STUDY ON THE EFFECTS OF BUTT WELD JOINT BEVEL ANGLES ON TENSILE PROPERTIES OF ALUMINUM ALLOY 6061

by

MOHAMAD FARIS BIN AB MANAS

Dissertation submitted in partial fulfillment
of the requirements of the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

September 2013

CERTIFICATE OF ORIGINALITY

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

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Mohamad Faris Bin Ab Manas

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Given this opportunity, I would like to acknowledge those who have been helping me, either directly or indirectly, in continue working on the project – starting from preliminary research, to the development phase and until the completion phase of this Final Year Project in Universiti Teknologi PETRONAS.

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ABSTRACT

The purpose of this study is to examine the effects of different bevel angle of butt weld joint to the tensile properties of aluminum alloy. Gas tungsten arc welding (GTAW) will be the selected welding process and aluminium alloy 6061 will be the subject of the study. Tensile test will be conducted to acquire the tensile properties of the aluminum alloy. The samples of aluminum alloy 6061 will be cut into desired dimension and shape for the welding process. Then, for the tensile test, the samples will be cut into required shape depends on the testing machines. Data will be collected and comparison between the tensile properties of the samples with different weld joint will be made. Then we can see how the bevel angle of the butt weld joint affected the tensile properties of aluminum alloy 6061.

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ABBREVIATIONS AND NOMENCLATURES

GTAW	Gas Tungsten arc Welding
GMAW	Gas Metal arc Welding
TIG	Tungsten Inert Gas
FSW	Friction Stir Welding
UTM	Universal Testing Machine
ASTM	American Society for Testing and Materials
UTS	Ultimate Tensile Strength
HAZ	Heat Affected Zone
DC	Direct current
AC	Alternate current
FCC	Face Centered Cubic
BCC	Body Centered Cubic
Al	Aluminum
Si	Silicon
Mg	Magnesium
Cu	Copper
Mg_2Si	Magnesium Silicide
Mn	Manganese
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Aluminum and its alloys are used extensively in wide range of industries such as structural, transportation and manufacturing. The reasons behind that are because they possessed good mechanical properties, acceptable corrosion resistance, light weight, high strength, appropriate weldability, and high toughness [1].

Welding of aluminum alloys is a challenging and difficult operation. This is due to the high level of defects that may occur during welding process because aluminum and its alloys are well known that they are highly reactive with oxygen, they have high thermal conductivity, and they have high hydrogen solubility at high temperature [2]. Gas Tungsten Arc Welding (GTAW) is one of the most important welding processes. It uses a non-consumable tungsten electrode to produce the weld and is widely used to weld Al-Mg alloys.

Butt weld joint is the most basic welding joint and widely used in welding of metal plates. There are many types of butt weld joint for example single bevel, double bevel, single-V, double-V, single-U and many more. These types of joint are determined by the thickness of material to be welded. Usually, double sided groove is used to weld material that has a high thickness, greater than 10mm [15]. For this project, the thickness of sample is about 10mm. Double bevel butt weld with bevel angle of 30°, 35°, and 40° will be used to weld the sample.

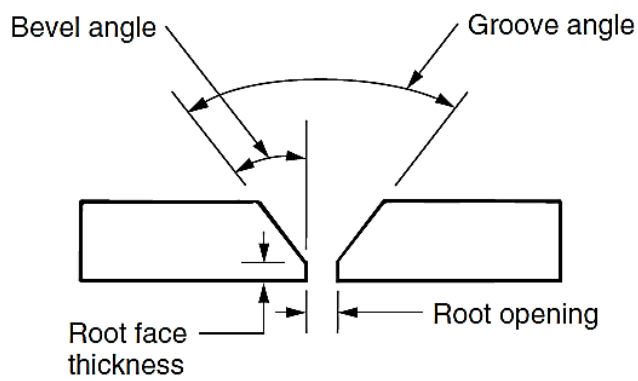


Figure 1: Bevel angle of double bevel butt weld [16]

This proposed project focuses on the effect of butt weld joint bevel angles using GTAW to the tensile properties of aluminum alloy 6061. The tensile properties of aluminum alloy 6061(base metal) will be tested and be the datum for this study. The sample of aluminum alloy 6061 will be welded using GTAW process with different butt weld bevel angles and then undergo tensile testing.

