

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

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## 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 berlapis 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 berlapis pada besi aluminium-besi galvanize bagi mengkaji sifat-sifat mekanikal dan macrostruktur serta microstruktur sampel. Sambungan berlapis 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 berlapis 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 berlapis 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.

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**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 <sub>o</sub>	Area
P	Load
mm	Milimeter
μm	Micrometer
kN	kilo Newton
sec	Second
δ	Specimens Gage Length
L <sub>o</sub>	Original Gage Length
HV	Hardness Value
MPa	Mega Pascal

## **CHAPTER 1**

### **1.0 INTRODUCTION**

#### **1.1 INTRODUCTION**

Welding is the coalescence or joining together of metals, with or without a filler metal, using heat, and/or pressure. Bonding of metals during welding occurs through localized melting or microstructure changes at the interface between metals. Welding is used throughout industry building construction, aircraft manufacturing, and for automobile production. (Moniz, 2004)

Welding is used to joint metal of different type of strength and for joining of commercial metals and alloys. It has become one of the most important manufacturing methods as well as the most necessary construction method. Nearly everything made of metal is welded. Due to its strength and versatility, welding is applied in the manufacturing of almost all the products used in our everyday life. If there is no welding process, many communities cannot afford the cost of the goods and services they need to earn a living. (Cary and Helzer, 2005)

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  $\text{Fe}_2\text{Al}_5$  and  $\text{FeAl}_3$  (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).

## **CHAPTER 2**

### **2.0 LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

Welding is one of the mainly important and versatile ways of fabrication available to industry. It is used to join hundreds of different commercial alloys in many different shapes. In fact, a lot of products could not even be made without the use of welding, for example, guided missiles, nuclear power plants, jet aircraft, pressure vessels, chemical processing tools, transportation vehicle and plainly thousands of others. Several of the problems that are inherent to welding can be avoided by good consideration of the particular characteristics and the need of the process. Good design of the joint is critical. Proper consideration must be given to the selection of the process and the design of the joint if the potential benefits of welding are to be obtained and risky side effects are to be avoided. (Khalid, 2010)

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).

