (the applied load) is in kg, while D, d, d_1, and l are all in mm.

Figure 7: Summary of hardness test (Kalpakjian, 2010)

2.3.2.1 Rockwell Hardness Tests

The Rockwell tests constitute the most common method used to measure hardness because they are so simple to perform and require no special skills. Several different scales may be utilized from possible combinations of various indenters and different loads, which permit the testing of virtually all metal alloys (as well as some polymers). Indenters include spherical and hardened steel balls having diameters of and in. (1.588, 3.175, 6.350, and 12.70 mm), and a conical diamond (Brale) indenter, which is used for the hardest materials.

With this system, a hardness number is determined by the difference in depth of penetration resulting from the application of an initial minor load followed by a larger major load; utilization of a minor load enhances test accuracy. On the basis of the magnitude of both major and minor loads, there are two types of tests: Rockwell and superficial Rockwell. For Rockwell, the minor load is 10 kg, whereas major loads are 60, 100, and 150 kg. Each scale is represented by a letter of the alphabet; several are listed with the corresponding indenter and load. For superficial tests, 3 kg is the minor load; 15, 30, and 45 kg are the possible major load values. These scales are identified by a 15, 30, or 45 (according to load), followed by N, T, W, X, or Y, depending on indenter. Superficial tests are frequently performed on thin specimens. Table below presents several superficial scales. When specifying Rockwell and superficial hardnesses, both hardness number and scale symbol must be indicated. The scale is designated by the symbol HR.

Rockwell Hardness Scales

Scale Symbol	*Indenter*	*Major Load (kg)*
A	Diamond	60
B	$\frac{1}{16}$-in. ball	100
C	Diamond	150
D	Diamond	100
E	$\frac{1}{8}$-in. ball	100
F	$\frac{1}{16}$-in. ball	60
G	$\frac{1}{16}$-in. ball	150
H	$\frac{1}{8}$-in. ball	60
K	$\frac{1}{8}$-in. ball	150

Figure 8: Rockwell Hardness Scales (Kalpakjian, 2010)

Superficial Rockwell Hardness Scales

Scale Symbol	*Indenter*	*Major Load (kg)*
15N	Diamond	15
30N	Diamond	30
45N	Diamond	45
15T	$\frac{1}{16}$-in. ball	15
30T	$\frac{1}{16}$-in. ball	30
45T	$\frac{1}{16}$-in. ball	45
15W	$\frac{1}{8}$-in. ball	15
30W	$\frac{1}{8}$-in. ball	30
45W	$\frac{1}{8}$-in. ball	45

Figure 9: Superficial Rockwell Hardness Scales (Kalpakjian, 2010)

2.3.2.2 Brinell Hardness Tests

In Brinell tests, as in Rockwell measurements, a hard, spherical indenter is forced into the surface of the metal to be tested. The diameter of the hardened steel (or tungsten carbide) indenter is 10.00 mm (0.394 in.). Standard loads range between 500 and 3000 kg in 500-kg increments; during a test, the load is maintained constant for a specified time (between 10 and 30 s). Harder materials require greater applied loads. The Brinell hardness number, HB, is a function of both the magnitude of the load and the diameter of the resulting indentation. This diameter is measured with a special low-power microscope, utilizing a scale that is etched on the eyepiece. The measured diameter is then converted to the appropriate HB number using a chart; only one scale is employed with this technique. Semiautomatic techniques for measuring Brinell hardness are available. These employ optical scanning systems consisting of a digital camera mounted on a flexible probe, which allows positioning of the camera over the indentation. Data from the camera are transferred to a computer that analyzes the indentation, determines its size, and then calculates the Brinell hardness number. For this technique, surface finish requirements are normally more stringent that for manual measurements.

Maximum specimen thickness as well as indentation position (relative to specimen edges) and minimum indentation spacing requirements are the same as for Rockwell tests. In addition, a well-defined indentation is required; this necessitates a smooth flat surface in which the indentation is made.

2.3.2.3 Knoop and Vickers Microindentation Hardness Tests

Two other hardness-testing techniques are Knoop and Vickers (sometimes also called diamond pyramid). For each test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g. The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number (Table 6.5). Careful specimen surface preparation (grinding and polishing) may be necessary to ensure a well-defined indentation that may be accurately measured. The Knoop and Vickers hardness numbers are designated by HK and HV, respectively, and hardness scales for both techniques are approximately equivalent. Knoop and Vickers are referred to as microindentation -testing methods on the basis of indenter size. Both are well suited for measuring the hardness of small, selected specimen regions; furthermore, Knoop is used for testing brittle materials such as ceramics.