1.2 Problem Statement

Welding of aluminum alloy caused the material to lose its mechanical strength. For different bevel angle, different welding parameters (current, welding speed, welding voltage etc.) are needed. These parameters can influence the tensile properties of welded materials. Besides that, AA6061 is Al-Mg-Si base alloy and it is crack sensitive. Using filler 5356 which is Al-Mg base filler will reduce cracking tendency. Magnesium increases strength through solid solution strengthening and improves strain hardening ability. Difference bevel angle used difference volume of filler thus; this also could influence the tensile properties of welded AA6061.

1.3 Objective

- To find the tensile properties of welded aluminum alloy 6061of different butt weld bevel angles.
- To study the effects of different bevel angle on the tensile properties of welded aluminum alloy 6061.

1.4 Scope of Study

- Gas Tungsten Arc Welding process
- Weld Joint
- Filler metal 5356
- Mechanical properties and composition of aluminum alloy 6061
- Tensile test
- Cutting machine for sample shaping

1.5 Relevancy of the Project

From this project, by defining the right butt weld bevel angle for applications of welding of aluminum alloy 6061, it may bring the significance as a scientific reference to welding industries in improving the properties of welded aluminum alloy and in terms of economic also. This project may provide a wider application to the personnel involved in aluminum welding because of significant improvement in tensile properties of the welded material.

1.6 Feasibility of the Project

This project is analyzed to be feasible where the laboratory equipment is all provided in the university. The implementations of the experiments follow the standards and procedure, which become the fundamental to complete the project. The allocation of financial cost is sufficient for this project. Tables above show estimated cost and time for this project.

Estimated Cost

Table 1: Estimated cost for this project

Material/Process	Cost (RM)
GTA Welding (may pay for expert)	50-100
Aluminum alloy plates (100x100x10mm) x7 pieces	100
Sample Cutting, Tensile Testing (available in Campus)	–
Total cost	RM150-200

Estimated Time (FYP 2)

Table 2: Estimated time for this project

Process	Period (Week)
Sample preparation for welding	1
GTA welding	2
Sample preparation for tensile testing	1
Tensile testing	1
Data analysis	2
Data presentation	2
Total Weeks	9 weeks

From the tables, it is shown that the cost is less than the allocated financial cost and the time frame also within the allocated time which is about 14 weeks. I am sure that this project is feasible and practical to be done.

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminum Alloy

The aluminum industry uses a four-digit index system for the designation of its wrought aluminum alloys. As outlined below, the first digit indicates the alloy group according to the major alloying elements.

1xxx Series

In this group, minimum aluminum content is 99% and there is no major alloying element. The second digit indicates modifications in impurity limits. If the second digit is zero, there is no special control on individual impurities. Digits 1 through 9, which are assigned consecutively as needed, indicate special control of one or more individual impurities.

The last two digits indicate specific minimum aluminum content. Although the absolute minimum aluminum content in this group is 99% the minimum for certain grades is higher than 99%, and the last two digits represent the hundredths of a per cent over 99. Thus, 1030 would indicate 99.30% minimum aluminum without special control on individual impurities. The designations 1130, 1230, 1330, etc. indicate the same purity with special control on one or more impurities. Likewise, 1100 indicates minimum aluminum content of 99.00% with individual impurity control.

2xxx - 9xxx Series

The major alloying elements are indicated by the first digit, as follows:

Table 3: Major elements in aluminum alloy

Series	Element/s
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and silicon
7xxx	Zinc
8xxx	Other element
9xxx	Unused series

The second digit indicates alloy modification. If the second digit is zero, it indicates the original alloy: digits 1 through 9, which are assigned consecutively, indicate alloy modifications. The last two digits have no special significance, serving only to identify the different alloys in the group.

