INVESTIGATION ON WELD QUALITY USING DIFFERENT FILLER METALS

ZETTY AKHTAR ABD MALEK

Thesis submitted in fulfilment of

the requirements for the award of the degree of

Bachelor of Mechanical Engineering with Manufacturing

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

Dissimilar welding process yields unwanted disadvantages on the weld joint due to the large difference between stainless steel-aluminium sheets melting points and nearly zeros solid solubility between these two metals. Aluminium AA6061 and stainless steel SUS304 were lap-welded by using Metal Inert Gas (MIG) welding with aluminium filler ER5356 and stainless steel filler ER308LSi. The effect of welding voltage and type of filler metals used to the weld joints were studied. The welding voltage had significance effect to the welding process, as high voltage resulted in poor appearance of the weld joint. Joints between aluminium and stainless steel using aluminium filler have good microstructure as it shows enrichment of eutectic silicon particle, thus increase the hardness of the joint. The intermetallic compound layer occur between heat affected zone and fusion zone. The hardness value of welded seam in this joint range from 60 to 100 HV. The fracture in tensile test occurred at the edge of the joint before derive into welded seam with the highest tensile strength of 104.4 MPa. Meanwhile, aluminium-stainless steel joints using stainless steel filler contains carbide precipitate in its microstructure, which is undesirable in welding process. The enrichment of chromium particles indicates that there is element addition in weld joint throughout welding process. The hardness value of the welded seam range from 180 to 230 HV and the highest tensile strength is 61.76 MPa. Based on this study, it can be concluded that aluminium filler ER5356 is the optimum filler in joining dissimilar metal aluminium AA6061 and stainless steel SUS 304.

ABSTRAK

Proses kimpalan berbeza menghasilkan beberapa kekurangan yang tidak dikehendaki di cantuman kimpalan disebabkan perbezaan besar takat lebur antara kepingan aluminium dan keluli tahan karat juga hampir tiada kebolehlarutan pepejal antara dua logam ini. Aluminium AA6061 dan keluli tahan karat SUS304 dipateri berlapik dengan menggunakan kimpalan Gas Besi Lengai dengan bahan pengisi aluminium ER5356 dan bahan pengisi keluli tahan karat ER308LSi. Kesan voltan kimpalan dan jenis logam pengisi kepada cantuman kimpalan telah dikaji. Voltan kimpalan mempunyai kesan penting bagi proses kimpalan, kerana voltan tinggi menyebabkan rupa luaran cantuman kimpalan buruk. Cantuman antara aluminium dan keluli tahan karat menggunakan bahan pengisi aluminium mempunyai mikrostruktur baik apabila ia menunjukkan banyak zarah silikon eutektik, sekaligus meningkatkan kekuatan cantuman. Lapisan sebatian antara logam berlaku di antara kawasan yang terjejas oleh kepanasan dan zon gabungan. Nilai kekerasan cantuman kimpalan berada dalam julat 60 hingga 100 HV. Retakan dalam ujian tegangan berlaku di tepi cantuman sebelum beralih ke cantuman kimpalan dengan kekuatan tegangan tertinggi 104.4 MPa. Sementara itu, cantuman kimpalan keluli tahan karat dengan aluminium menggunakan bahan pengisi keluli tahan karat mengandungi mendakan karbida dalam mikrostrukturnya, yang tidak diingini dalam proses kimpalan. Jumlah zarah-zarah kromium yang banyak menunjukkan terdapat tambahan unsur dalam cantuman kimpalan sepanjang proses kimpalan. Nilai kekerasan cantuman kimpalan berada dalam julat 180 hingga 230 HV dan kekuatan tegangan tertinggi ialah 61.76 MPa. Berdasarkan kajian ini, ia dapat disimpulkan yang bahan pengisi aluminium ER5356 ialah bahan pengisi terbaik dalam penggabungan aluminium AA6061 dan keluli tahan karat SUS 304.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MIG	Metal Inert Gas
HAZ	Heat Affected Zone
GMAW	Gas Metal Arc Welding
TWB	Tailor Welded Blanks
AA	Aluminium Alloy
SUS	Stainless Steel
ER	Electrode Rod
SEM	Scanning Electron Microscope
HV	Hardness Value
ASTM	American Society for Testing and Materials
mm	Millimeter
μm	Micrometer
kN	kilo Newton
Mpa	Mega Pascal
gf	gram force
wt.	Weight Percentage
sec	Second
℃	Degree Celcius
V	Volt
Mg	Magnesium
Al	Aluminium
Si	Silicon
Mn	Manganese
Fe	Ferrous
Cu	Cuprum
Cr	Chromium
Zn	Zinc
Ti	Titanium
Ni	Nickel
Mo	Molybdenum
C	Carbon
P	Phosphorus
Bal.	Balance

