LAP JOINT DISSIMILAR WELDING OF ALUMINIUM AND STEEL SHEET USING TIG WELDING

UMI KALSOM BINTI MOHAMAD

A report submitted in partial fulfillment of the requirements
For the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

ABSTRACT

Dissimilar metals TIG welding of aluminium 6061 was lap joined to steel sheet and the experiments had been conducted using the filler metals of Al-4043 Si 5 % wt and Al-4047 Si 12 % wt to fabricate the lap joint of aluminium-galvanize iron in order to investigate the mechanical properties and the macrostructure and microstructure of the samples. The lap joint of aluminium-galvanize iron was analyzed by using the NDT test, microstructure of joint, tensile test and hardness test. It was found that the thickness of the IMC layer decreased and the tensile strength of the lap joint increased with the increasing of Si content in the filler metals. The decreasing of the Si content in the filler metals increases the hardness value of samples due to smaller grain size formation. The aluminium that was positioned on the upper part of the lap joint with filler type Al-4043 has the optimum mechanical properties with the tensile strength of 76.59 MPa and the average hardness value of 72 to 82 HV.

ABSTRAK

Kimpalan TIG logam berlainan aluminium 6061 telah disambungkan berlapik pada kepingan keluli dan ujikaji telah dijalankan telah menggunakan logam pengisi Al-4043 Si 5 % wt dan Al-4047 Si 12 % wt untuk menghasilkan sambungan berlapik pada besi aluminium-besi galvanize bagi mengkaji sifat-sifat mekanikal dan macrostruktur serta microstruktur sampel. Sambungan berlapik pada aluminium-galvanize dianalisis menggunakan ujian NDT, microstructure pada sambungan, ujian tegangan dan ujian kekerasan. Didapati bahawa ketebalan lapisan IMC menurun dan kekuatan tegangan sambungan berlapik meningkat dengan peningkatan kandungan Si dalam logam pengisi. Pengurangan kandungan Si dalam logam pengisi akan meningkatkan nilai kekerasan sampel disebabkan oleh pembentukan saiz bijian yang lebih kecil. Aluminium yang diletakkan di bahagian atas pada sambungan berlapik dengan pengisi jenis Al-4043 dimana mempunyai sifat-sifat mekanikal yang optimum dengan kekuatan tegangan daripada 76.59 MPa dan nilai purata kekerasan ialah 72 dan 82 HV.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TIG	Tungsten Inert Gas
GTAW	Gas Tungsten Arc Welding
IMC	Intermetallic Compound
NDT	Non-Destructive Test
TWB	Tailor Welded Blank
OVAT	One Variables At One Time
Fe	Ferum
Al	Aluminium
Zn	Zinc
Si	Silicon
Mg	Magnesium
GI	Galvanize
AC	Alternate Current
DC	Direct Current
°C	Degree Celcius
A_o	Area
P	Load
mm	Milimeter
μm	Micrometer
kN	kilo Newton
sec	Second
δ	Specimens Gage Length
L_o	Original Gage Length
HV	Hardness Value
MPa	Mega Pascal

There are many types of welding processes and as well as many ways to make a weld. One of them is the gas tungsten arc welding (GTAW). The gas tungsten arc welding (GTAW) process is sometimes referred to as TIG, or heliarc. The term TIG is short for tungsten inert gas welding, and the much older term heliarc was used because helium was the first gas used for the process. GTAW is an arc welding process which a shielding gas is used to protect the arc between a non-consumable (does not become part of the weld) tungsten electrode and the weld area. (Moniz, 2004)

Tungsten inert gas (TIG) welding is one of the possible welding processing for joining dissimilar metal between steel and aluminium alloys by using self-brazing technique where the molten zone of steel is controlled to form a partial penetration during lap joint welding between steel and aluminium alloys, since this method could produce partial penetration weld in steel sheet.

For some type of weld such as lap joint, based on structural stresses at the weld root in the joint as failure often initiates from the weld root, the fatigue strength is widely analyzed (Hsu and Albright, 1991; Wang, 1995). The lap joint gives double thickness at the joint, but in many applications (plumbing connections, for example) the double thickness is not objectionable. And the lap joint is generally self-support during the brazing process. Resting one flat member on the other is usually enough to maintain a uniform joint clearance. Lap joint is widely used in applications such as sugar mills & distilleries, pumps & petrochemicals, cement and construction industries

Dissimilar welding of metal joints becomes widely accepted as the superior design alternative for manufactured products between their quality, reliability, and serviceability. The advantages of this dissimilar welding are; no waste produced and it is cheap. The welding industries are working on in areas where there is concern on welded joints due to limitations of materials, process, and ability to ensure quality. Recently, welding dissimilar metal joint promotes a variety of service conditions such as resistance to corrosion, heat resistance and magnetic properties. (Shahrir, 2010) . A lot of study has been done with the dissimilar welding technology nowadays. The most famous welded dissimilar research is between aluminium and steel. (Song, 2009).

