The Effect Of Voltage To Welded Aluminum And Steel By Using Gas Metal Arc Welding (GMAW)

by

Athira Binti Azman

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Turnad Lenggo Ginta)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2013

CERTIFICATION OF ORIGINALITY

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

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(ATHIRA BINTI AZMAN)

ABSTRACT

The purpose of this research is to assess the possibility of joining two different materials (aluminum and steel) by using one of the thermal joining that is gas metal arc welding (GMAW) which can be used in the industries such as in aviation and automotive. The joints will be obtained by GMAW process in which melts metal by heat supplying an electric arc established between a continuously fed filler wire electrode. Test will be conducted with constant welding parameter but with the different voltage. The results will be analyzed by means of hardness test, impact test, ultimate tensile test and microstructure at the welded joint. The strength of the joints varied with increasing of voltage when welding process is implied. The results will be proved after the tests are being done whether the technique of joining aluminum and steel by using GMAW is applicable.

Keywords: Gas metal arc welding, Thermal joint, Aluminum, Steel, Dissimilar materials.

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LIST OF ABBREVIATION

GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
SMAW	-	Shielded Metal Arc Welding
OAW	-	Oxy-Acetylene Welding
CMT	-	Cold Metal Transfer
AC	-	Alternating Current
DC	-	Direct Current
CC	-	Constant Current
CV	-	Constant Voltage
DCRP	-	Direct Current Reverse Polarity
WFS	-	Wire Feed Speed

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The use of joints between dissimilar materials has increased. Conventional products that are made from steel have been replaced to lighter materials that capable of providing high strength and good corrosion resistance. Aluminium is already used in many fields because of its good corrosion resistance and good welding ability (Bruckner, 2004). The low specific weight of aluminium is also a very important property as it helps to decrease weight and fuel consumption in the aviation and automotive industries. The joint will minimizes the energy consumption through the reduction of weight. Aluminium welded with steel has been widely used especially in automotive industries. The joint of these two metals can lead to economy advantages. When joining aluminium with steel, the specific advantages of each of these materials can be utilized.

The methods of mechanical joint that commonly been used until now are clinching, screwing and riveting. There are many thermal joining research have been done to joint aluminium with steel. But still, thermal joining is strongly restricted due to the formation of the intermetallic phases. This project will discuss and continue more research about the joint of aluminium and steel by using gas metal arc welding (GMAW).

2.2 Problem Statement

GMAW is a thermal joining process which joins metals by heating the metal to their melting point with continuous and consumable electrode wire. The arc is shielded

from contaminants in the atmosphere by a shielding gas. GMAW has been chosen to perform the research of joining aluminium and steel together. But the differences in physical and chemical properties such as melting point, E-modulus and many other properties cause many problems to join aluminium and steel. The insolubility of aluminium and steel can lead to the formation of very brittle intermetallic phases. There are many problems that are possible to happen when joining these two dissimilar metals such as the possibility of joining aluminium with steel using GMAW and welding quality (Davis, 2006). It is necessary to find the effect of current during welding of steel with aluminium by using GMAW.

2.3 Objective and Scope of Study

Reducing weight by joining aluminium with steel is an important task that can be fulfilled by the use of materials with different characteristic. All the benefits of the two materials such as weight reduction, and high thermal conductivity can be obtained. The study consists of choosing the right type of steel and aluminium to be joined together. The hardness and the microstructure of the welding plate are investigated in order to analyze the suitable current for the material, hence, the material successfully be joined. This research objective of joining aluminium with steel using GMAW is focusing on:

- To investigate the effects of the welding quality by changing voltage
- To find the best voltage to weld aluminium and steel together
- To study the result of hardness test and the microstructure of the welded plate

CHAPTER 2

LITERATURE REVIEW

2.1 Recentness of Literature

The literature review in this project provides the information for the research. The need of literature review research is to identify what are the sources and information that can be implied in order to complete the research. The literature review consists of:

- Research of Aluminium to Steel Joint
- Research of Welding Type
- Gas Metal Arc Welding (GMAW)
- The Welding of Aluminium
- Filler Material
- Current and Voltage in Welding Industry
- Metallography Microstructure
- Testing of Welded Joints

2.1.1 Research of Aluminum to Steel

Recently, mechanical joining of aluminium and steel has been done before with many types of joining such as screwing, clinching and riveting. The joint of these two dissimilar metals in manufacturing are being used in the industries widely to reduce the cost of materials, workmanship and weight in order to produce a product. For example, in transportation manufacturing, the used of aluminium and steel joint is to reduce the weight and therefore, the energy consumption will reduce because of the light weight material.

The thermal joint of aluminium and steel are also still in the research such as laser welding, gas metal arc welding (GMAW), and gas tungsten arc welding (GTAW). There is also a new research of thermal joint of aluminium and steel which used modified gas metal arc welding system called cold metal transfer (CMT) (Fronius Canada Ltd., 2009). But the thermal joint of these two dissimilar materials is still in hanging situation where the quality and the strength of the welded joint are still in doubt. This is because the properties of each metal differ and it is not easy to obtain good quality welding.

A study of joining aluminium and steel has been done by using AC pulse GMAW in Korea. The study evaluates the characteristic of welds from joining dissimilar metals and the arc characteristic in relation with varying EN ratios were analyzed. The study shown the result of joining the two dissimilar materials with GMAW are easily breakable, brittle intermetallic compound layer because of the differences physical characteristic (Park, Rhee, Kang, & Kim, 2009).

The study of joining aluminium and steel in car body manufacturing has been done by using laser welding. This study that been held in Austria used conventional laser welding and bi-metal-wire laser welding. The conventional laser welding has been carried with 3kW CO2 laser and 3kW Nd:YAG laser with a welding flux and an AW-6016 alloy and resulting to the increased of the shear strength and very uniform intermetallic phases. The second study of joining the two dissimilar by using bi-metal-wire laser is being held with 2 samples of welding. The result shown that the tensile strength of bi-metal wire laser welded is slightly higher compared to pure aluminium laser welded sample, and the bending test results shown that in cracks or debonding of the aluminium-steel interface occurred (Liedl, 2011).

2.1.2 Research of Welding Type

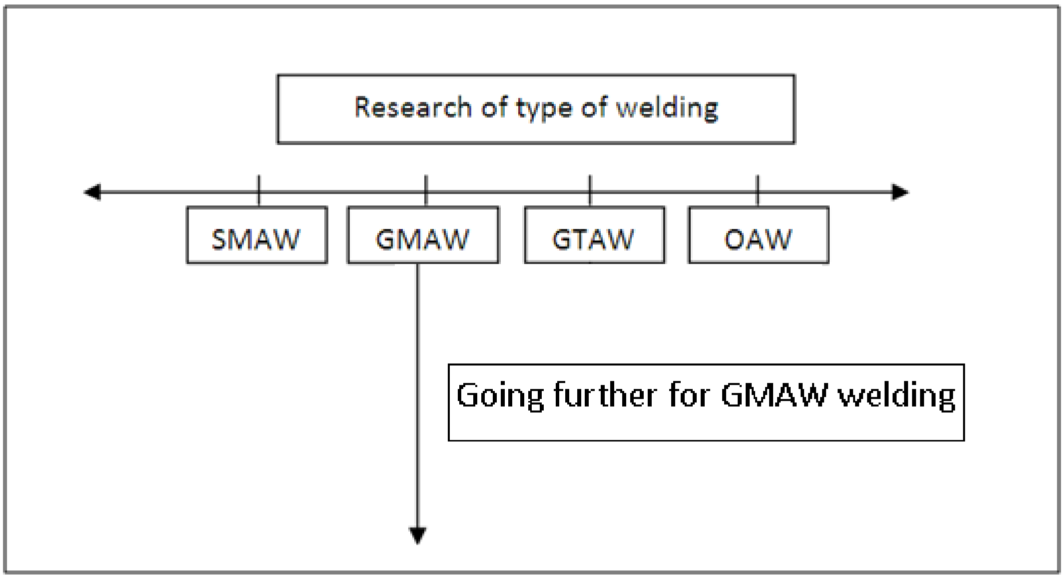


Figure 2.1: Welding Type

Shielded Metal Arc Welding (SMAW) is a welding type that covered welding electrodes consists of an alloy core wire and a flux coating. The core wire is usually similar to the base metal in composition. However, various alloy additions are made in the coating, so that the weld bead chemistry will not be the same as the chemistry of the core wire itself. The additional carbon, manganese and chromium required in the weld deposit are added to the flux coating (Fronius, 1980). During welding, these additions melt in and adjust the chemistry of the weld bead to the specified composition. The electrode coating does four basic jobs:

i. Provides a gas that shields the metal crossing the arc from oxidation
ii. Produces a molten slag which further protects the molten weld bead from oxidation, affects out-of-position weld ability, and controls the bead shape
iii. Adds more alloying elements, such as manganese, carbon or chromium
iv. Promotes electrical conductivity across the arc and helps to stabilize the arc, important when alternating current (AC) is used.