CHAPTER 1

INTRODUCTION

Welding is the way of joining two or more pieces of metal to make them act as single piece. Welding has become one of the most important metalworking processes as almost everything made of metal is welded. Product of the welding industry includes automobiles, airplanes, jet engines and etc. Some of the advantages of welding are it is the lowest cost for permanent joining method and it provides design flexibility.

1.1 PROJECT BACKGROUND

Dissimilar welding is where weldments are made from metals of different compositions and melting temperature. It has gotten attention nowadays, due to its manufacturing cost and working operations reduction ability. Besides that, this type of joining offers the potential to utilize the advantage of different materials that often provides a whole structure with unique mechanical properties. For example, hybrid structure of aluminium alloy and stainless steel are suggested in spacecraft, automotive and steamship to improve the fuel efficiency, increase the fly range and control air pollution by reducing the weight.

1.2 PROBLEM STATEMENT

Even so, the dissimilar welding process yields unwanted disadvantages on the weld joint, such as brittle intermetallic reaction phase formation at elevated temperature. The defect that may occur in the specimens of this project is due to the large difference between steel-aluminium sheets melting points and nearly zero solid solubility of iron in aluminium. Furthermore, differences in thermo physical properties such as expansion coefficient, conductivity and specific heat can lead to residual stresses after fusion welding. Weld joint is the most important area and heavily affected by the selection of filler metals. Thus, selection of the filler metals make such an impact to the weld joint as it adds to the base metal elements that improve the properties of the weld metals. This project looks into the effect of welding fillers on the quality of the weld joint and defects that may occur during the welding process of steel-aluminium sheets. Besides that, we also investigate the mechanical properties of the weld joint.

1.3 OBJECTIVES

The objectives of this project include;

1) Fabrication of welded stainless steel-aluminium sheets using different fillers.

2) Investigate the weld quality and defects, also the mechanical property of the joints.

3) Investigate optimum filler metals to be used to joint stainless steel-aluminium sheets.

1.4 SCOPE OF WORK

1) Fabrication of aluminium-stainless steel joints using different fillers by Metal Inert Gas (MIG) welding process.

2) Analyzed the microstructure and phase composition of the joints using optical microscope.

3) Investigate the specimen’s mechanical properties (fracture behaviour) of the joints using tensile tests and Vickers hardness test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are many types of material joining process which includes; welding, brazing, adhesive and diffusion bonding, and mechanical joining. Welding refers to a process in which the base metal itself is melted and allowed to flow together, forming a single piece as the molten weld pool solidifies. During welding, additional filler metal may be added to assist in forming weld bead (Larry Jeffus, 1999). Welding involving melting of the parent metal requires the attainment of quite elevated temperatures in a concentrated area (Dr. Barry M. Patchett,2003).

2.2 WELD AREA

Welding area is the area which resulted from welding process. Figure 2.1 shows the thermal cycles in weld zones. The darkest gray in the cross-section of a welded butt joint, represent the weld or fusion zone, the medium gray are the heat affected zone (HAZ), and the white are the base material. HAZ is the area of base material, which had its microstructure and properties altered by welding or heat intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change in the area surrounding the weld. The extent of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