Svensson L.E. and B. Greteoft [9] has done some research on the effect of impact toughness towards the weld. Two longitudinal all-weld-metal tensile specimens (10 mm/0.4 in. in diameter) and 25 Charpy V-notch impact specimens were taken from each weld. The specimens were taken from the middle of the plate. The impact toughness was tested at five different temperatures, with five specimens tested at each temperature. The microstructures of the weld metals were examined by conventional metallography, using light optical microscopy. The etching was made using first a solutionof 4% picric acid in

2.4 Theory of Steel

Figure 10: Steel Plate and atomic structure of carbon steel (Lansky,2013)

Steel is an alloy of iron and other elements, including carbon. When carbon is the primary alloying element, its content in the steel is between 0.002% and 2.1% by weight. The following elements are always present in steel: carbon, manganese, phosphorus, sulphur, silicon, and traces of oxygen, nitrogen and aluminium. At both room temperature and elevated temperature, the material characteristics of stainless steel differ from those of carbon steel due to the high alloy content. At room temperature, stainless steel displays a more rounded stressstrain response than carbon steel and no sharply defined yield point, together with a higher ratio of ultimate-to-yield stress and greater ductility. At elevated temperatures stainless steel generally exhibits better retention of strength and stiffness in comparison to carbon steel. (L. Gardner et. al, 2009).(8)

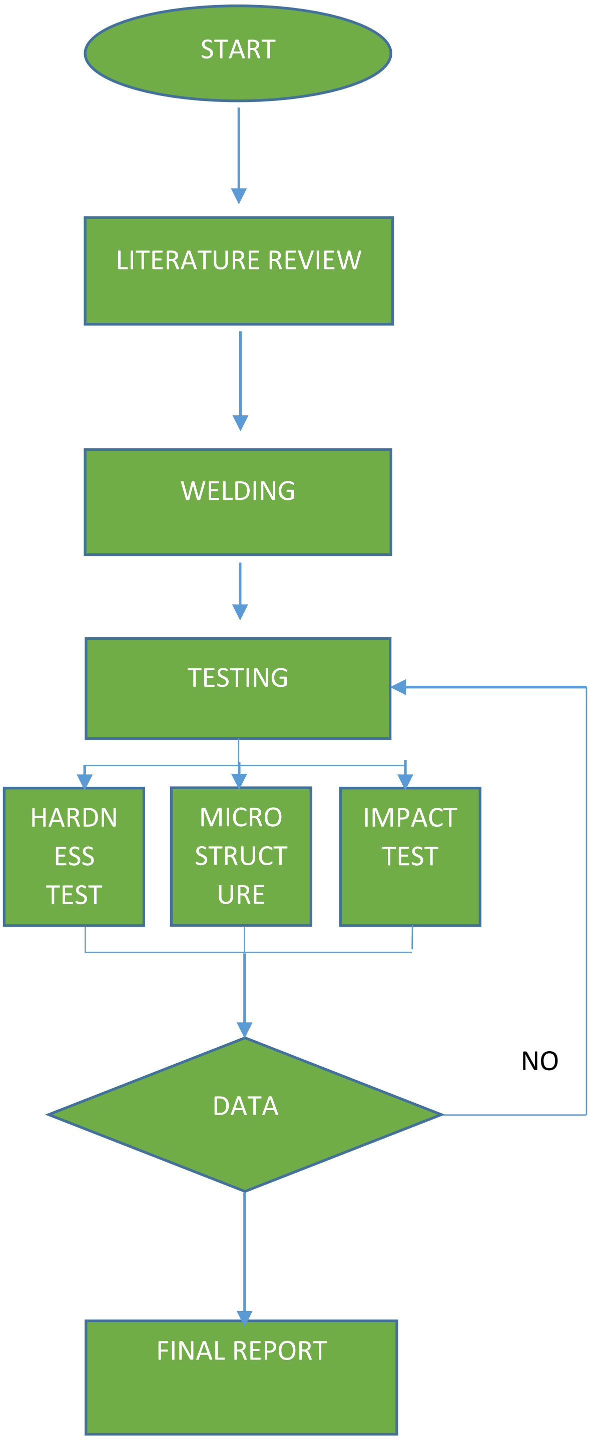
2.5 Theory of Stainless Steel

Stainless steel is the term used to describe an extremely versatile family of engineering materials, which are selected primarily for their corrosion and heat resistant properties In metallurgy, stainless steel, also known as inox steel or inox from French "*inoxydable*", is a steel alloy with a minimum of 10.5% to 11% chromium content by mass. (11)

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low oxygen, high salinity, or poor circulation environments.[3] It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and resistance to corrosion are required.

CHAPTER 3
METHODOLOGY

3.1 Project Flow



- Preview / Problem Analysis
- Studying the welding methods
- Review of what people has done on this topic from journals and books.

- Weld stainless steel and carbon steel using SMAW

- Four samples of the welded materials will be prepared for, hardness, microstructure and impact test.
- The results of the experiments will be validated from the experts.
- The process will be repeated if validation is failed.