1.2 PROBLEM STATEMENT

In the real world, it would really hard to have a dissimilar welding process because it's new development technique and have different material properties. Even though dissimilar welding have a advantages, it also have a drawback due to its attribution to the large difference between their melting points, the nearly zero solid solubility of iron in aluminum, and the formation of brittle intermetallic compound (IMC) such as Fe_2Al_5 and $FeAl_3$ (J.L. Song, 2009) which can cause a detrimental effect on the mechanical property of the workpiece. Due to this reason, there is a demand to fabricate it. Therefore, the details investigation will be done on the dissimilar welding especially aluminium and steel sheet. Both of the materials will be lap joined by the TIG welding process and researching of the microstructure and mechanical properties of the dissimilar welding will be done.

1.3 OBJECTIVE

The project objectives are to:

1) Fabricate of the lap joint dissimilar welding of aluminium-galvanized iron using different filler.
2) Investigate the mechanical properties of the lap joint dissimilar welding.
3) Investigate the macrostructure and microstructure of the lap joint dissimilar welding.

1.4 SCOPE OF STUDY

The scopes of study in this project are:

1) Fabrication of the lap joint dissimilar welding of aluminium-galvanized iron with different aluminium filler by using the tungsten inert gas (TIG).
2) Investigate the mechanical properties of the joint using tensile test and Vickers hardness test.
3) Analyzed the macrostructure and microstructure of the joint using the optical microscope and non-destructive test (NDT).

Welding generally is the economical way to join the component in terms of material usage and fabrications cost. It is the permanent joining of two materials generally metal and resulting from a suitable combination of temperature, pressure and metallurgical conditions. In terms of temperature and pressure, both are usually combined and achieved from the various welding process change. The attention must be given to the cleanliness of the metal surfaces prior to welding and to possible oxidation or contamination of the metal during welding process (Khairi, 2007).

2.2 TIG WELDING

Tungsten inert gas (TIG) arc welding–brazing is a latest technique and becomes a hot research field in joining of aluminum alloy to steel. In this process, the sheets and filler metals are heated or melted by arc (Song, 2009). One of the commonly used techniques for joining ferrous and non-ferrous metals is TIG welding. TIG welding process offers quite a few advantages like joining of dissimilar metals, low heat effected zone, and absence of slag. (Khalid, 2010)

TIG is suitable for joining thin sections because of its limited heat inputs. The feeding rate of the filler metal is somewhat independent of the welding current, hence allowing a variation in the relative amount of the fusion of the base metal and the fusion of the filler metal. Hence, the management of dilution and energy input to the weld can be achieved not including changing the size of the weld. Since the GTAW process is a very clean welding process, it can be used to weld reactive metals, such as titanium and zirconium, aluminum, and magnesium. (Anna, 2006)

On the other hand, the deposition rate in GTAW is low. Too much welding current scan will effect melting of the tungsten electrode and produce brittle tungsten inclusions in the weld metal. Still, by using preheated filler metals, the deposition rate can be improved. The arc welding process constitutes an important segment of welding in manufacturing (Albrecht, 2006). The figure 2.1 shows the GTAW process.