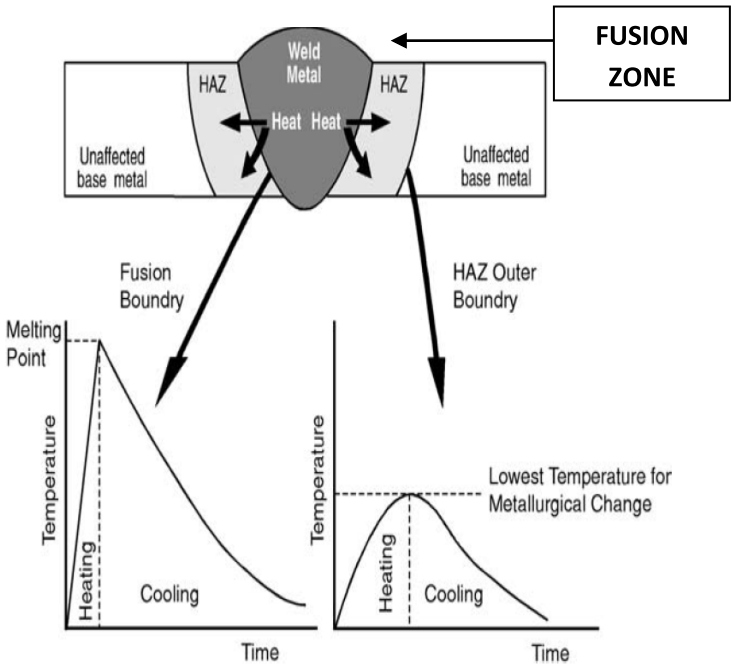

Figure 2.1: Thermal cycles in weld zones

Source: Dr. Barry M. Patchett, 2003

2.3 TYPE OF WELDING

Welding is most commonly accomplished using one of these following process; shielded metal arc welding (SMAW), Gas Metal Arc Welding (GMAW), Resistance Spot Welding, Brazing or Soldering. This type of welding are grouped into the fusion type welding. For this project, we choose to focusing on using GMAW because its availability and practicality in the industry area.

2.4 GAS METAL ARC WELDING (GMAW)

Gas Metal Arc Welding (GMAW) is frequently referred to as Metal Inert Gas (MIG) welding. MIG welding commonly uses high deposition rate welding process. MIG welding uses a welding wire that is fed automatically at a constant speed as an electrode. An arc is generated between the base metal and the wire, and the resulting heat from the arc melts the welding wire and join the base metal together. This method is called a semiautomatic arc welding process, because wire is fed automatically at a constant rate and the welder provides gun movement. During the welding process, a shielding gas protects the weld from the atmosphere and prevents the oxidation of the base metal. Figure 2.2 shows welding area on MIG welding. Whereas, the Figure 2.3 shows schematic diagram of MIG welding device.

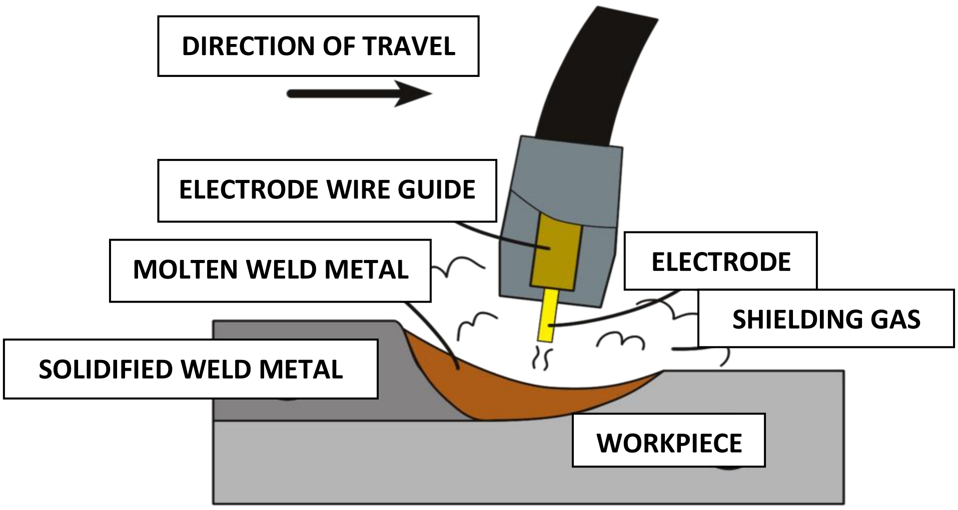

Figure 2.2: Welding area of MIG welding.