Gas metal arc welding (GMAW) started where wire is fed continuously through a hollow cable to the welding gun, where it makes electrical contact. The arc between weld wire and work piece melts the metal. Molten weld filler transfers as either a spray of fine drops, or as larger globs. The metal is protected from oxidation by a continuous flow of shielding gas, usually argon, through the weld torch and around the wire (Miller Electric Mfg. Co, 2012). Current is always Electrode Positive (DCRP, direct current reverse polarity)

In GTAW welding, the arc is struck between the work piece and a tungsten electrode, which remains unmelted. The argon shielding gas, which protects both the hot tungsten electrode and the molten weld puddle, is brought in through a nozzle or gas cup which surrounds the electrode. This process used to be called TIG (Tungsten Inert Gas). For both stainless and nickel alloys the current used is DCSP, direct current straight polarity (Durgutlu, 2004). The work is electrically positive and the tungsten electrode is the negative electrical pole. The electrode is usually thoriated tungsten, that is, tungsten metal added to improve the emissivity of electrons.

OAW is a welding process that melts and joins metals by heating them with a flame caused by the reaction between a fuel gas and oxygen. OAW is the most commonly used gas welding process because of its high flame temperature. A flux may be used to deoxidize and cleanse the weld metal. The flux melts, solidifies, and forms a slag skin on the resultant weld metal. There are three different types of flames in oxyacetylene welding that are neutral, reducing, and oxidizing (Fronius, 1980).

2.1.3 Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW) is a welding process that its electricity is passed through a continuous wire electrode and is surrounded by a shielding gas. The welding rod is consumed in the heat generated by the arc. The shielding of the arc and the molten pool are obtained by using inert gases such as argon and helium. This type of welding is often used in aluminum and aluminum alloy (Miller Electric Mfg. Co, 2012).

The process of GMAW welding starts where the arc is protected by argon gas (or argon-helium gas mix) to shield the welding spot and the electrode from being exposed to surrounding. The arc functions as a heat source to provide high temperature and provides high heat input, thus a stable arc, smooth metal transfer with low spatter loss and good weld penetration can be obtained. The figure below shows the process of GMAW.

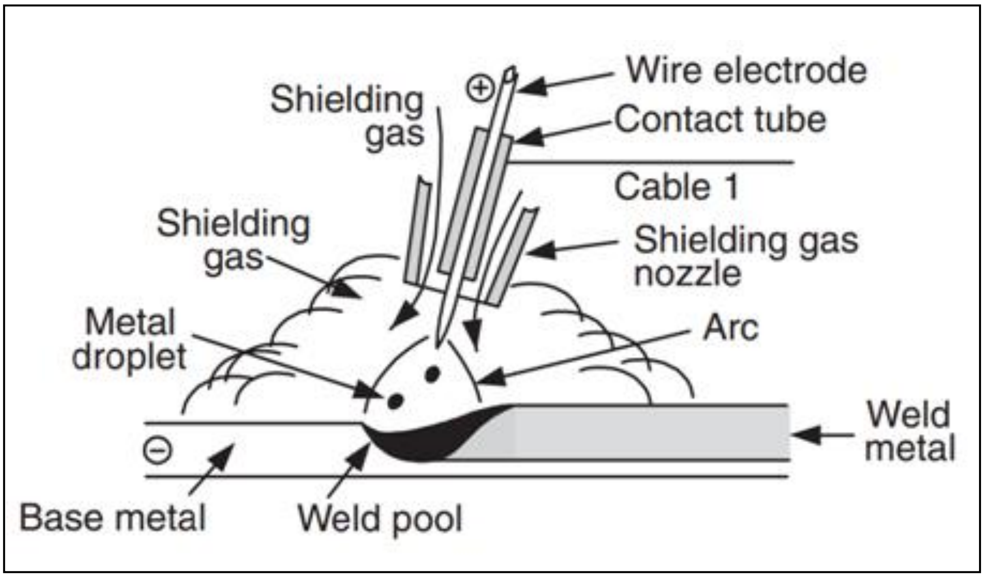


Figure 2.2: The GMAW Welding Process

The settings of the GMAW machine are according to the plate thickness, current and materials. There are two types of GMAW welding machine:

i. Constant Speed Feeder

Can be used only with a constant voltage (CV) power source. This type of feeder has a control cable that will connect to the power source. The control cable supplies power to the feeder and allows the capability of remote voltage control with certain power source/feeder combinations. The wire feed speed (WFS) is set on the feeder and will always be constant for a given preset value.

ii. Voltage-Sensing Feeder

Can be used with either a constant voltage (CV) or constant current (CC) - direct current (DC) power source. This type of feeder is powered off of the arc voltage and does not have a control cord. When set to (CV), the feeder is similar to a constant speed feeder. When set to (CC), the wire feed speed depends on the voltage present. The feeder changes the wire feed speed as the voltage changes. A voltage sensing feeder does not have the capability of remote voltage control

(The Welding of Aluminium MIG & TIG Fusion Pocket Guide, 2004).

The advantages of GMAW are:

- Semi-automatic arc welding process
- Feeding a shielding gas and a consumable wire electrode through a welding gun to melt and join pieces of metal together.
- Constant voltage, direct current (DC) power source is usually used; however, constant current, as well as alternating current (AC), can also be used.

2.1.4 The Welding of Aluminium

Aluminium nowadays is a popular material that often used in many new applications as an engineering material. It takes place mainly in the transport sector such as cars, buses, trains and marine vessels. Welding of aluminium with other material is a new technology which is shown by the growing interest in aluminium welding. The research regarding thermal joint of aluminium with other metal is still new and welding of aluminium has often hindered. The properties of aluminium differ substantially from other metal. The most interesting aspect of aluminium usage is the weight saving that becomes possible. Weight savings of 40-60% are often mentioned in many cases, reducing fuel consumption in transport vehicles (The Welding of Aluminium MIG & TIG Fusion Pocket Guide, 2004).

Aluminium is a family of a variety of alloys grouped according to the alloy elements added and that provide the best combination of properties. The requirements of alloy include strength, corrosion resistance enhancement ductility and ease of welding.

2.1.5 Filler Material

The most important characteristic for a particular welding is to select welding filler material. Welding filler material is a metal added in the making of a joint through welding such as covered electrodes, bare electrode wires, tubular electrode wires and welding fluxes. Welding dissimilar alloys requires careful selection and it is important as the required strength, ductility, corrosion resistance, may be the dominant factor in deciding which filler to use. The filler metals are used or consumed and become a part of the finished weld. Electrodes normally considered non-consumable such as tungsten and carbon electrodes, fluxes for brazing, submerged arc welding and electro-slag welding (Key to Metals, 2002). The term filler metal does not include electrodes used for resistance welding and stud welding. Below is the list of filler material:

Table 2.1: Filler Metal Specification and Welding Process

Specifications	**Process**					
	OAW	**SMAW**	**GTAW**	**GMAW**	**SAW**	**Other**
Aluminuim & aluminium alloy arc welding electrodes		X				
Low-alloy steel covered arc welding electrodes		X				
Copper & copper alloy covered electrodes				X		
Copper & copper alloy welding rods	X		X			PAW
Aluminium & aluminium alloy welding rods & bare electrodes	X		X	X		PAW
Tungsten arc welding electrodes			X			PAW

2.1.6 Current and Voltage in Welding Industry

Current is the flow of the electrons that pass through voltage at different points. Whereby voltage is the electric potential between different point. Current and voltage can also be compared as water flow in the pipe where current measures how much water travels through the pipe (which means it measures how much electrons pass through the wire), while voltage measure the force of water through the pipe (it measures the potential electricity from one point to another). These two things are very important to each other and help the working of electricity (Brinkster, 2006). They are two different concepts. A voltage can exist without a current however current requires voltage to exist. The relationship between current and voltage can be represented in the mathematical equation derived, $I = V/R$, where I is the current, V is the voltage and R is the resistance. Experts state that if a person died from being exposed to high voltage, it is not the voltage that kills the person, but the amount of current that flows through the body. This means, if the voltage is high but the current is low, the chances of the person to survive are higher (etorgerson.net, 2001).

There are two types of current that is direct current (DC) and alternating current (AC). DC current is when the electrons flow in constant one direction while AC current is when the electrons flow with constant changing direction. DC is being used for batteries and AC is being used for current that have relation with generators. In welding sector, the AC and DC current usage are depending on the type of material that will be welded. Nowadays, DC is more popular than AC because of its advantageous; it uses lower current, has wider weld lobes and introduces less electrode wear (Cerjanec, Feng, Li, & Grzadzinski, 2004).

There are also constant current (CC) and constant voltage (CV) used in welding. These are two different types of welding power source that will produce CC output and CV output. CC is to maintain current at constant level, but large changes in voltage, while CV jobs is vice versa. These are related to the effect of the welding rod. Current effects the melting of the electrode, which means the higher the current level, the faster the electrode melts. Voltage controls the length of the welding arc and resulting width and volume of the arc cone. As voltage increases, the arc length gets longer (Lincoln Electric). Figure below shows the effect of voltage in the electrode.