- Finalizing the results of the research.

Figure 11: Project Flow

3.2 Gantt Chart

Table 1: Gantt chart for the first semester of project

	WEEK														
ACTIVITIES	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mid Semester Break**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of Project Topic	■														
Study on welding method		■	■												
Study on test method				■	■										
Submission of Extended Proposal						★									
Survey to find plate							■								
Finding electrode in the market									■						
Proposal Defence										★					
Finding supplier for plate											■	■	■		
Submission of Interim Draft Report														★	
Submission of Interim Report															★

■ Processes

★ Milestones

Table 2: Gantt chart for the second semester of project

ACTIVITIES	1	2	3	4	5	6	7	Mid Semester Break	8	9	10	11	12	13	14
Welding of sample	■	■	■												
Ordering new electrode an continuation of welding				■	■										
Grinding of Sample						■	■								
Cutting of Sample						■	■ ★								
Submission of Progress Report									★						
Hardness Test										■	■	■			
Impact Test										■	■	■			
Microstructure test										■	■	■			
Analysing & Documentation of result												■	■		
Submission of Draft Final Report														★	
Oral Presentatiom															★
Submission of Final Report															★

■ Proces

3.3 Preparation of Welding Specimen

A mild steel plate with dimension of 20x50x4.5 mm was joined a stainless steel plate with the same dimension with Shielded metal Arc Welding (SMAW). After the plate is welded, it will be cut for the width of 20 cm for every specimen for difference current.

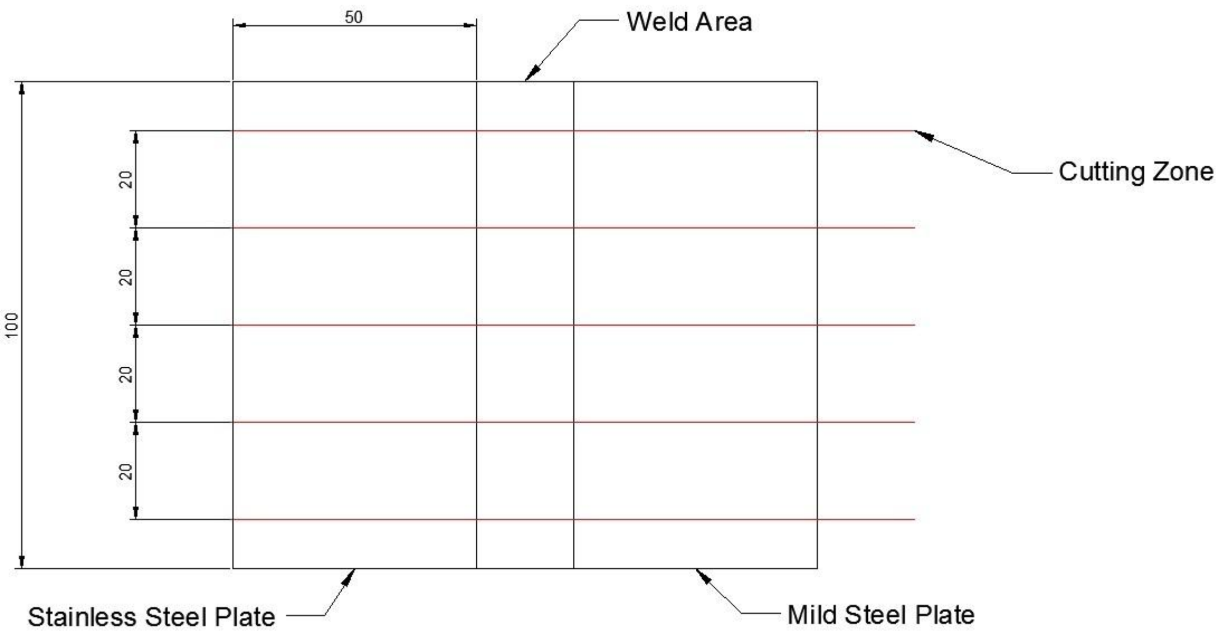


Figure 12: Illustration of plates

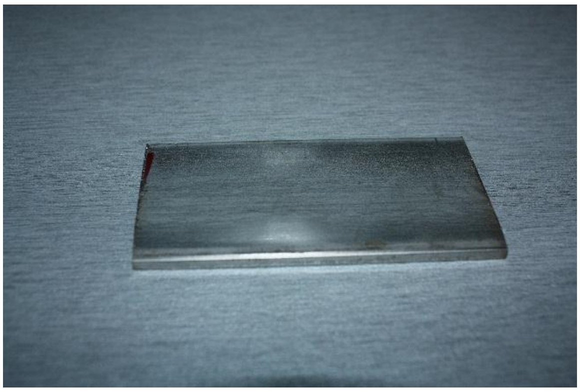


Figure 13: Stainless Steel Plate 304 (100x50mm)

Figure 14: Mild Steel Plate (100x50mm)

3.4 Welding of Sample

The mild steel plate and stainless steel plate has been joined together by using SMAW at different current which is at 90A, 110A and 130 A. The electrode that is used for this experiment is E312-16 electrodes.