Source: The Procedure Handbook of Arc Welding, 1994

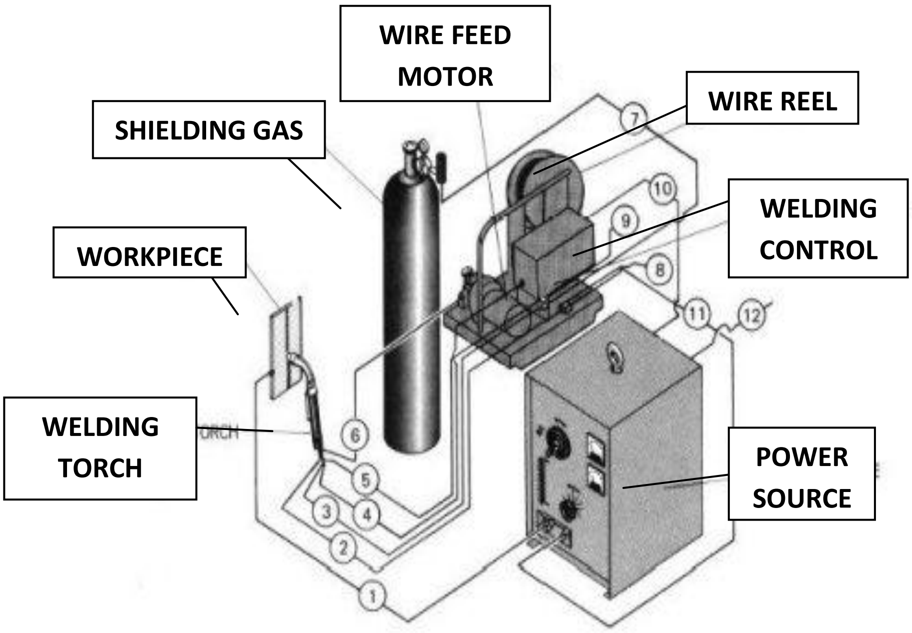

Figure 2.3: Schematic diagram of MIG welding device

Source: MIG handbook (Equipment-Manual and Mechanized), 2006

2.4.1 Advantages of MIG Welding

The advantages of MIG welding includes; can produce higher quality welds faster and more consistently, low current can be used to MIG-weld thin metals, and fast welding speeds and low currents prevent heat damage to adjacent areas that can cause strength loss and warping (Larry Jeffus, 1999). Some researchers have used solid state and fusion welding processes to join aluminium and steel. These welding processes include friction welding, resistance spot welding, impact welding, ultrasonic butt welding and etc. However, some these methods need rather high pressure or costly equipments and other methods could not guarantee the joint mechanical property for the generation of excessive brittle intermetallic compounds. So high efficiency and low cost joining method still is a target for joining aluminium and steel in promoting the use of hybrid structures (Hongtao Zhang and Jiakun Liu, 2011).

2.5 TAILOR WELDED BLANKS (TWB)

One of the fastest growing technologies in metal- working today is the application of Tailor Welded Blanks (TWB) for the manufacture of automobiles and trucks. A TWB is a blank that is comprised of two separate pieces of sheet metal that has been welded together previous to stamping. TWB allow the welding of the different grades, different thickness or different corrosion coatings together in order to give the properties needed in different areas, without increasing the number of tools needed to form the part and eliminating the fit ability concerns. They also allow a high degree of flexibility in designing parts and large blanks can be formed from much smaller sheets (Frederick I. Saunders, 1994). The TWB industry continues to experience steady growth. Each automotive company now has TWB applications and the growth rate is approximately 25% to 30% per year in North America, Europe and Japan. The leading objectives continue to be cost reduction, structural improvement and mass reduction. Figure 2.4 shows application of TWB to the construction of car bodies.

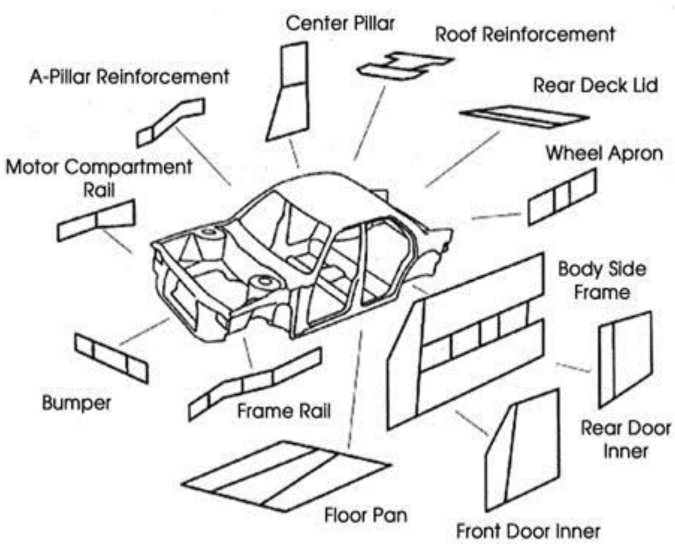

Figure 2.4: Application of TWB to the construction of car bodies.