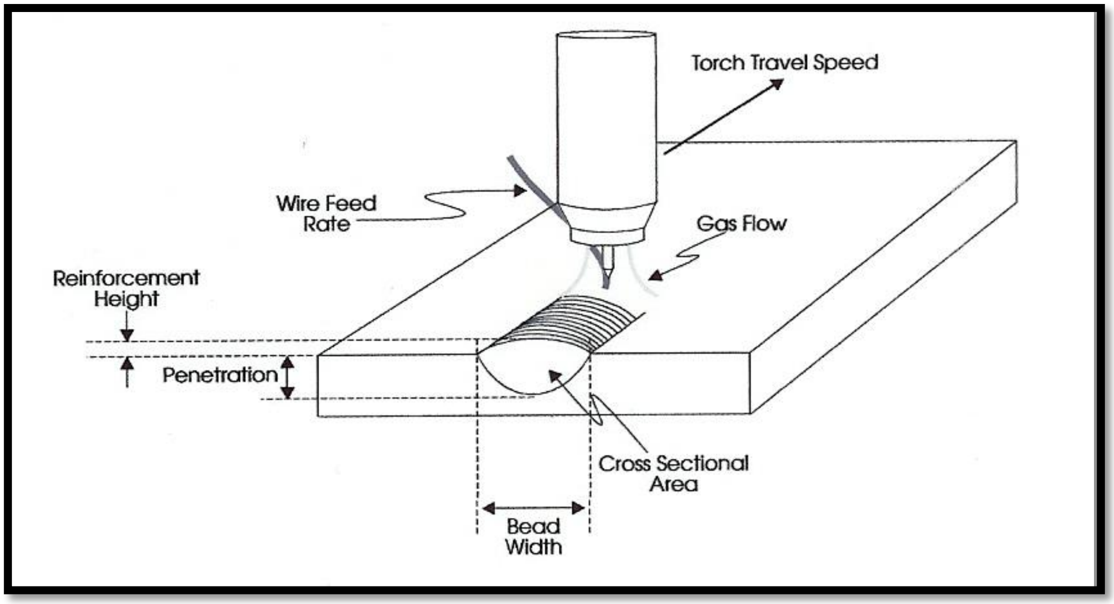

Figure 2.1: The GTAW process (Albrecht, 2006)

2.3 DISSIMILAR WELDING

Dissimilar welding or Tailor Welded Blank (TWB) is a growing requirement of welded. At the moment, it is a new development technique and has becomes a hot research field in study. The most famous joining metals are aluminium and steel dissimilar welding (Song, 2009). The advantages obtain a cost favorable and weight-optimization body with a high stiffness, no waste and energy saving (Honggang, 2011)

Al Wadleigh (1991) stated that dissimilar metals have different chemistries, so they have different physical properties such as melting temperature. Many who have involved with joining metal with different melt temperature experience frustration. This is due to the difficulties arising when trying to melt different metal together at same weld temperature (Shahrir, 2010).

Joining of two dissimilar materials has been an attraction in recent years because of their advanced capabilities. The example of the combination two dissimilar materials is between aluminum and steel due to their potential in automotive applications. Proper welding process and the welding technique is a significant consideration in TWB process. The selection of the welding technique depends on the making of a sound, mixture of aluminum and steel at the interface (Khairi, 2007).

2.4 TYPE OF JOINT

A weld joint is the physical configuration at the juncture of the workpiece to be welded. Weld joint must be correctly designed and have adequate root openings to support load transferred from one workpiece to another through the weld. Weld joint design is based on the strength of the joint, safety requirements, and the service conditions under which the joint must perform (Moniz, 2004). Figure 2.2 shows the basic weld joint.

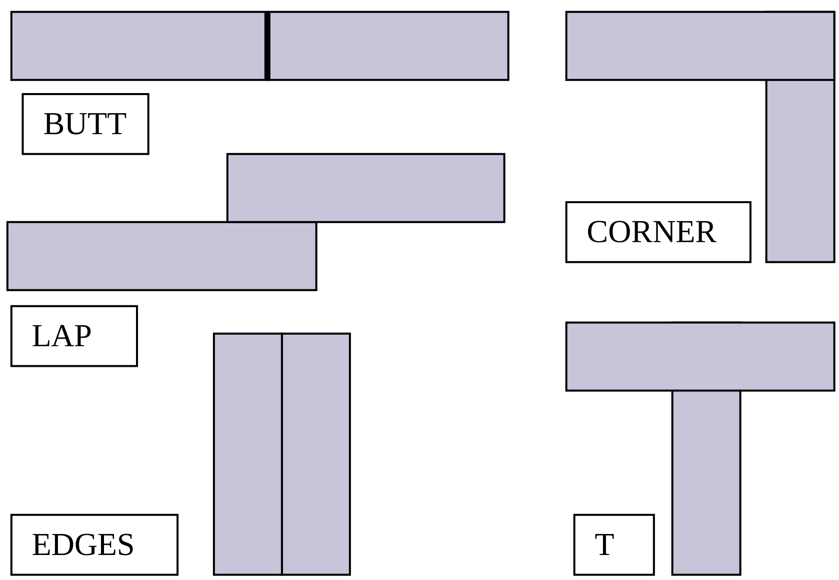

Figure 2.2: Basic weld joint (B.J. Moniz, 2004)

For the given research, single lap joint is chosen from the recommendations given by Broughton (2000), as it is relatively easy to fabricate and test. Lap joint is a weld joint between two overlapping members in parallel planes. It is one of the strongest joint available despite the lower unit strength of the filler metal. Commonly, it is welded in both sides (Moniz, 2004). Figure 2.3 shows lap joint illustration. The bonding area of lap joint is larger and it is show in figure 2.4.