Figure 15: Electrode E312-16

Figure 16: The weld

3.5 Grinding of Sample

Grinding was done to remove the weld splatter on the metal to make sample cutting easier.

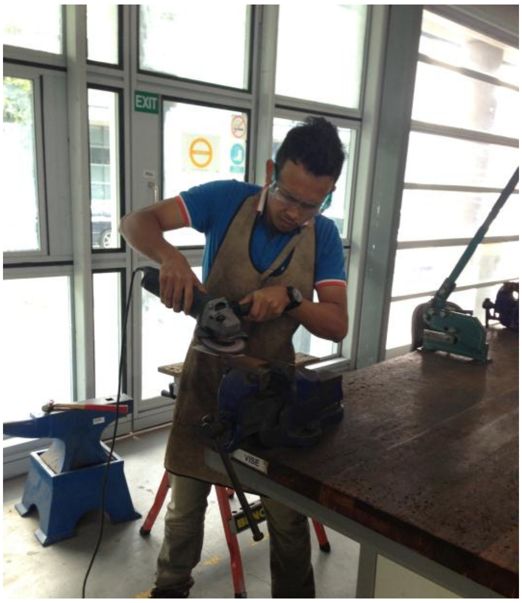


Figure 17: Sample Grinding

Figure 18: Sample was clamped for grinding

3.6 Cutting of Sample

After the sample has been smoothen by grinding, the sample is ready to be cut. The sample was cut using a linear hack saw machine as in the picture below. To prevent damage to the microstructure, water was used as a coolant.

Figure 19: Linear Saw Hack Machine

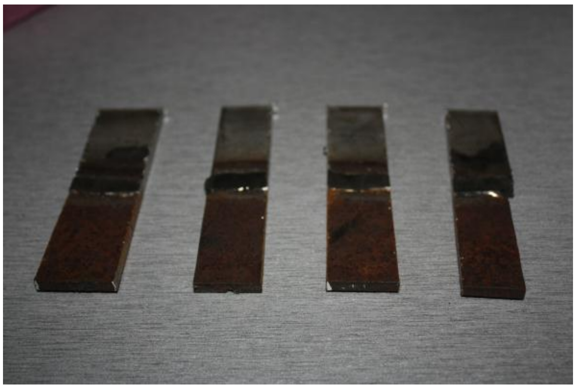


Figure 20: The sample was cut into 4 pieces.

3.7 Moulding of Sample

After the sample was cut into 4 pieces, the sample was further cut using an abrasive cutter to get a smaller sample for moulding. Then the sample was put into the auto moulding press machine.

Figure 21 : Auto Moulding Press Machine

3.8 Hardness Test

The hardness test used in this project is Vickers Hardness. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the **Vickers Pyramid Number** (**HV**)

Figure 22: Grinding of Sample

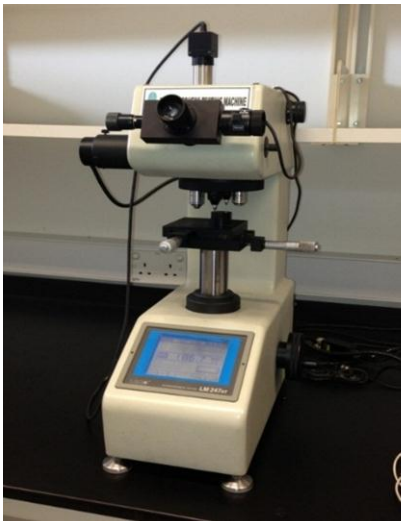


Figure 23: Vickers Hardness Testing Machine

3.9 Microstructure Test

The test was done by using the optical microscope to observe the characteristic of the microstructure. Before the test can be done, the sample need to be grinded to ensure the surface is flat and polishing is done to give a mirror-like finish. Then, etching was done to reveal the microstructure under the optical microscope. Etching can be fined as cutting into a surface of a material using acid.

The basic technique for acid metal etching is to apply a resist to the areas of metal plate, specifically on the surface of the mounted carbon steel and stainless steel plate. The surface of plate was swabbed and immersed into a specific solution that react with the specific metal.

Etchant	Composition	Concentration	Conditions	Comments
Kalling's No. 2	CuCl2 Hydrochloric acid Ethanol	5 grams 100 ml 100 ml	Immersion or swabbing etch at 20 degrees Celsius	For etching duplex and 400 series stainless steels and Ni-Cu alloys and superalloys.
Nital	Ethanol Nitric acid	100 ml 1-10 ml	Immersion up to a few minutes.	Most common etchant for Fe, carbon and alloys steels and cast iron - Immerse sample up from seconds to minutes; Mn-Fe, MnNi, Mn-Cu, Mn-Co alloys.