Source: Frederick I. Saunders, 2001

2.5.1 Advantages of TWB

The advantages of such a process are numerous. Approximately 30 to 50% of the sheet metal purchased by some stamping plants ends up as scrap; scrap which can be used for new blanks with TWB technology. Alternatively, TWB can be constructed leaving unused area open, thus minimizing offal directly. Part consolidation, made possible by distributing material thickness and properties, allows for reduced costs and better quality, stiffness and tolerances. TWB provide greater flexibility for component designers. Instead of being forced to work with the same gage, strength or coating throughout an entire part, different properties can be selected for different locations on the blank (F.I.Saunders and R.H.Wagoner, 1995).

2.5.2 Progress on TWB Research

There have been only few published results on the formability of tailor-welded blanks. Azuma et.al. studied the behaviour of tailor-welded blanks in three standard forming operations, while Nakagawa et.al. and Iwata et.al. used the finite element method (FEM) to analyze similar geometries (F.I.Saunders and R.H.Wagoner, 1995). In 2002, there was a study of damage initiation and fracture in aluminium tailor welded blanks made via different welding techniques. Different weld orientations have been considered in the research, which is transverse and longitudinal. In general, TWBs show two different types of fracture: weld failure and failure of the thinner aluminium sheet. Interaction of several factors determines the type of failure occurring in a TWB specimen. These factors are weld orientation, morphology and distribution of weld defects (H.R Shakeri, A.Buste, M.J. Worswick, 2002). The study on formability and weld zone analysis of Tailor-Welded Blanks for various thickness ratios was conducted on 2005. Cold-rolled steel sheets of thicknesses ranging from 0.5 to 1.0 mm were used to produce tailor-welded blanks (TWBs) with various thickness ratios. In this study, the formability of the TWBs, as well as the mechanical characteristics of the weld zones were analyzed experimentally under the effects of various thickness ratios of TWBs. The experimental findings in this study showed that the higher the thickness ratio of the

TWBs, the lower the forming limit curve level, and the lower formability. The minimum major strain was clearly inversely proportional to the thickness ratio of the TWBs. On the other hand, the results of uniaxial tensile tests clearly illustrated that there was no significant difference between the tensile strengths of the TWBs and those of the base metals. The metallographic study demonstrated a difference of grain size in the materials at base metal, heat-affected zones, and fusion zone. The microhardness measurement indicated that the hardness in the fusion zone increased by about 60% of the base metal (L. C. Chan, S. M. Chan, C. H. Cheng, and T. C. Lee, 2005). As of now, very few have taken into accounts the effects of filler metals in formation of TWB in terms of weld joint quality. This project intends to clarify the effect of these type of parameter using available resource.

2.6 SELECTION OF MATERIAL (ALUMINIUM AND STAINLESS STEEL)

Aluminium and stainless steel are used in this project for its various advantages and availability. Aluminium can reduce the weight of structural parts for its light weight and stainless steel has a high strength and excellent corrosion resistance (Hongtao Zhang, Jiakun Liu, 2011). Figure 2.5 shows typical cross-section of the aluminium–steel lap joint as observed by Hongtao Zhang and Jiakun Liu. The characteristic properties of aluminium, high strength stiffness to weight ratio, good formability, good corrosion resistance, and recycling potential make it the ideal candidate to replace heavier materials (steel or copper) to respond to the weight reduction demand within the industry (W.S. Miller, L. Zhuang, J. Bottema, 2000). For this project, aluminium with coding AA6061 and stainless steel SUS304 are used. These Al-Mg-Si alloys (AA6061) are primarily used for extrusion alloys, although they can also often be found as sheet and plate. The hardening constituent in 6XXX series alloys is magnesium silicide Mg2Si. These alloys contain small amount of silicon and magnesium, typically less than 1% each, and may be further alloyed with equally small amounts of manganese, copper, zinc and chromium. The alloys are sensitive to weld metal cracking, particularly when the weld metal is rich in parent metal (Gene Mathers, 2002). Austenitic stainless steels include the 200 and 300 series of which type 304 is the most common. The primary alloying additions are chromium and nickel as chromium provides basic corrosion resistance and nickel provides high temperature strength and ductility (Jeff Nadzam, 2010).