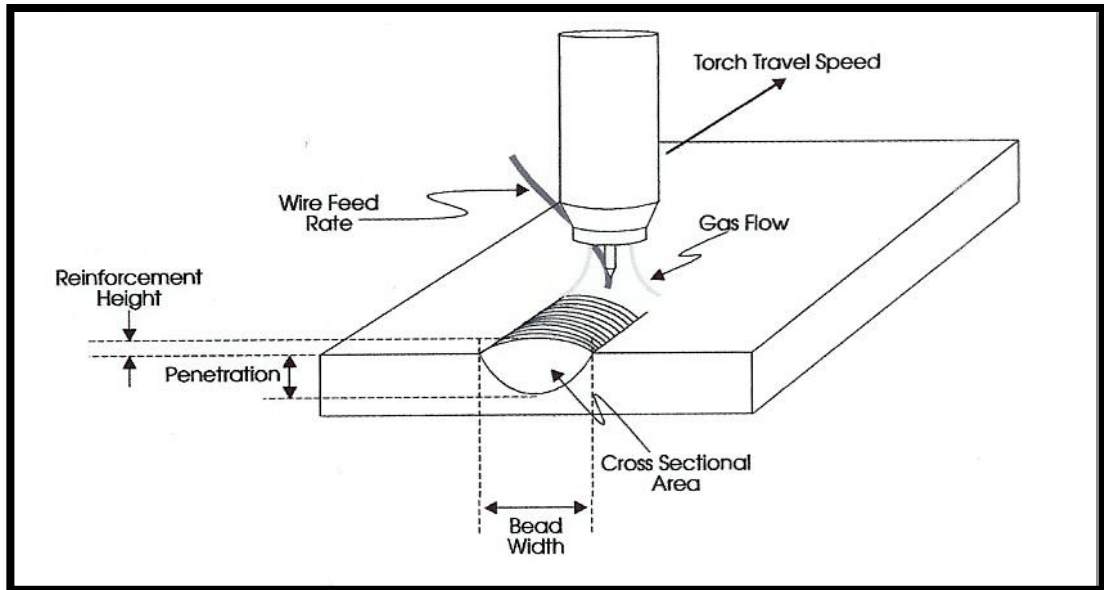
## **2.2 TIG WELDING**

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

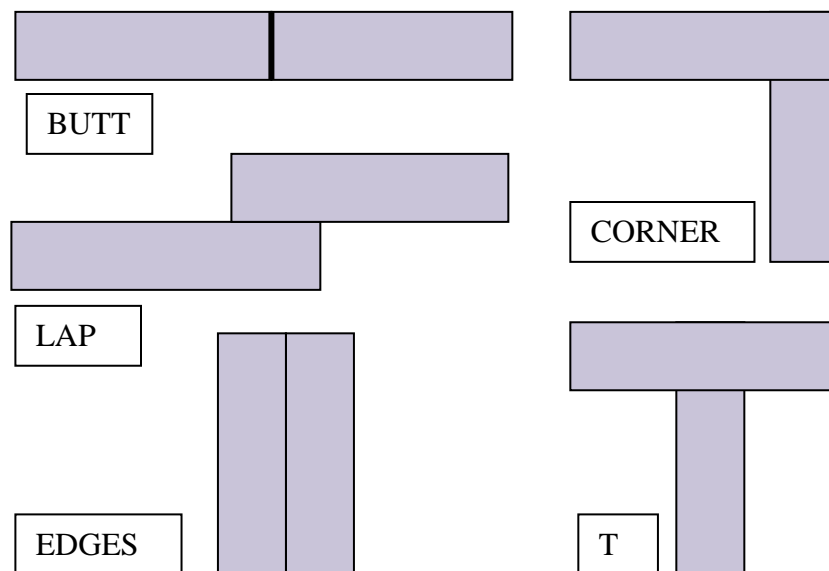
Dissimilar welding or Tailor Welded Blank (TWB) is a growing requirement of welded. At the moment, it is a new development technique and has become a hot research field in study. The most famous joining metals are aluminium and steel dissimilar welding (Song, 2009). The advantages obtain a cost favorable 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.

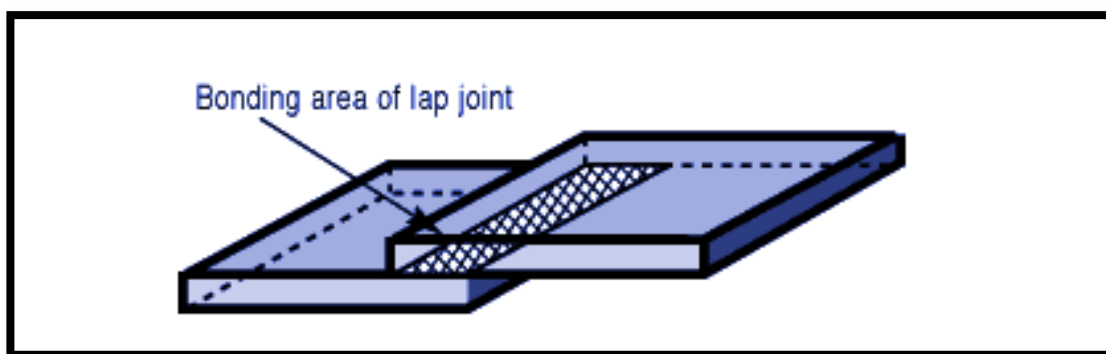


**Figure 2.2:** Basic weld joint (B.J. Moniz, 2004)

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](http://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 °C. (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 °C. (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)