Table 3: Common Etchants for Carbon Steel and Stainless Steel

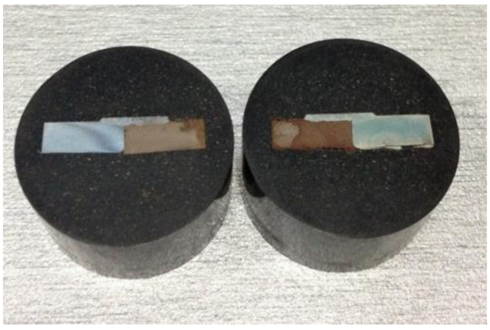


Figure 24: Etching of Sample

Figure 25: Sample was viewed under microscope

3.10 Impact Test

Charpy impact test is practical for the assessment of brittle fracture of metals and is also used as an indicator to determine suitable service temperatures. The Charpy test sample has 10x10x55 mm3 dimensions, a 45o V notch of 2 mm depth and a 0.25 mm root radius will be hit by a pendulum at the opposite end of the notch as shown in figure 2. To perform the test, the pendulum set at a certain height is released and impact the specimen at the opposite end of the notch to produce a fractured sample. The absorbed energy required to produce two fresh fracture surfaces will be recorded in the unit of Joule. Since this energy depends on the fracture area (excluding the notch area), thus standard specimens are required for a direct comparison of the absorbed energy.

The specification of the Tensile Test Machine used are as follow:

Technical Data	**Measuring Unit**	
Capacity Nominal Energy	Joules	300
Hammer Mass	kg theoretical	21.9
Pendulum Weight	N theoretical	214.76
Drop Height	m theoretical	1.3969
Pendulum Length	m theoretical	0.7486
Reduced Pendulum Length	m theoretical	0.747
Impact Velocity	m/s theoretical	5.23
Weight of Machine	kg	600
Machine Base	kg	399
Foundation (Drawing 3.43003 .3500)	kg	1570
Dimensions (without safety device) Width Depth Height	 mm mm mm	 1890 800 1900
Electrical Connection	V Hz KW	3x380 50 0.5

Table 4: Impact Test Machine Specifications

As the pendulum was raised to a specific position, the potential energy (mgh) equal to approximately 300J was stored. The potential energy was converted into the kinetic energy after releasing the pendulum. During specimen impact, some of the kinetic energy was absorbed during specimen fracture and the rest of the energy is used to swing the pendulum to the other side of the machine. The greater of the high of the pendulum swings to the other side of the machine, the less energy absorbed during the fracture surface. This means the material fractures in a brittle manner. On the other hand, if the absorbed energy is high, ductile fracture will result and the specimen has high toughness.

Figure 26: The Impact Test Machine

Figure 27: Placement of the sample on the anvil

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Microstructure Test

These are the microstructure view of the samples under 100x magnification.