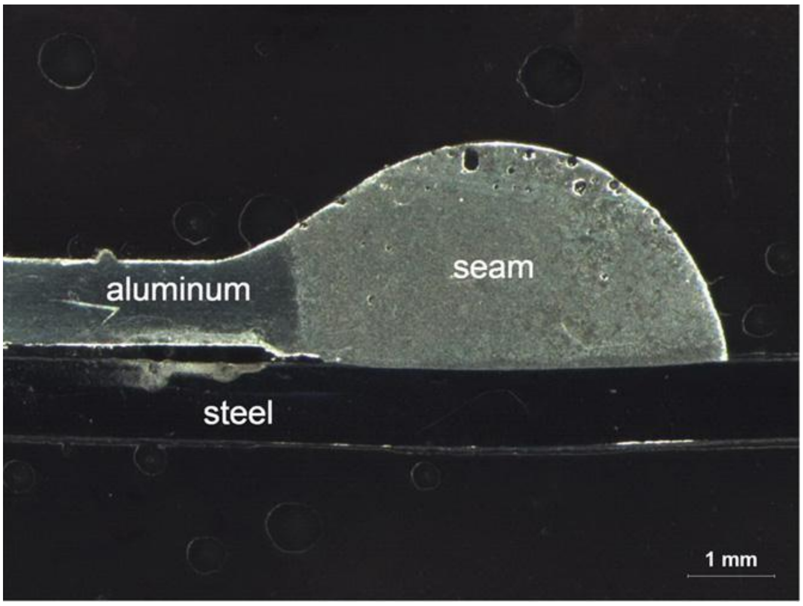

Figure 2.5: Typical cross-section of the aluminium–steel lap joint

Source: Hongtao Zhang and Jiakun Liu, 2011.

2.7 SELECTION OF FILLER METALS (ALUMINIUM AND STAINLESS STEEL)

For applications where both pieces are the same alloy, select filler metal with a composition similar to that of the base metals. This will ensure the weld has similar properties. Dissimilar base metal applications require selection based on mechanical properties, freedom from cracking, and compatibility. The 6XXX alloys are readily weldable using either 4043 or 5356 filler metal (Jeff Nadzam, 2010). But, for the joint with a slightly increased risk of hot cracking, the filler with higher magnesium alloys such as ER 5356 were used. The Alloying Elements by Weight (AWS) for stainless steel is different than for steel wires. Stainless steel filler wires are designated like the American National Standards Institute (ANSI) base metal designations. The AWS specification for solid stainless steel electrode wire is AWS A5.9. An example of AWS specification is ER308L; where ER stands for electrode rod, 308 for electrode composition and L for additional requirements change in original alloy. ER308LSi electrode is used for welding dissimilar base metal. This electrode is one of the most versatile stainless electrodes and is recommended for welding stainless steel to mild steel, and stainless steel to low alloy steels, and for joining heat-treatable stainless steel when heat treatment is not possible (David Hoffman, Kevin Dahle, David Fisher, 2011).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describe the flow and details of this project, starting from fabrication of aluminium-stainless steel joint to analyzing the microstructure and mechanical properties of the specimen.

3.2 EXPERIMENT SETUP

3.2.1 Material Preparation

Materials used are AA6061 aluminium alloy and SUS304 stainless steel plates in 2.0 mm thickness. The filler metal used ER 308LSi and ER 5356, with a diameter of 2.5 mm. Table 3.1 represents chemical composition of AA6061 and aluminium filler ER 5356. Chemical composition for SUS 304 and stainless steel filler ER 308LSi are shown in Table 3.2. All plates were cut into the sizes of 110 mm x 25 mm using MVS/C 6/31 shearing machine with maximum capacity up to 209 kN. After setting up the machine, the length of work piece should be entered to its screen along with the blade clearance (maximum and minimum position), rake angle and percentage of cutting that can be referred in specification table pasted on machine. Figure 3.1 shows the MVS/C 6/31 shearing machine.

Table 3.1: Chemical Composition for AA6061 and ER 5356 (wt. %)

	Mg	Al	Si	Mn	Fe	Cu	Cr	Zn	Ti
AA 6061	0.84	97.7	0.54	0.01	0.40	0.24	0.18	0.006	0.031
ER 5356	4.5	Bal.	0.50	0.20	0.50	0.10	0.20	0.10	0.06

Table 3.2: Chemical Composition for SUS 304 and ER 308LSi (wt. %)

	Cr	Ni	Mo	Cu	C	Si	Mn	P	Fe
SUS 304	18.36	9.23	0.07	0.08	0.051	0.76	0.97	0.027	Bal
ER 308LSi	19.5	9.0	0.75	0.08	0.03	0.65	2.5	0.03	Bal

Figure 3.1: MVS/C 6/31 Shearing machine