## **CHAPTER 3**

### **3.0 METHODOLOGY**

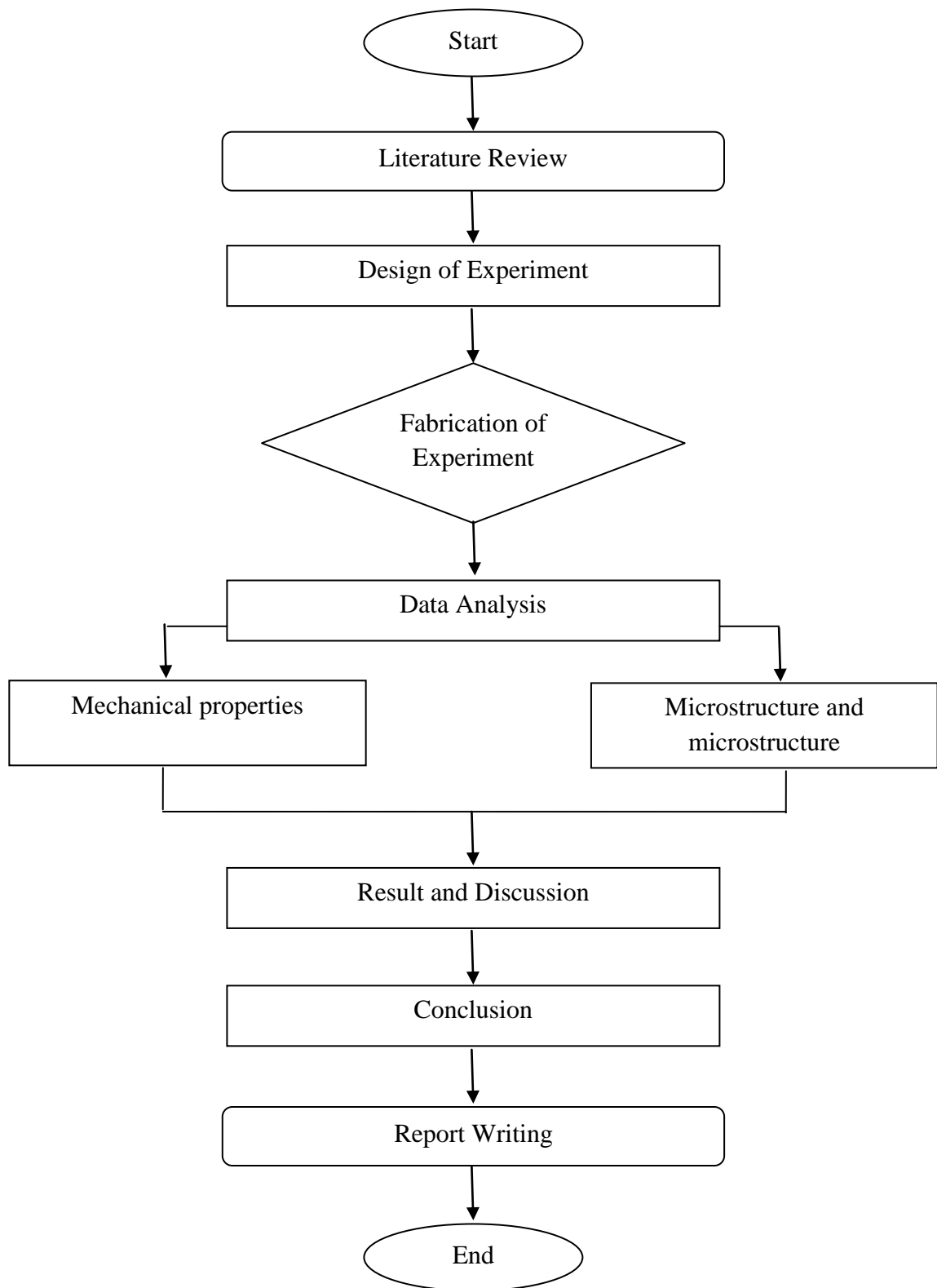
#### **3.1 INTRODUCTION**

These researches are done based on experimental method. Experimental method enables researches to study cause and effect because it involves the intentional manipulation of one variable, while trying to keep all other variables constant. This method is commonly known as OVAT. The experiment is carried to analysis the data for this research.

The first step before starting any research is to plan the research systematically. A specific procedure or methods in methodologies are usually used to solve the problem within the scope. Methodologies show how is to conduct the study when carrying out a research. Mostly, the beginning of research is by identifying the main problem and the sequence of systematic tools to solve the problem.

### **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