Current: 90 A

Figure 28: Microstructure at Stainless steel HAZ

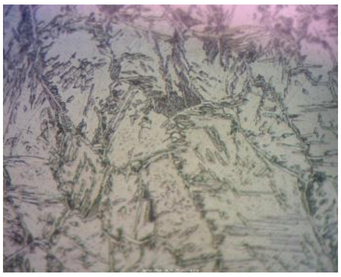


Figure 29: Microstructure at Weld Zone

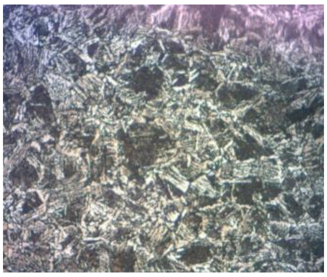


Figure 30: Microstructure at Carbon Steel HAZ

Current: 110 A

Figure 31: Microstructure at Stainless steel HAZ

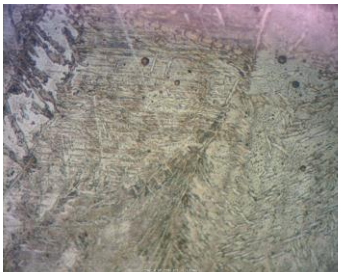


Figure 32: Microstructure at Weld Zone

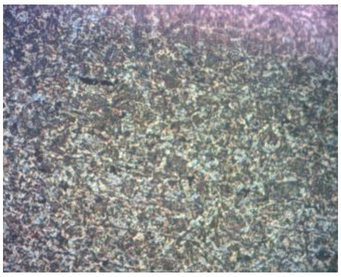


Figure 33: Microstructure at Carbon Steel HAZ

Current: 130 A

Figure 34: Microstructure at Stainless steel HAZ

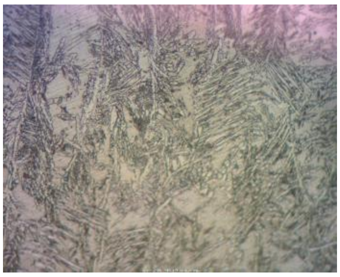


Figure 35: Microstructure at Weld Zone

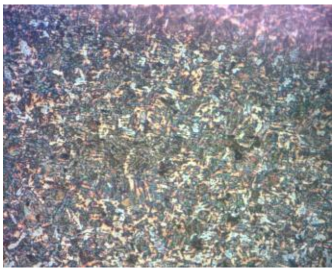


Figure 36: Microstructure at Carbon Steel HAZ

Figure 29 shows the microstructure of the weld zone at 90 A. As the current increase, the heat input also increase. The microstructure of the weld zone became more pack as the current increase from 90 A – 130 A. It can be observed that the microstructure at the weld zone are needle like microstructure.

It was observed that increasing the welding current caused the increase in mechanical properties of welded metal. It related when increasing in arc voltage and welding current or reducing in welding speed increases the welding heat input. With increasing the input energy, grain size in the heat affected zone of carbon steel and stainless steel 304 showed a decrease in size of crystallite and the size of the grain boundaries increase. Increment in grain boundaries as locks for movement of dislocations, decreases possibility and amount of dislocation movement as line defects in structure. It will cause an increment in strength and hardness of welded metal. The phenomenon of grain growth does not occur as the grain size decrease and lead to recrystallization.

The microstructure of the stainless steel could not be seen clearly perhaps due to under etching. A several samples of stainless steel were tried using the same etchant with different number of time but it still can't be seen clearly.

4.2 Hardness Test using Vickers Hardness

Table 5: Hardness of Stainless Steel

Current (A)	Stainless Steel					
	Parent Material			HAZ		
	1	2	3	4	5	6
90 A	200.40	195.30	198.40	218.80	214.60	215.60
Average	**198.03**			**216.33**		
110 A	196.60	207.10	201.40	221.10	224.50	223.40
Average	**201.70**			**223.00**		
120 A	190.30	193.40	205.30	234.31	230.70	226.70
Average	**196.33**			**230.57**		

Table 6: Hardness of Weld Zone

Current (A)	Weld Zone					
	1	2	3	4	5	6
90 A	252.20	268.10	270.70	258.60	261.60	262.30
Average	**262.25**					
110 A	267.60	276.40	273.40	271.40	273.60	274.60
Average	**272.83**					
120 A	267.60	289.10	292.70	268.10	278.20	283.30
Average	**279.83**					

Table 7: Hardness of Carbon Steel

Current (A)	Carbon Steel					
	HAZ			Parent Material		
	1	2	3	4	5	6
90 A	180.40	173.40	167.70	155.50	155.40	162.30
Average	**173.83**			**157.73**		
110 A	195.70	189.30	192.10	162.10	155.60	157.90
Average	**192.37**			**158.53**		
120 A	233.70	187.70	181.20	157.30	152.40	153.60
Average	**200.87**			**154.43**		