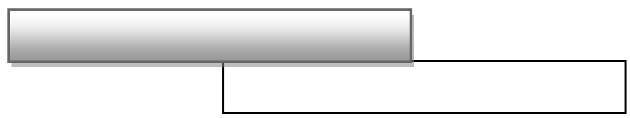

Figure 2.3: Lap joint

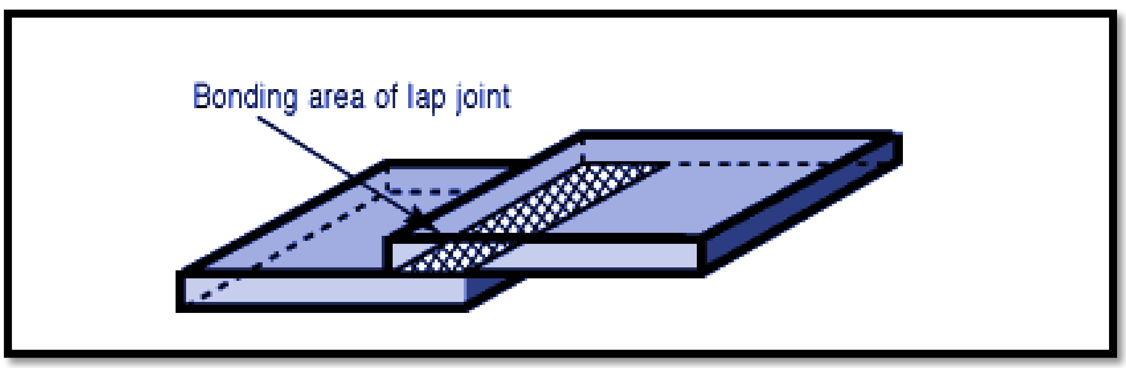

Figure 2.4: The bonding area of lap joint (www.lucasmilhaupt.com)

2.5 MATERIALS

2.5.1 Aluminium 6061 (Al-Mg-Si Alloys)

There are many types of aluminium. The aluminium chosen for this research are aluminium 6061. Aluminium 6061 is in the 6xxx series and has good weldability (J.M. Gomez de Salazar, 2010). The 6xxx alloys have moderately higher strength coupled with excellent corrosion resistance. It also have a higher strength and broad use in

welded structural, such as truck and marine frames and railroad cars and pipelines (N.R. Mandal, 2002). The aluminium melting point is 660 ℃. (Song, 2009)
The characteristic of 6xxx series materials are:

- Heat treatable
- High corrosion resistance, excellent extrudability, moderate strength
- Typical ultimate tensile strength range is 124-400 MPa.
- Building and construction, highway, automotive, marine application

(Mandal, 2002)

2.5.2 Galvanized Iron

Galvanized iron is coated in a layer of zinc to help the metal resist corrosion. The zinc layer protected the metal by forming a physical barrier, usually around 15 μm in thickness. When using galvanized steel, no flux was required to ensure wetting of the zinc-coated steel surface. It is due to the good metallurgical compatibility between Fe, Al and Zn (Sierra, 2008). It also one of the favored as a means of protective coating because of its low cost, ease of application and comparatively long maintenance-free service life. The melting and boiling point of galvanized iron is depending on the zinc layer which coats the steel surface. The zinc layer melting point is 420 ℃. (Virginia, 2010).

2.5.3 Fillers metals

There are two types of filler that will be used in the study which is Al 4047 and Al 4043. This type of fillers will have a great cause in preventing growth of the IMC layer and minimizing its thickness due to its alloying elements. Si composition in Al-based filler metal are used to be in charge of the growth of brittle Al–Fe IMC layer by replacing Al–Fe phases with a smaller amount detrimental Al-Fe–Si phases. (Song, 2009)

3.2 METHODOLOGY FLOW CHART

In this research, it has been identified that the difficulty of the dissimilar welding between aluminium and steel was due to different melting point and nearly zero solubility of iron in aluminium. It becomes one of a reason for a research to be carried out for minimizing the formation of brittle IMC layer in the weld joint. All the related information was collected from journals, reference books and internet from reliable sources. The collected information will be a guideline for this research. Experiments for this research will be performed using TIG welding. Data analysis of this research was to identify the mechanical properties and microstructure and macrostructure of the joint area. Figure 3.1 shows the methodology of this research in flow chart form.