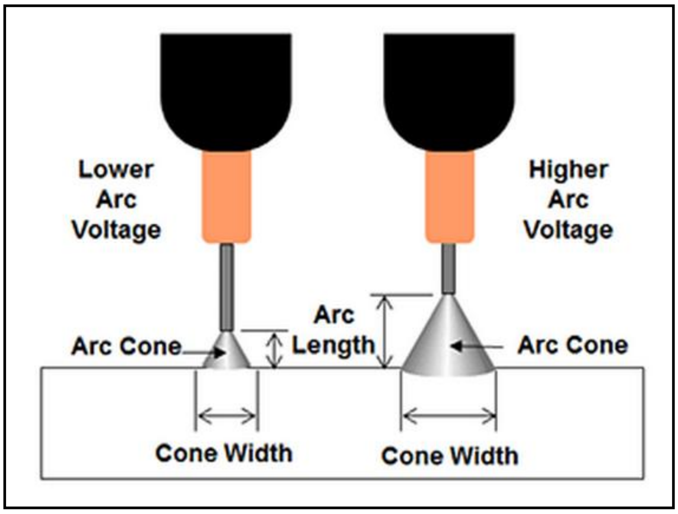


Figure 2.3: Voltage Effect at the Electrode

The type of power source, whether it is CC or CV, is determined on which type of welding process that will be used. The manual welding process such as shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW) are more preferred to use CC type of output from the power source. This is because all of the welding variables such as welding angle, travel speed and arc length are controlled by hand. CV is the type of power source that more likely to be used in semi-auto welding such as gas metal arc welding (GMAW). This is because all of the welding variables are still being controlled by hand, but the electrode feeding rate is controlled automatically by constant speed wire feeder (Lincoln Electric).

2.1.7 Metallography Microstructure

The examination of microstructure is one of the methods to examine the effect of welding, fabrication and heat treatments. This type of examination purpose is to analyze the cause of failure. Microstructure of certain materials can change during freezing, hot or cold working, annealing and many more (Cerri & Evangelista, 1999). In general, the metallographic of aluminium and its alloys is a hard job to do. The nature properties of aluminium itself are soft and non-shining. These will make the process to get the microstructure difficult. As for the aluminium alloys, it represents a great variety of chemical compositions and thus a wide range of hardness and different mechanical properties and moreover, one specific alloy can contain several microstructure features, like matrix, second phases, dispersoids, grains, sub grains and thus grain boundaries or sub-boundaries according to the type of the alloy and its thermal or thermo-mechanical history (Cerri & Evangelista, 1999).

The techniques required for metallographic examination may vary considerably between soft and hard alloys. Some methods of sample preparation and observation are quite general and can be applied to all aluminium alloys. In other cases one should refer to specific developed methods.

a) Mechanical Grinding

As the starting of the job, grinding the samples to get the smoother surface is done. This job is performed in steps using SiC abrasive papers (sandpapers) of different grade. The grade of the sandpapers usually starts from the rough one, depends on the type of cut surface to be removed. The grade will increase gradually from 120, 180, 240, 400, 800, 1000, 1200, 1500, 2400 and 2500.

b) Mechanical Polishing.

Polishing is done right after grinding. It is important for removing the surface scratches produced during grinding. It is usually performed in two steps, rough and final polishing. The rough polishing is done by using 3 µm and 1 µm diamond paste on the cloth disk (grinding turntable) and final polishing step is done by using 0.25 µm diamond paste, also on the cloth disk the samples should be washed in order to remove the all the abrasive. In cases where polishing with 1 µm or 0.25µm diamond paste does not produce a sufficiently deformation - free and scratch-free, highly reflective surface, as it is the case of pure aluminium and its soft alloys, the final polishing can be carried out using metal oxides in aqueous suspension (Zwleg, 2007). Polishing can be also performed in an electrolytic way. This technique is suited for polishing homogeneous structure such as pure aluminium or very soft alloys which are difficult to polish mechanically (Goodhew, 1984). The polishing also can influence the quality of the microstructure.

c) Etching

Etching is done after the polishing of the samples is finished. It is a process where corrosion is controlled and resulting from electrolytic action between surface areas of different potential (Vander Voort, 1984). The etching process will clearly reveal the grain boundaries, crystallized structure, dendritric cells, depending on etchant used. Below is the list of common etchant and its specification that.

Table 2.2: The Common Etchant Used for Aluminium and Steel

Solution	Concentration	Specification
Hydrofluoric Acid	• HF – 0.5ml • H_2O – 99.5ml	General multi-purpose etch for aluminium
General Etchant for Aluminum	• HF – 2ml • HNO_3 – 25ml • H_2O – 73ml	Most useful reagents for etching Aluminium
Sulphuric acid	• H_2SO_4 – 20ml • H_2O – 80ml	For separating (Al-Cu-Fe-Mn) from (Al-Fe-Mn) or (Al-Cu-Fe)
Keller's Reagent	• H_2O – 95ml • HNO_3 – 2.5ml • HCl – 1.5ml • HF – 1ml	Good general purpose etchant for Al & Al alloys, except for high Si alloys. Outline all common constituents, reveal grains structure in certain alloys when immersed
Graff's & Sargent's	• H_2O – 84ml • HNO_3 – 15.5ml • HF – 0.5ml • CrO_3 – 3g	For grain size of 2XXX, 3XXX, 6XXX, 7XXX wrought alloys.
Poulant's Reagent	• HCl – 12parts • HNO_3 – 6parts • HF – 1part • H_2O – 1part	For aluminium alloys, use polarized light
Modified Poulant's Reagent	50ml of : • HCl – 12parts • HNO_3 – 6parts • HF – 1part • H_2O – 1part	Very good macro-etchant, must over etch (4L02)
	• HNO_3 – 25ml	
	• Chromic Acid – 12g • H_2O – 40ml	
Hume-Rothery's Reagent	• Cupric Chloride • H_2O – 1000ml	Etching aluminium to reveal grain boundaries

Weck's	• Potassium – 3g • Sodium Hydroxide – 1g • H_2O – 100ml	Colour tinting very good for revealing grain structure in 6000 series. Wait until sample turns brown, view under polarized light
Tucker's Reagent	• HCl – 45ml • HNO_3 – 15ml • HF – 15ml • H_2O – 25ml	For aluminium revealing crystallized structure
10% Phosphoric Acid	• H_3PO_4 – 10ml • Ethanol/Methanol – 100ml	Shows dendritric cells in aluminium
Macro-Etch	• HF – 5ml • HNO_3 – 20ml • HCl – 20ml • H_2O – 60ml	Useful macro-etch for most Al based materials. Reveals grain size, rolling direction and welded joints
Nital	• Ethanol – 100ml • HNO3 – 1-10ml	For low carbon steel etchant
Picral	• Ethanol – 100ml • Picric Acid – 2-4g	Revealing grain boundaries

2.1.8 Testing of Welded Joints

<u>Hardness Test</u>

Hardness is the ability of materials to resist plastic deformation. Hardness of materials has been assessed by resistance to scratching or cutting. The usual method to get the hardness value is by measuring the depth or area of an indentation with specific force applied and specific dwelling time. Hardness test is a measuring method to test the materials by indentation. Different materials have different result of test and it also depends on the force applied to the materials and type of indenter used to indent the materials. There are three common types of hardness test that often measures welding joint, Rockwell, Brinell, and Vickers.

a) **Rockwell Hardness Test**

Rockwell hardness test basically being done by two step process. The applied load of Rockwell hardness test can be up to 100kg. There are two types of indenter which is diamond indenter or ball indenter. First, the indenter is pushed into the surface until the desired preload (minor load) is reached. This indentation will provide a depth reference, and when major load is applied this will results in deeper penetration to the materials surface. The second step is the preload is re-applied. The difference between the depth of minor load and major load is calculated to find the Rockwell hardness number (Gordon England, 2000). Below is the illustration of Rockwell working principle.