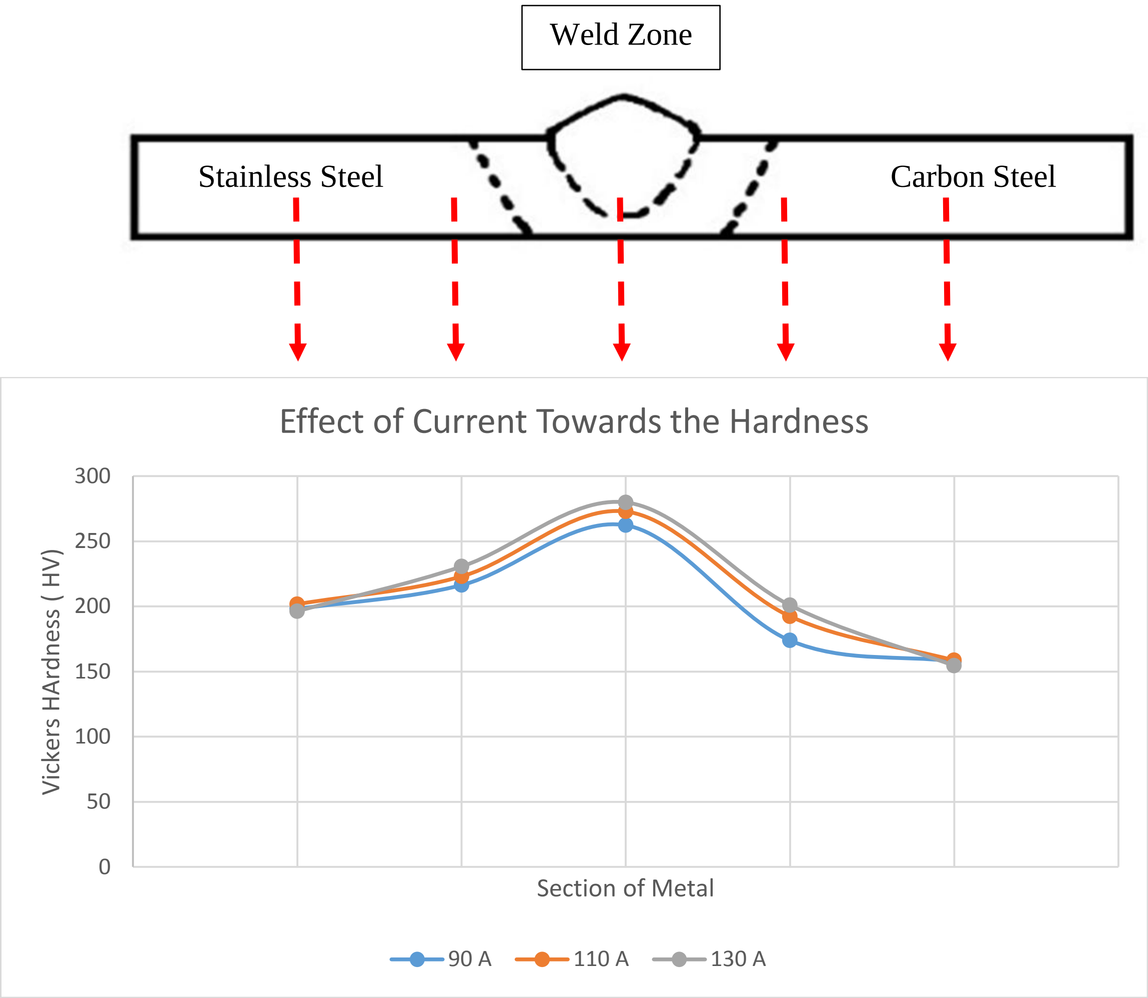


Figure 37: Effect of Current towards the hardness by section of specimen

Table 8: Effect of Current towards the hardness by section of specimen

Current (A)	Base Metal (Stainless Steel)	HAZ	Weld Zone	HAZ	Base Metal
90 A	198.03	216.33	262.25	173.83	157.73
110 A	201.7	223	272.83	192.37	158.53
130 A	196.33	230.57	279.83	200.87	154.43

Figure 37 shows the hardness result. The value shown on the graph is the calculated average value of a specific region that was taken from table 8. The zone that has the highest hardness value is at the weld zone of 130 A with a value of HV=279.83. Theoretically, stainless steel 403 has a higher value of hardness compared to the carbon steel. As the indenter was moved towards different region of the weld, the trends of the hardness will increase until the weld zone. The hardness of stainless steel affected zone increase from 216.33, 223 and lastly 230.57. The hardness value of carbon steel also shows the same trend where it increase from 173.83 to 192.37 and 200.87.

From the experiment, it is shown, in this range of current which is from 90 A – 130 A, the hardness of the weld and the heat affected zone of the base metal increase.

4.3 Impact Test

The ability of the material to withstand the applied load is referred to as toughness

Table 9**:** Effect of current towards impact strength

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Current (A)	**Av**
90 A	95.826
110 A	145.264
130 A	233.842

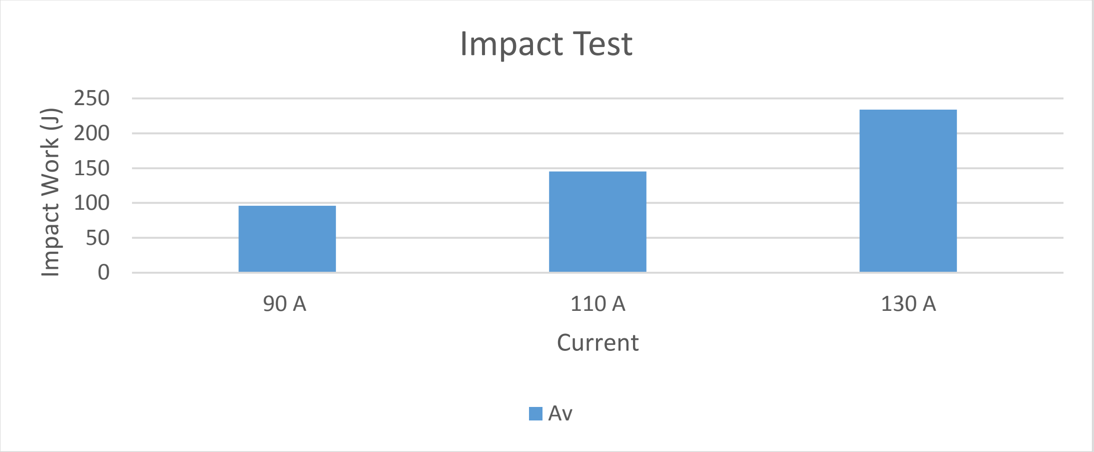

Figure 38: Effect of Current towards impact strength

From Figure 38, it was observed that the impact strength of the carbon steel and stainless steel weld with 130 A has the best value with an average value of 233.842 J while the 90 A welded sample has low impact strength. This is followed by the samples B (110 A) with impact strength of 145.624 J. The weld with 90 A of current has the impact strength of 95.826 J.