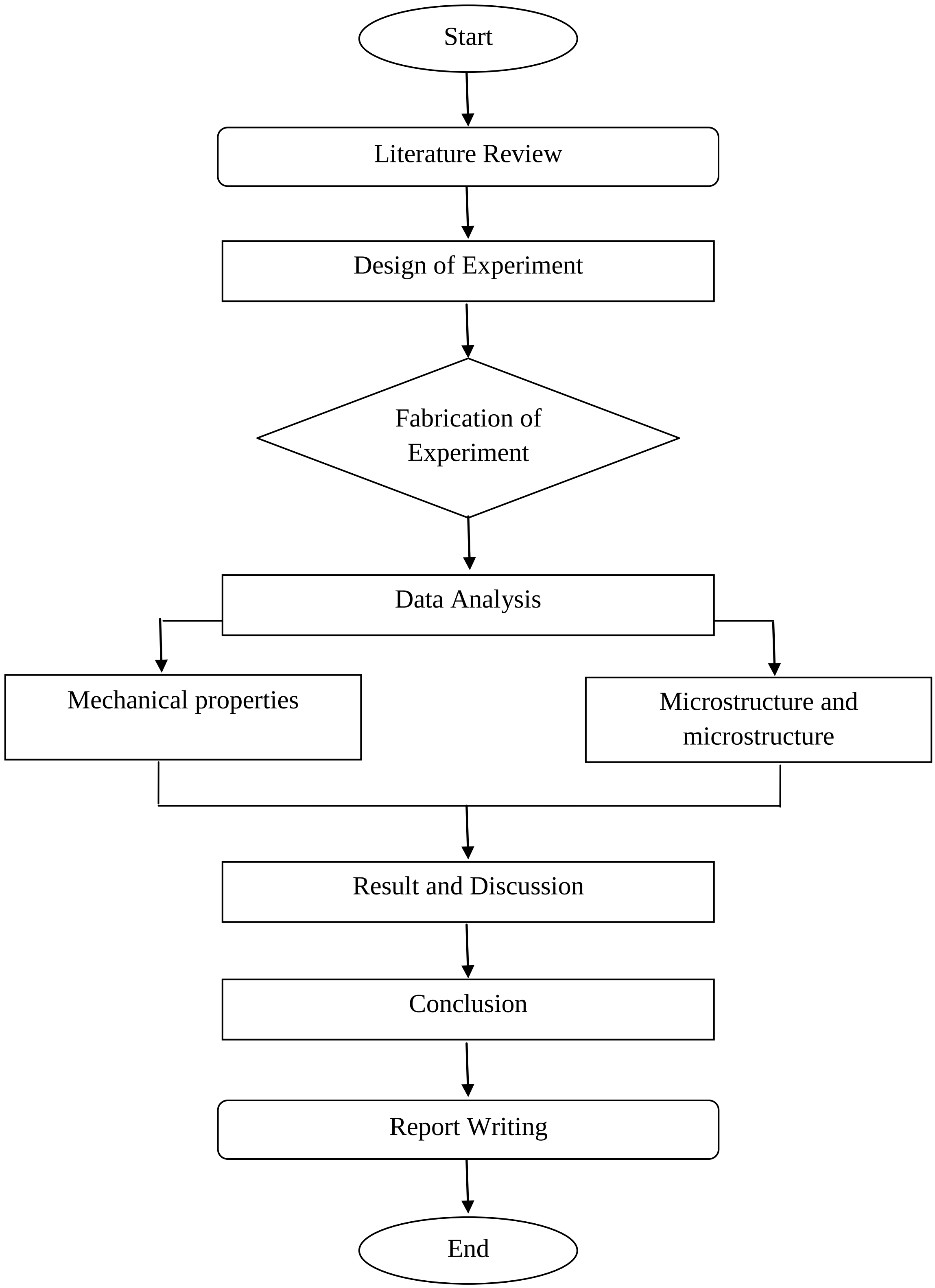

Figure 3.1: Methodology Flow Chart

3.3 DESIGN OF EXPERIMENT

3.3.1 Tungsten Inert Gas (TIG) Welding Machine

TIG welding also known as gas Tungsten Arc Welding (GTAW) uses a non consumable electrode and a split filler metal with an inert shielding gas. TIG process welding set utilizes suitable power sources, a cylinder of argon gas, a welding torch that was linked to electric cable for current supply, and tubing for shielding gas supply. The characteristic of the torch formed is, having a cap at the back end to protect the quite long tungsten electrode against unintended breakage. (Ahmed, 2010). Figure 3.2 shows the Model Miller TIG welding machine is used in this experiment.