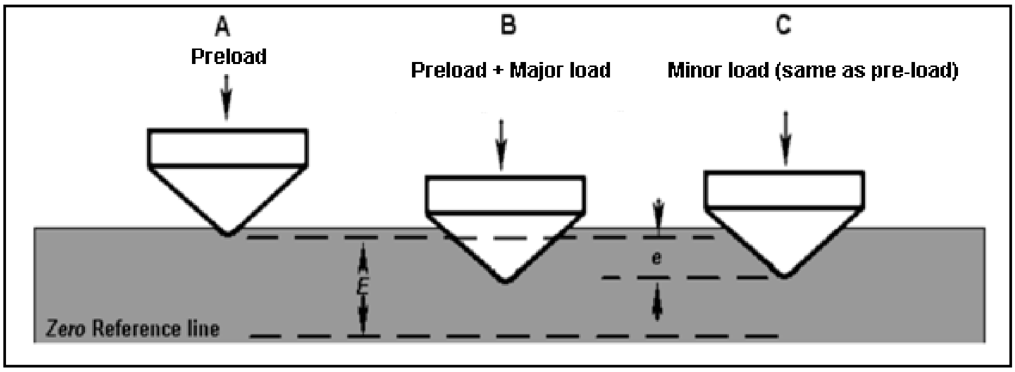


Figure 2.4: Rockwell Working Principle

With;

With;	E	= constant depending on types of indenter. Diamond = 100, ball = 130
	e	= permanent increase in depth of indention due to major load (0.002mm)
	A	= preload (kgf)
	B	= preload + major load (kgf)
	C	= minor load (same with preload) (kgf)
	d	= ball diameter

The hardness of Rockwell can be measured by using this formula and the list of Rockwell scales can be obtained as below:

$HR = E - e$ for diamond indenter	$HR = E - (d/e)$ for ball indenter

Table 2.3: Rockwell Hardness Scales for Typical Application

Scale	Indenter	Minor load (kgf)	Major Load (kgf)	Total load (kgf)	E
HRA	Diamond cone	10	50	60	100
HRB	1/16” steel ball	10	90	100	130
HRC	Diamond cone	10	140	150	100
HRD	Diamond cone	10	90	100	100
HRE	1/8” steel ball	10	90	100	130
HRF	1/16” steel ball	10	50	60	130
HRG	1/16” steel ball	10	140	150	130
HRH	1/8” steel ball	10	50	60	130
HRK	1/8” steel ball	10	140	15-	130
HRL	1/4” steel ball	10	50	60	130
HRM	1/4” steel ball	10	90	100	130
HRP	1/4” steel ball	10	140	150	130
HRR	1/2” steel ball	10	50	60	130
HRS	1/2” steel ball	10	90	100	130
HRV	1/2” steel ball	10	140	150	130

With; HRA = Cemented carbides, thin steel, shallow case hardened steel

HRB = Copper alloys, soft steel, aluminium alloys, malleable irons, etc

HRC = Steel, hard cast iron, case hardened steel and materials harder than 100

HRD = Thin steel and medium case hardened steel and pearl malleable iron

HRE = Cast iron, aluminium and magnesium alloys, bearing metals

HRF = Annealed copper alloys, thin soft sheet metals

HRG = Phosphor bronze, beryllium copper, malleable irons

HRH = Aluminium, zinc, lead

HRK =
HRL =
HRM =
HRP = } Soft bearing metals, plastics and other very soft material
HRR =
HRS =
HRV =

b) Brinell Test

Brinell test basically a test that applying specific load by using hardened steel or tungsten carbide spherical indenter of a specified diameter (1mm – 10mm). It is calculated by dividing the load applied to the surface area of indention. The maximum load for hard materials can be up to 3000kg (Dannyeqs, 2012). This test is the best for achieving the bulk or macro-hardness of a material. The formula of the Brinell test can be written as:

$$BH = \frac{F}{\frac{\pi}{2} D \left(D - \sqrt{D^2 - D_i^2}\right)}$$

With; F = Force applied to the specimen

D = Ball diameter

D_i = Indention diameter

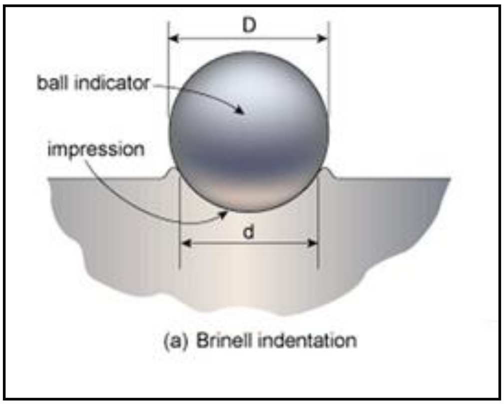


Figure 2.5: Brinell Working Principle

c) Vickers Test

Vickers harness test works on similar principles with Brinell hardness test. The only difference is the indenter of Vickers test used square based cross section diamond rather than steel ball. The applied loads for Vickers are small, which are only 100gf to 1kgf. Hardness Vickers can be calculated by dividing the applied load by the surface area of indention. The Vickers test machine has built-in microscope that allows for more precise measurement of the diagonal cross section length (Dannyeqs, 2012). It is possible to target specific area to indent by looking at the microscope. The advantages of the Vickers hardness are that accurate readings and just one type of indenter will be used for all types of material. The formula of Vickers hardness is as below:

$$HV = \frac{2F \sin \frac{136^{0}}{2}}{d^2}$$

$$HV = 1.854 \frac{F}{d^2}$$

F = Load in kgf

d = Arithmetic mean of the two diagonals (mm)

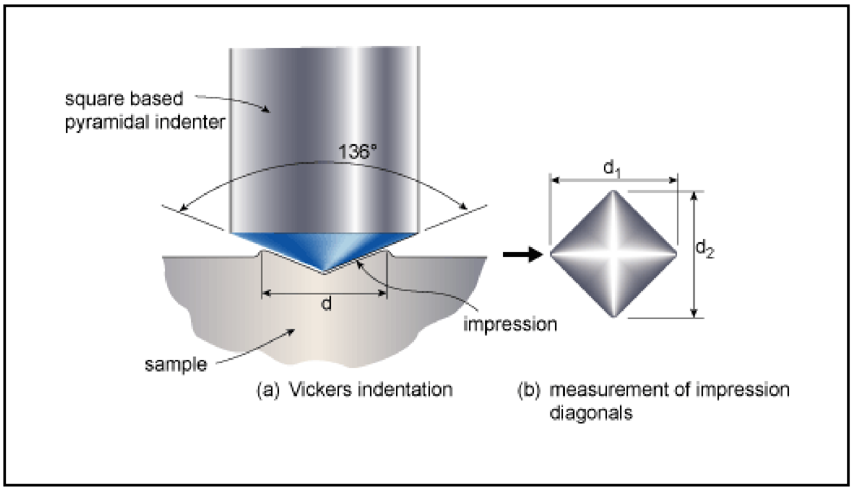


Figure 2.6: Vickers Working Principle

2.2 Critical Analysis

There are various problems that have occurred to implement the project. At first, gas tungsten arc welding (GTAW) is used as a medium to join the plates. But, the method is unsuccessful. By observations, it could not be fixed because the melting point of aluminium and steel are not the same. In fact, the difference is too high.

GMAW is implemented to affix the two plates and it was successful. To obtain the optimal rate for attaching the plates, several ranges of current and voltage have been tested. However, the joint is very brittle and this resulted that ultimate tensile strength test and impact test are impossible to be done.

CHAPTER 3

METHODOLOGY

3.1 Project Process Flow

The methodology of the project has been discovered in order to proceed with the experiments. The project is starts from material preparation, characterization, sample preparation and finally sample testing. The welding process will come up with specimens and these specimens will experience, hardness test, and analyzing the microstructure of the samples. The summary of methodology process is listed below:

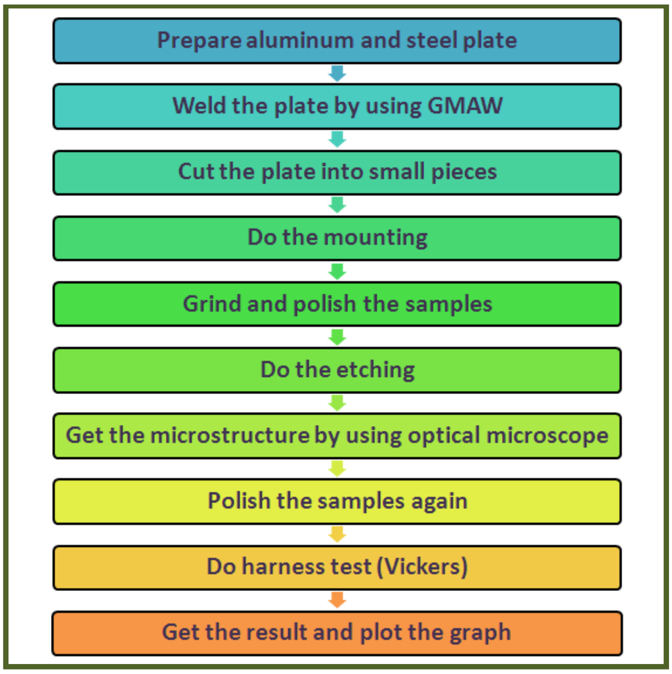


Figure 3.1: The Summary of Methodology Process

3.2 Welding Type

The first thing to be completed is the type of welding that will be used for the project. At first, GTAW is implemented. Various type of filler material had been chosen but failed to join the plates. A quick solution has been found out to make the join possible, that is by using GMAW. Then several thicknesses of the plates are tested with GMAW, 5mm, 4mm, and 3mm. The 3mm plates are chosen because the other two thicknesses failed to join.