As the current increase, the heat input of the welding heat is also increase and it gives effect in increasing of impact strength within this value of currents.

From the experiment, it is shown, in this range of current which is from 90 A – 130 A, the impact strength of the weld and the heat affected zone of the base metal increase.

CHAPTER 5

CONCLUSION

5.1 Conclusion

As a conclusion, the increasing of arc welding current from 90 A to 130A in carbon steel and stainless steel will increase the welding heat input. It will affect the microstructure of the weld itself and give impact on the strength and hardness of the materials. Besides that the high welding current also increase the hardness and toughness value of carbon steel and stainless steel welded metal. Thus, the objective of the project which is to investigate the mechanical properties of the welded joint part using SMAW between steel and stainless steel and to investigate the effect of current towards the weld is achieved.

5.2 Suggested future work

To continue this project, the author has suggests that:

i) Increase the range of current until 200 A

   By increasing the range of current, more data can be achieved and optimum current can be obtained as too high current could damage the microstructure and give defects to the weld.

ii) Include tensile test results in the experiment

   Tensile test is one of major characteristic in the mechanical properties testing. Due to unforeseen circumstances, tensile test could not be done in this project. Including the tensile test could be beneficial in term of information.

CHAPTER 6
REFERENCES

1) Kalpakjian, S., Schmid, Steven R., (2010). *Manufacturing Engineering Technology*. 6th ed. Singapore: Prentice Hall.

2) Callister, William D., (2007). *Material Science and engineering An Introduction*. 7th ed. USA: Quebecor Versailles.

3) Welding Information Center (2004). *History of Welding*. [ONLINE] Available at: http://www.weldinginfocenter.com/history/his_01.html. [Last Accessed 22 June 2013].

4) Lakhsminarayanan, A. K., Shanmugam, K., Balasubramaniam, V., (2009). Effect of Welding Processes on Tensile and Impact Properties, Hardness and Microstructure of AISI 409M Ferritic Stainless Joints Fabricated by Duplex Stainless Steel Filler Metal. *JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2009, 16(5): 66-72*. e.g. 32 (e.g. 2), pp.7

5) H.W. Hayden,W. G. Moffatt, and J.Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York.

6) Gunaraj, V., Murugan, N., 2002. Prediction of heat-affected zone characteristics in submerged arc welding of structural steel pipes. Welding Research, 94s–98s.

7) Huang, C.A., Wang, T.H., Lee, C.H., Han, W.C., 2005. A study of the heat-affected zone (HAZ) of an Inconel 718 sheet welded with electron-beam welding (EBW). Materials Science and Engineering A 395, 275–281.

8) L. Gardner et. al, (2009). Elevated Temperature Material Properties of Stainless Steel Alloys.***Journal of Constructional Steel Research***. , pp.**1**

9) Svensson, L.E. & Gretoft, B., (1990). The formation of acicular ferrite in over half of the weld appears to be the key to improving impact toughness. ***Microstructure and Impact Toughness of C-Mn Weld Metals.*** (), pp.1

10) NDT Resource Center (2001). ***Impact Toughness***. [ONLINE] Available at: http://www.ndt-ed.org/EducationResources/CommunityCollege/Materials/Mechanical/ImpactToughness.htm. [Last Accessed 28 June 2013].

11) International Stainless Steel Forum . *The Stainless Steel Family*. [ONLINE] Available at: http://www.worldstainless.org/Files/issf/non-image-files/PDF/TheStainlessSteelFamily.pdf. [Last Accessed 29 June 2013].

12) Lansky (2013). *The Secret of Steel*. [ONLINE] Available at: https://lansky.com/index.php/blog/the-secrets-of-steel-part-1/. [Last Accessed 28 June 2013].

13) Woei-Shyan, L. , Jen-I, C. , Chi-Feng, L., (2004). Deformation and failure response of 304L stainless steel SMAW joint under dynamic shear loading., pp.207

14) Karalis, D.G., Papazoglou, V.J., Pantelis, D.I. , (2009). Mechanical response of thin SMAW arc welded structures: Experimental and numerical investigation. ., pp.88

15) Kumar, R. , Tewari, V.K., Prakash, S. , (2009). Oxidation behavior of base metal, weld metal and HAZ regions of SMAW weldment in ASTM SA210 GrA1 steel., pp.433