Figure 3.2: TIG Model Miller welding machine.

3.3.2 Power Sources for TIG Welding

Power sources for use with TIG welding process must be capable of delivering a constant current at a preset value. TIG can provide either alternating current (AC) or direct current (DC). The choice of AC or DC current depends on the metal and weld requirement. In this research, the TIG with AC current will be use. Generally, AC current will give a better result. (Moniz, 2004)

3.3.3 Shielding Gas for TIG welding

Shielding gas prevents nitrogen and oxygen in the atmosphere from entering and contaminating the weld pool. Shielding gases use for TIG are inert gases such as argon or helium. The shielding gas chosen for this research was argon. It was commonly used and heavier than air which facilities efficient coverage of the weld area so less gas is used and is more economical. (Moniz, 2004).

3.3.4 Fixed Parameter

In this research, there were several parameters which were fixed. The Table 3.1 shows the fixed parameter of the research and Table 3.2 shows the composition of the materials used.

Table 3.1: Fixed parameter

Parameters	**Elements**
Aluminium	6061
Steel type	Galvanized iron
Workpiece thickness	2 mm
Workpiece size	100 mm x 50 mm
Types of joint	Lap joint
Welding current	45A

Table 3.2: Material composition

Adapted from: Honggang (2011)

Elements	**Cu**	**Si**	**Mn**	**Mg**	**Cr**	**C**	**P**	**S**	**Fe**
Al 6061	0.205	0.680	0.0829	0.884	0.167	-	-	-	-
Steel	0.0083	<0.0050	0.286	-	0.0843	0.0683	0.0281	0.0290	98.6

3.3.5 Variable Parameter

Normally, the quality of a weld joint was strongly inclined by process parameters during the welding process. To achieve high quality welds a good selection of the process variables should be utilized (Ahmed, 2010). In this research, the formation of IMC was the main concern. The two types of filler were selected as the main of the research were filler 4043 $AlSi_5$ and 4047 $AlSi_{12}$. Si compositions in the filler metals have a great effect on preventing the growth of IMC layer and minimizing its thickness (Song, 2009). Table 3.3 shows the composition of the fillers.

Table 3.3: Fillers composition

Adapted from: Song (2009)

Elements	Si	Fe	Cu	Zn	Mn	Mg	Ti	Al
4043	4.5-6.0	<0.80	<0.30	<0.10	<0.05	<0.05	<0.20	Bal
4047	11.0-13.0	<0.80	<0.30	<0.20	<0.05	<0.10	-	Bal

3.4 EXPERIMENTAL PROCEDURE

3.4.1 Material Preparation

Materials used were aluminium 6061 and galvanized steel plates with the thickness of 2 mm. The filler metals adapted were Al-4043 and Al-4047, which the two kinds of aluminium based welding wires with different Si compositions.

3.4.2 Cutting Process

Before starting the experiment, both types of plates were cut into 100 mm x 50 mm. The materials were cut into 16 workpieces. The cutting process was done using the MVS-C 6/31 shearing machine. The setting of cutting process was based on the thickness and types of material that needs to be cut. Figure 3.3 shows the dimension of the workpiece to be cut. Figure 3.4 shows the MVS-C 6/31 shearing machine used.

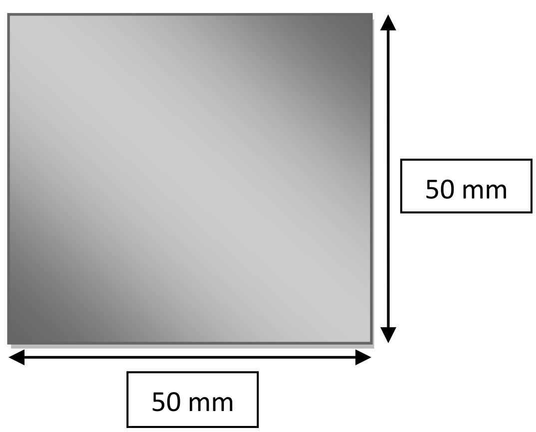

Figure 3.3: Sample dimension cut