3.3 Material Preparation

The preparation of the plates that need to be joined is determined. 3 pieces of aluminium and steel plate with 3mm thickness, 125mm width and 200mm length are cut. The length 200mm is chosen because the welder can maintain constant speed while welding the plate so the welding process will be smoothed. The width 125mm also is chosen because when two plates are joined, the length will be 250mm, which is very compatible to do impact and ultimate tensile strength test. 1 piece of aluminium plate is joined with 1 piece of steel with chosen parameter by using GMAW. All the plates are joined and these make the plates are total in 3 with different voltage and current. Below is the picture of the plates after the welding process:

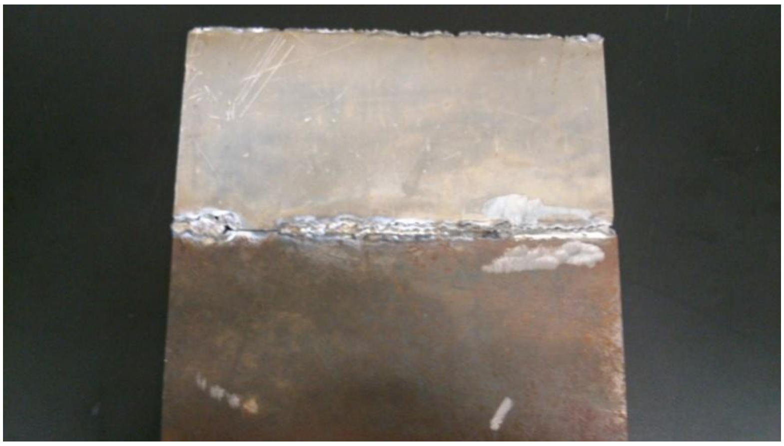


Figure 3.2: Welded Aluminium and Steel Plate

3.4 Characterization

The characterization for the welding process is current, voltage, and type of power source. As mention in literature review, the type of power source that suitable to be used in semi auto welding is constant voltage (CV). So, when the welding process starts, the DC GMAW welding machine is set to CV mode.

The ranges of current and voltage are the most crucial that need to be determined. There is no research of welding dissimilar materials by using GMAW, so the process of choosing the right and suitable current with constant increasing voltage is difficult. The plates are being weld tested by using many types of current until it can be joined. From the welding experiment found out that the optimum current and voltage to join the dissimilar material is 70 ampere and 18 volt.

By using the optimum current and voltage obtained, the minimum and maximum voltage need to be discovered. The same welding process is tested until the right minimum and maximum current been found. The minimum current and constant voltage is 60 ampere and 17 volt, and the maximum current and constant voltage is 80 ampere and 19 volt. Below is the table of the welding characterization:

Table 3.1: Welding Characterization

<table>
<tr><th>Current (I)</th><th>Voltage (V)</th><th>Specification</th></tr>
<tr><td>60</td><td>17</td><td rowspan="3">The other welding parameter such as electrode travel speed, welding speed, welding angle is set to constant</td></tr>
<tr><td>70</td><td>18</td></tr>
<tr><td>80</td><td>19</td></tr>
</table>

3.5 Sample Preparation

After the welding process is completed, the joined plates are cut into small pieces (approximately 25mm length and 5mm width). The cutting area is at the welding zone (heat affected zone) of the plate. The part of the welding is taken at the most fine and beautiful welding structure. The small pieces are cut in order to make samples and this is to make the samples fit in the mounting mold. Mounting the samples is important to make it more tidy and easy to be tested. The mounting process is conducted as below:

Figure 3.3: Small Pieces of Welded Plates

i. The mounting process starts with swapping the release agent to the mounting deck. This is to prevent the mold stuck on the deck when the mounting process is done.

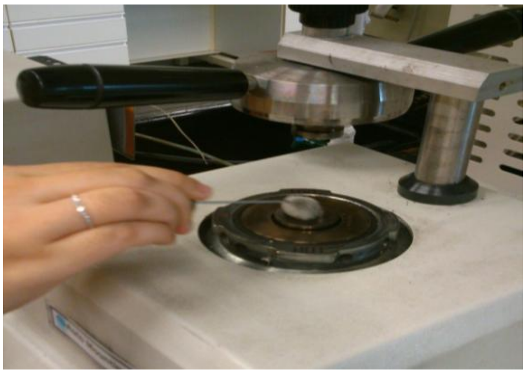


Figure 3.4: Swapping Release Agent

ii. Then the sample is place on the deck. The surface that will be mounted will face the deck.

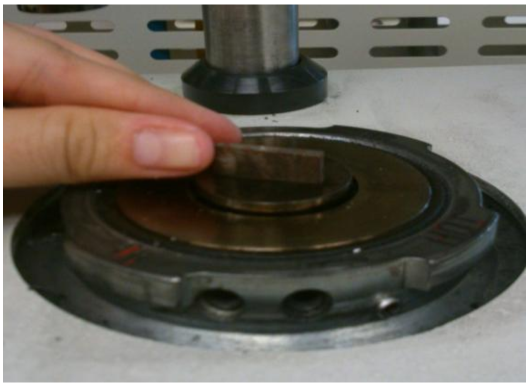


Figure 3.5: Sample is Place on the Deck

iii. Press the ram down button in order to put mounting powder.

iv. Put the phenolic powder (mounting powder) in the mounting press machine.

Figure 3.6: Put the Mounting Powder

v. The mounting machine cap is close tightly.

Figure 3.7: Lock the Cap

vi. Press the start button and wait for the mounting process done.

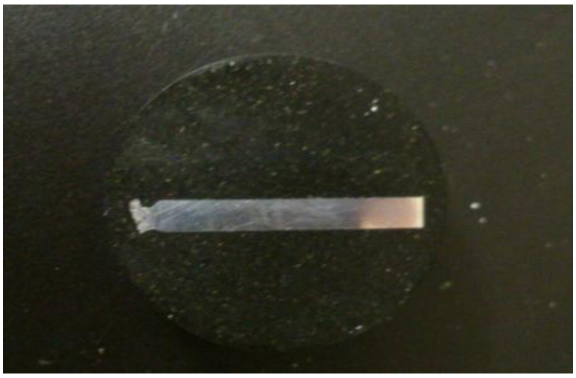


Figure 3.8: Sample is Ready to be Grinded and Polished

vii. Grind and polish the sample until the surface is smooth and mirror like surface

Figure 3.9: Grind and Polish Process

3.6 Sample Testing

3.6.1 Hardness Test

After the surface of the sample is clean and smooth, testing process will take place. . Hardness test is a usual method to get the hardness value by measuring the depth or area of an indentation with specific force applied and specific dwelling time. In this case, load applied is 300gf and the dwelling time is 10 second. This parameter is set according to the type of material that will be tested. The hardness test is performed as below:

i. The machine is set to zero and the sample that has been polished is place at the hardness test machine.

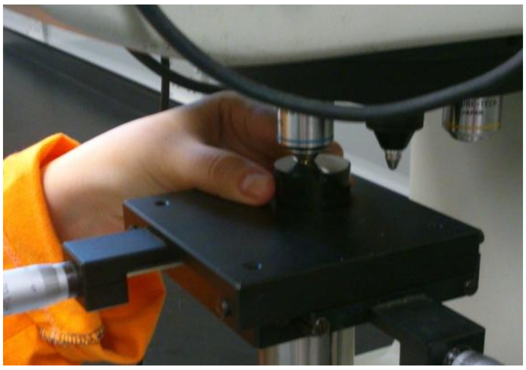


Figure 3.10: Sample is Place at the Test Machine

ii. The machine is adjusted by until the macrostructure of the sample can be seen and the first point that will be indented is set.

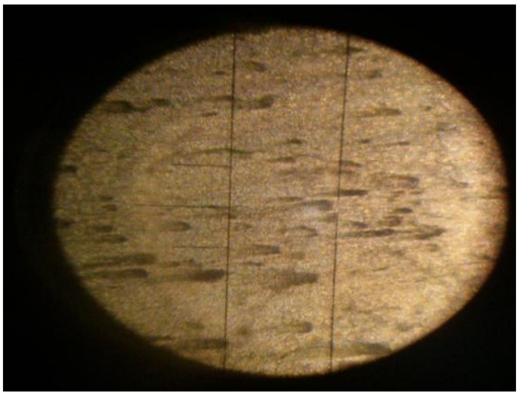


Figure 3.11: Macrostructure of the Sample

iii. Press start button in order to indent the sample.

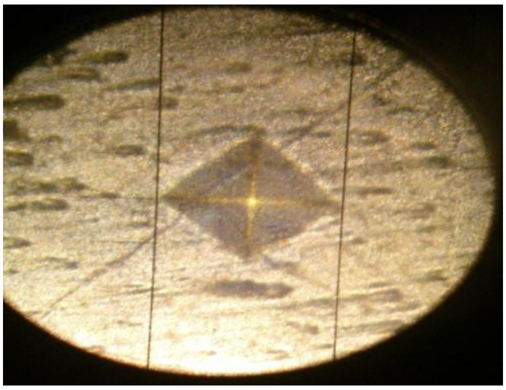


Figure 3.12: After Indent (Diamond Shape Indenter)

iv. The horizontal and vertical reading is captured and the final figure is the hardness number.

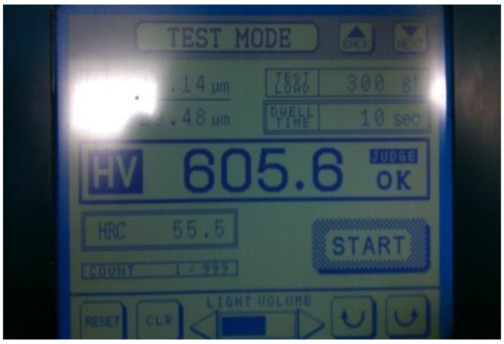


Figure 3.13: HV Readings

v. The process is repeated for 7 more point and the data is collected to be analyzed in a graph.

3.6.2 Microstructure

After taking the hardness measurement, the sample is being taken to the optical microscope to get the surface microstructure. But to get the microstructure can clearly be seen at the microscope, etching must be done to the sample first. The etchant solution is different according to the type of materials that need to be etched. In this case, Nital solution is being used for steel samples, and Keller's solution for aluminium samples. The procedures of etching are as below:

i. For steel, the etching time is about 10 seconds. For aluminium, the etching time is around 2 to 3 minutes. The sample is immersed or swabbed by cotton wipes with the solution.

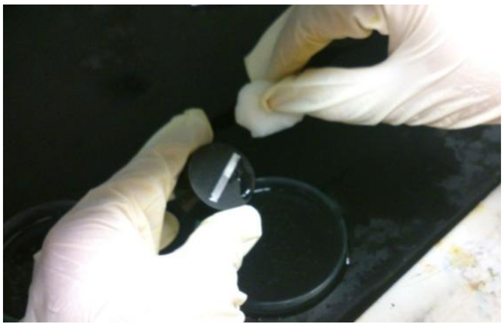


Figure 3.14: Etching Process

ii. The time of etching is done by looking at the sample until it has reaction (haze like surface).

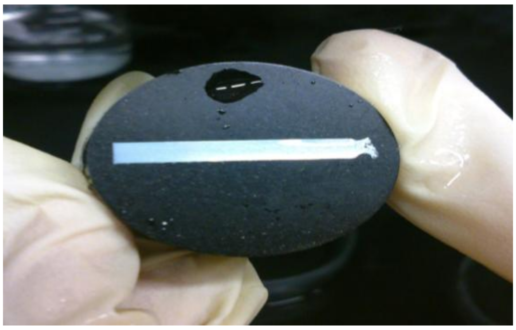


Figure 3.15: Haze Surface During Etching

iii. Rinse the sample with distilled water and followed by ethanol.

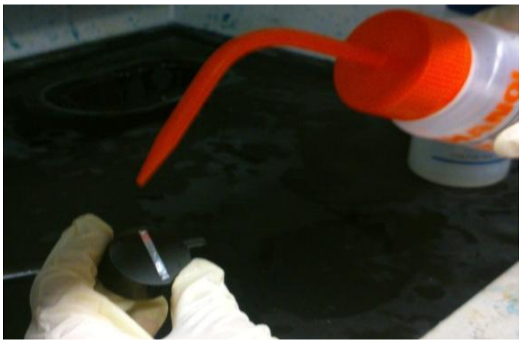


Figure 3.16: Rinse by Using Distilled Water and Ethanol

iv. Put the sample at the dryer until it completely dry.

Figure 3.17: Drying the Sample

v. Put the sample at the microscope to see the microstructure.

Figure 3.18: Microstructure Capture

3.7 Project Activity & Key Milestone

	FYP Schedule Timeline	**FYP I (20 May – 23 Aug 2013)**														**FYP 2 (23 Sept – 27 Dec 2013)**													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	
1	**Introduction** Introduction to Welding of Dissimilar Material																												
2	**Literature Review** Research on the thermal joints (GMAW)																												
	Methodology Determine the welding variable, welding process & Collecting data																												
4	**Result & Discussion** Data analysis & Data collection																												
5	**Final Report**																												

CHAPTER 4

RESULT AND DISCUSSION

4.1 Welding Outcome

From the welding of the 3 welded plates, the possibility to join the dissimilar material is nearly zero. Only one welded plate that manage to survive, that is the plate that using optimum current and voltage. The maximum and minimum current manage to stick at first, but after cooling it for a couple of minutes, the plate starts to separate by itself. So the optimum current that successfully join the plate is 70 Ampere with 18 Volt as constant voltage.

4.2 Hardness Vickers Data and Graph

The hardness Vickers test is done after polishing the sample smoothly. It has been done by taking the hardness measurement at the cross section of the plate, which is near welding zone (heat affected zone). The distance between each indentation is 0.5mm, which can be set at the hardness Vickers test machine itself. The point taken for each sample is 14 points. Below are the data captured by the hardness Vickers testing and the graph plotted from the data:

Table 4.1: Hardness Vickers Data

No.	Point (mm)	Minimum Current, 60A, 17V	Optimum Current, 70A, 18V	Maximum Current, 80A, 19V
1	0.0	181.0	121.7	117.4
2	0.5	174.0	121.4	108.0
3	1.0	180.7	120.2	120.1
4	1.5	182.2	116.2	112.2
5	2.0	193.6	117.1	119.3
6	2.5	182.0	135.1	195.7
7	3.0	235.6	256.5	195.5
8	3.5	90.9	207.2	97.4
9	4.0	90.6	47.7	91.2
10	4.5	79.0	50.9	80.1
11	5.0	77.0	31.4	76.4
12	5.5	76.8	31.9	74.0
13	6.0	77.4	32.3	72.2
14	6.5	75.5	34.6	70.9

*Note: The 7th and 8th Point is at the Heat Affected Zone

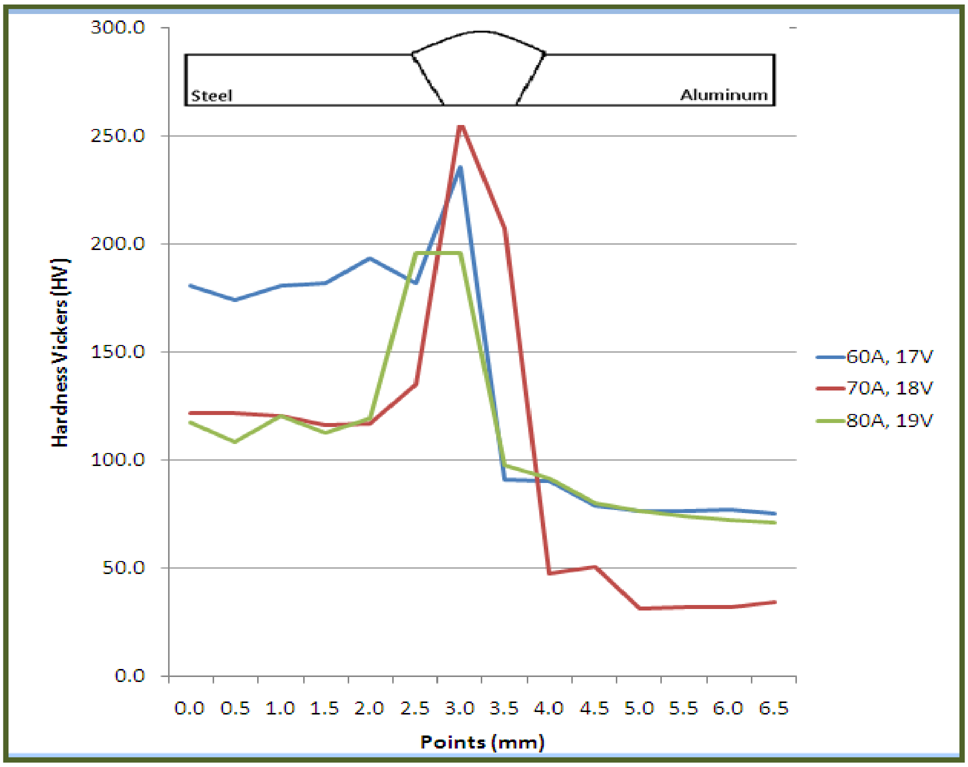


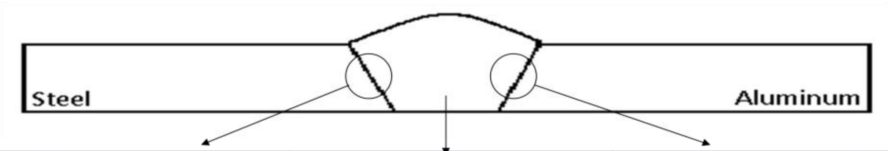
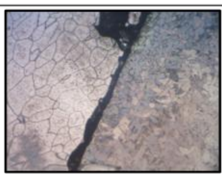
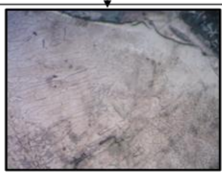
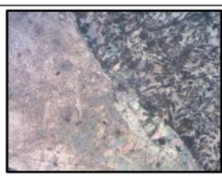
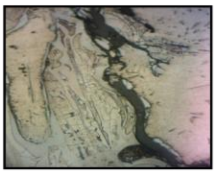
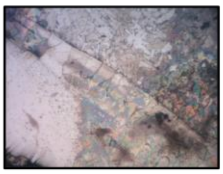
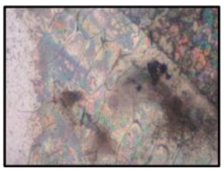
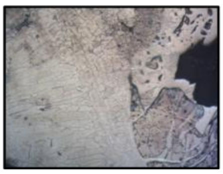
Figure 4.1: Hardness Vickers Graph

From the graph shown, the hardness of the steel is higher compare to aluminium. When the hardness is tested near the welding zone, the hardness of the welding zone near the steel plate is over 100 but it suddenly drop when the hardness is tested on welding zone in aluminium side. There are 3 types of current and voltage used to join the plates but only 1 type is successfully make the plates joint that is 70 Ampere and 18 Volt. The graph line of 60 Ampere with 17 Volt (blue line) and 80 Ampere with 19 Volt (green line) show the difference in hardness at the steel side. The blue line gets the higher hardness than the green line. This is because the heat that has been applied to the plate is 60 Ampere with 17 Volt, which is lower than 80 Ampere with 19 Volt. So, the plate that subjected to more heat is more likely to have lower hardness.

4.3 Microstructure Outcome

Below is the table with figures of microstructure of the welded plate that have been captured after the etching process. The microstructure is taken at the welding joint between steel and the filler material, in the welding zone, and also at the welding joint between filler material and aluminium.

Table 4.2: Microstructure within Heat Affected Zone

			
60A, 17V			
70A, 18V			
80A, 19V			

The table shows 3 pictures of microstructure. The left upper side is the microstructure of the steel plate and welding zone. The grain boundaries can be seen and at the heat affected zone, the grain boundaries of the material become bigger. The below picture shown the grain boundaries inside the welding zone. The grain boundaries are big because of the heat applied in that zone. As for the right upper side picture, the joint is clearly shown near the aluminium. The heat that has been applied to the aluminium by using 309 multi-purpose filler material burnt the aluminium plate. This is due to the aluminium lower melting point.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the result findings, the aluminum and steel plate are nearly impossible to be joined because of its different properties and different melting points. Several currents and voltages had been applied to the plate in order to joint these two different materials.

Although the process is crucial and challenging to be completed, the project is done successfully. With huge different melting point, the possibility of the plate to stick to each other is lower, hence it can easily be broken. The testing method that have to be abandoned are impact test and ultimate tensile strength test (UTS). This is because the joined section is not strong enough to take the high load and force applied from the abandon tests mention.

As the conclusion, the plates with 60 Ampere with 17 Volt and 80 Ampere with 19 Volt which are the minimum and maximum current are failed to be joint whereby the 70 Ampere with 18 Volt which is the optimum current, yet is successful but very brittle.

5.2 Recommendation

The GMAW is chosen because there are not many research have been done to joint dissimilar materials by using thermal joining method. By having some research, the parameter and welding variable is identified to test the specimen. 3 different voltages and currents will be set as the welding process begin to each specimen. The welding angle and welding speed will be set at constant. To avoid any drift to the experiment result, the welding process will have variety of voltages and currents each time it is being weld. This is also important as to obtain desired result and the graft of testing will not be biased. The tests that will be conducted in the project are hardness test and the microstructure of the welded specimen. These tests are usually done by previous research in order to get the best result.

For the recommendation, more research about joining dissimilar material by using thermal joining process must be done in order to get the best result. Recently, many new technology of thermal joined have been implemented in the industry. For example, in Honda, the company manages to develop a new technology to join the dissimilar material by using laser welding. The purpose is only for weight reduction. Although the parts that have been joined are small and not the main parts, but still, the result is good which is they can reduce the weight and also the energy consumption.

From the results, it is actually impossible to join the dissimilar material by just using conventional welding method. In the future, the research can be expand more with adding special treatment to the dissimilar materials before sticking it to each other.

REFERENCE

Brinkster, G. (2006). *Question and Answer*. Retrieved august 2013, from http://misterguch.brinkster.net/q113.html

Bruckner, J. (2004). *Cold Metal Transfer Has a Future Joining Steel to Aluminium*. Retrieved July 2013, from American Welding Society: http://www.aws.org/w/a/wj/2005/06/038/

Cerjanec, D., Feng, E., Li, W., & Grzadzinski, G. A. (2004). Energy Consumption in AC and MFDC Resistance Spot Welding. *Sheet Metal Welding Conference XI* , 1-12.

Cerri, E., & Evangelista, E. (1999). Metallography of Aluminium Alloys. *EAA - European Aluminium Association* (p. 20). Ancona, Italy: TALAT.

Dannyeqs. (2012, June 26). *Hardness Testing: Rockwell/Brinell/Vickers Scales and Applicability to Stamped Sheet Steel Parts*. Retrieved November 2013, from The Future is Forming: http://thefutureisforming.wordpress.com/2012/06/26/hardness-testing-rockwell-brinell-vickers-scales-and-applicability-to-stamped-sheet-steel-parts/

Davis, J. R. (2006). Chapter 9 - Corrosion of Dissimilar Metal Weldments. In *Corrosion of Weldments* (pp. 169-175). USA: ASM International.

Durgutlu, A. (2004). Experimental Investigation of the Effect og Hydrogen in Argon as a Shielding Gas on TIG Welding of Austenitic Stainless Steel. *Materials and Design* , 19-23.

etorgerson.net. (2001). *Difference Between Current and Voltage*. Retrieved august 2013, from Difference Between.info: http://www.differencebetween.info/difference-between-current-and-voltage

Fronius. (1980). In *Welding Handbook* (7th ed., Vol. 3, pp. 170-238). American Welding Society.

Fronius Canada Ltd. (2009). Cold Metal Transfer/The technology. *shifting the limits.* Canad: Fronius.

Goodhew, P. J. (1984). Specimen Preparation for Transmission Electron Microscopy. *Oxford University Press-Royal Microscopy Society* , 12.

Gordon England. (2000). *Hardness Test.* Retrieved November 2013, from Thermal Spray Coatings: http://www.gordonengland.co.uk/

Key to Metals. (2002, March). *Filler Metals for Welding:*. Retrieved July 2013, from Key to Metals: http://www.keytometals.com/page.aspx?ID=CheckArticle&site=kts&NM=71#

Liedl, G. (2011). Joining of Aluminium and Steel in Car Body Manufacturing. *Physics Procedia , 12*, 150-156.

Lincoln Electric. (n.d.). *Constant Current vs. Constant Voltage Output*. Retrieved August 2013, from Lincoln Electric The Welding Expert: http://www.lincolnelectric.com/en-us/support/process-and-theory/Pages/constant-current-vs-constant-coltage-output.aspx

Miller Electric Mfg. Co. (2012). *Guidelines For GMAW.* USA: Miller.

Park, H., Rhee, S., Kang, J. M., & Kim, D. C. (2009). Joining of Steel to Aluminium Alloy by AC Pulse MIG Welding. *Materials Transactions* , 2314-2317, vol. 09.

The Welding of Aluminium MIG & TIG Fusion Pocket Guide. (2004). *Aluminium Federationof South Africa* .

Vander Voort, G. F. (1984). In *Metallography, Principle and Practice* (pp. 165-170). Mc Graw Hill.

Zwleg, T. (2007). *A Universal Method for the Mechanical Preparation of Aluminium Alloy Specimens with High Edge Retention and their Subsequent Colour Etching.* Aarhus, Denmark: Danish Institute of Technology.

APPENDICES

The Effect of Current to Welded Aluminium And Steel By Using Gas Metal Arc Welding (GMAW)

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***Abstract*— in this paper discussed the possibility of joining two different materials (aluminum and steel) by using one of the thermal joining that is gas metal arc welding (GMAW) which can be used in the industries such as in aviation and automotive. The joints will be obtained by GMAW process in which melts metal by heat supplying an electric arc established between a continuously fed filler wire electrode. Test will be conducted with constant welding parameter but with the different voltage. The results will be analyzed by means of hardness test, impact test, ultimate tensile test and microstructure at the welded joint. The strength of the joints varied with increasing of voltage when welding process is implied. The results will be proved after the tests are being done whether the technique of joining aluminum and steel by using GMAW is applicable.**

Keywords— gas metal arc welding, thermal joint, aluminium, steel, dissimilar materials.

I. Introduction

The use of joints between dissimilar materials has increased. Conventional products that are made from steel have been replaced to lighter materials that capable of providing high strength and good corrosion resistance. Aluminium is already used in many fields because of its good corrosion resistance and good welding ability (Bruckner, 2004). The joint will minimizes the energy consumption through the reduction of weight. Aluminium welded with steel has been widely used especially in automotive industries. The joint of these two metals can lead to economy advantages. When joining aluminium with steel, the specific advantages of each of these materials can be utilized.

A. Background of Study

The methods of mechanical joint that commonly been used until now are clinching, screwing and riveting. There are many thermal joining research have been done to joint aluminium with steel. But still, thermal joining is strongly restricted due to the formation of the intermetallic phases. This project will discuss and continue more research about the joint of aluminium and steel by using gas metal arc welding (GMAW).

B. Objective

- To investigate the effects of the welding quality by changing voltage
- To find the best voltage to weld aluminum and steel together
- To study the result of hardness test and the microstructure of the welded plate

C. Problem Statement

There are many problems that are possible to happen when joining these two dissimilar metals such as the possibility of joining aluminium with steel using GMAW and welding quality (Davis, 2006). The insolubility of aluminium and steel can lead to the formation of very brittle intermetallic phases. The differences in physical and chemical properties such as melting point, E-modulus and many other properties cause many problems to join aluminium and steel (Fronius Canada Ltd., 2009). It is necessary to find the effect of current during welding of steel with aluminium by using GMAW.

D. Scope of Study

Reducing weight by joining aluminium with steel is an important task that can be fulfilled by the use of materials with different characteristic. All the benefits of the two materials such as weight reduction, and high thermal conductivity can be obtained (Liedl, 2011). The study consists of choosing the right type of steel and aluminium to be joined together. The hardness and microstructure of the welding plate are investigated in order to analyze the suitable current for the material to be joined successfully.

II. Literature Review

The literature review in this project provides the information for the research. The need of literature review research is to identify what are the sources and information that can be implied in order to complete the research. The literature review consists of:

- Research of Aluminum to Steel Joint (Park, Rhee, Kang, & Kim, 2009)
- Research of Welding Type (The Welding of Aluminium MIG & TIG Fusion Pocket Guide, 2004)
- Gas Metal Arc Welding (GMAW)
- The Welding of Aluminum
- Filler Material (Key to Metals, 2002)
- Current and Voltage in Welding Industry
- Metallography Microstructure (Vander Voort, 1984)
- Testing of Welded Joints (Dannyeqs, 2012)

A. *Critical Analysis*

There are various problems that have occurred to implement the project. At first, gas tungsten arc welding (GTAW) is used as a medium to join the plates. But, the method is unsuccessful. By observations, it could not be fixed because the melting point of aluminium and steel are not the same. In fact, the difference is too high.

GMAW is implemented to affix the two plates and it was successful. To obtain the optimal rate for attaching the plates, several ranges of current and voltage have been tested. However, the joint is very brittle and this resulted that ultimate tensile strength test and impact test are impossible to be done.

III. Methodology

A. *Material Preparation*

1. 3mm thick aluminium and steel plate are cut to 125mm long and 125mm width.
2. The plates are weld together by using GMAW.

B. *Characterization*

The welding parameter such as welding speed and welding angle have been set to constant. Whereas the welding current and voltage are set in order to join the dissimilar plates. The plates are weld together by using 3 types of current and voltage as stated in table below:

Current (*I*)	Voltage (*V*)
60	17
70	18
80	19

Table 1 : Welding parameter

C. *Sample Preparation*

1. After the welding process has completed, the joint plates is cut to small pieces. The cutting area is at the welding zone (heat affected zone) of the plate.
2. The small pieces of the plate are mounted at the cross section to make samples.
3. To get the fine finishing, the samples are grinded and polished until mirror like surface.
4. Before putting the samples at the microscope, the samples have to be etched by using suitable etchant.

D. *Sample Testing*

1. The microstructure of each samples are captured for analysis.
2. The hardness Vickers test is conducted to each of the samples.
3. The data of hardness Vickers test are obtained for graph plotting to get the results.

IV. Result and Discussion

A. *Hardness Vickers Graph*

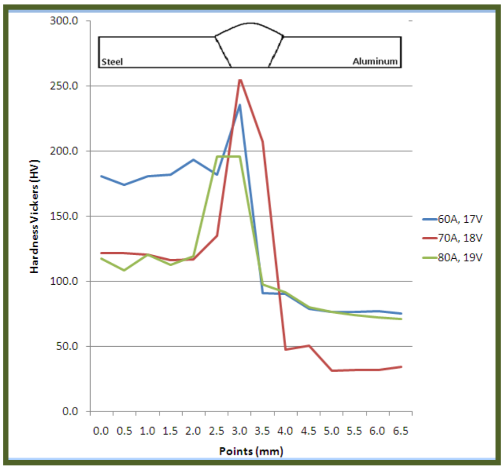

Figure 1 : Hardness Vickers graph

From the graph shown above, the hardness of the steel is higher compare to aluminium. When the hardness is tested near the welding zone, the hardness of the welding zone near the steel plate is over 100 but it suddenly drop when the hardness is tested on welding zone in aluminium side. There are 3 types of current and voltage used to join the plates but only 1 type is successfully make the plates joint that is 70A and 18V. The graph line of 60 Ampere with 17 Volt (blue line) and 80 Ampere with 19 Volt (green line) show the difference in hardness at the steel side. The blue line gets the higher hardness than the green line. This is because the heat that has been applied to the plate is 60 Ampere with 17 Volt, which is lower than 80 Ampere with 19 Volt. So, the plate that subjected to more heat is more likely to have lower hardness.

B. *Microstructure*

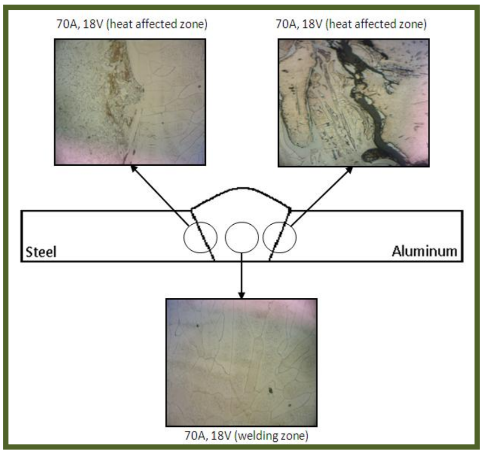

Figure 2 : Microstructure of the welding zone

The figure above shows 3 picture of microstructure. The left upper side is the microstructure of the steel plate and welding zone. The grain boundaries can be seen and at the heat affected zone, the grain boundaries of the material become bigger. The below picture shown the grain boundaries inside the welding zone. The grain boundaries are big because of the heat applied in that zone. As for the right upper side picture, the joint is clearly shown near the aluminium. The heat that has been applied to the aluminium by using 309 multi-purpose filler material burnt the aluminium plate. This is due to the aluminium lower melting point.

V. Conclusion

From the result findings, the aluminum and steel plate are nearly impossible to be joint because of its different properties and different melting points. Several currents and voltages had been applied to the plate in order to joint these two different materials. The plates with 60 Ampere with 17 Volt and 80 Ampere with 19 Volt which are the minimum and maximum current are failed to be joint whereby the 70 Ampere with 18 Volt which is the optimum current is successful but very brittle.

VI. Recommendation

The GMAW is chosen because there are not many research have been done to joint dissimilar materials by using thermal joining method. By having some research, the parameter and welding variable is identified to test the specimen. 3 different voltages and currents will be set as the welding process begin to each specimen. The welding angle and welding speed will be set at constant. To avoid any drift to the experiment result, the welding process will have variety of voltages and currents each time it is being weld. This is also important as to obtain desired result and the graft of testing will not be biased. The tests that will be conducted in the project are hardness test and the microstructure of the welded specimen. These tests are usually done by previous research in order to get the best result.

VII. References

Bruckner, J. (2004). *Cold Metal Transfer Has a Future Joining Steel to Aluminium*. Retrieved July 2013, from American Welding Society: http://www.aws.org/w/a/wj/2005/06/038/

Dannyeqs. (2012, June 26). *Hardness Testing: Rockwell/Brinell/Vickers Scales and Applicability to Stamped Sheet Steel Parts*. Retrieved November 2013, from The Future is Forming: http://thefutureisforming.wordpress.com/2012/06/26/hardness-testing-rockwell-brinell-vickers-scales-and-applicability-to-stamped-sheet-steel-parts/

Davis, J. R. (2006). Chapter 9 - Corrosion of Dissimilar Metal Weldments. In *Corrosion of Weldments* (pp. 169-175). USA: ASM International.

Fronius Canada Ltd. (2009). Cold Metal Transfer/The technology. *shifting the limits.* Canad: Fronius.

Key to Metals. (2002, March). *Filler Metals for Welding:*. Retrieved July 2013, from Key to Metals: http://www.keytometals.com/page.aspx?ID=CheckArticle&site=kts&NM=71#

Liedl, G. (2011). Joining of Aluminium and Steel in Car Body Manufacturing. *Physics Procedia , 12*, 150-156.

Park, H., Rhee, S., Kang, J. M., & Kim, D. C. (2009). Joining of Steel to Aluminium Alloy by AC Pulse MIG Welding. *Materials Transactions* , 2314-2317, vol. 09.

The Welding of Aluminium MIG & TIG Fusion Pocket Guide. (2004). *Aluminium Federationof South Africa* .

Vander Voort, G. F. (1984). In *Metallography, Principle and Practice* (pp. 165-170). Mc Graw Hill.

Zwleg, T. (2007). *A Universal Method for the Mechanical Preparation of Aluminium Alloy Specimens with High Edge Retention and their Subsequent Colour Etching.* Aarhus, Denmark: Danish Institute of Technolog