Aluminum alloy 6061 is the most extensively used of the 6xxx series aluminum alloy. It is the least expensive, most versatile of the heat-treatable aluminum alloys and has most of the good qualities of aluminum. It offers a range of good mechanical properties, good corrosion resistance, good surface finish and can be fabricated by most of the commonly used techniques [3]. In the annealed condition it has good workability. In the T4 condition fairly severe forming operations may be accomplished. The full T6 properties may be obtained by artificial aging. It is welded by all methods and can be furnace brazed. It is available in the clad form (“Alclad”) with a thin surface layer of high purity aluminum to improve both appearance and corrosion resistance [5]. This grade is used for a wide variety of products and applications from truck bodies and frames to screw machine parts and structural components. 6061 is used where appearance and better corrosion resistance with good strength are required [4]. 6061 is highly weldable, for example using GTAW or gas metal arc welding (GMAW).

Properties and composition of aluminum alloy 6061

Aluminum alloy 6061 has a density of 2.7 g/cm ³ and melting point of approximately 580°C. Table 4 and 5 below show the composition of elements in aluminum alloy 6061 and its mechanical properties respectively.

Table 4: Composition of Aluminum alloy 6061

Element	Wt %	Element	Wt %	Element	Wt %
Al	95.8 - 98.6	Mg	0.8 - 1.2	Zn	Max 0.25
Cr	0.04 - 0.35	Si	0.4 - 0.8	Other, each	Max 0.05
Cu	0.15 - 0.4	Mn	Max 0.15	Other, total	Max 0.15
Fe	Max 0.7	Ti	Max 0.15		

Table 5: Mechanical Properties of Aluminum alloy 6061

Mechanical Properties	Metric unit	English unit	Remarks
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness

Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

2.2 GTAW Process

Gas Tungsten Arc Welding (GTAW) also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. Manual gas tungsten arc welding is often considered the most difficult of all the welding processes commonly used in industry is because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece. Similar to torch welding, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other.

The equipment for GTAW process are welding torch, electrode, power supply and shielding gas. Welding torch usually is equipped with cooling system using air or water. Air cooling system is often used for low-current operations (up to about 200 A), while water cooling is required for high-current welding (up to about 600 A). GTAW uses a constant current power source, meaning that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change [8]. Too much current can lead to splatter and workpiece damage while too little current can lead to sticking of the filler wire. More often with GTAW, aluminum is welded using alternating current (AC). In AC welding, the arc's action when the electrode is positive and the workpiece is negative, called reverse polarity, breaks up the oxide on the surface of the aluminum, making welding much easier. Unfortunately, reverse polarity doesn't provide good weld penetration. While in reverse polarity, much of the arc's energy goes into the tungsten electrode and the welding torch. For this reason, larger-diameter tungsten electrodes and heavier-duty torches, often water-cooled, are needed for AC welding. The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion (called burn-off) can occur. Filler metals are also used in nearly all applications of GTAW, the major exception being the welding of thin materials. Filler metals are available with different diameters and are made of a variety of materials. In most cases, the filler metal in the form of a rod is added to the weld pool manually, but some applications call for an automatically fed filler metal, which often is stored on spools or coils [9]. However, most nonheat-treatable aluminum alloys can be welded without adding filler. This is referred to as an autogenous weld. But for 6061 series which is a heat-treatable alloy, welding without adding filler metal will cause cracking. Shielding gas (commonly used is Argon-helium mixture) is necessary for protection of the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal [9]. Usually, 100 percent argon gas is preferred for aluminum GTAW, but when working with thicker materials, such as 1/2 inch or greater, helium is added in the range of 25 to 50 percent [14]. Helium makes the arc hotter and provides for more penetration. However, the choice of gas is specific to the working metals and affects the production costs, electrode life, and temperature.

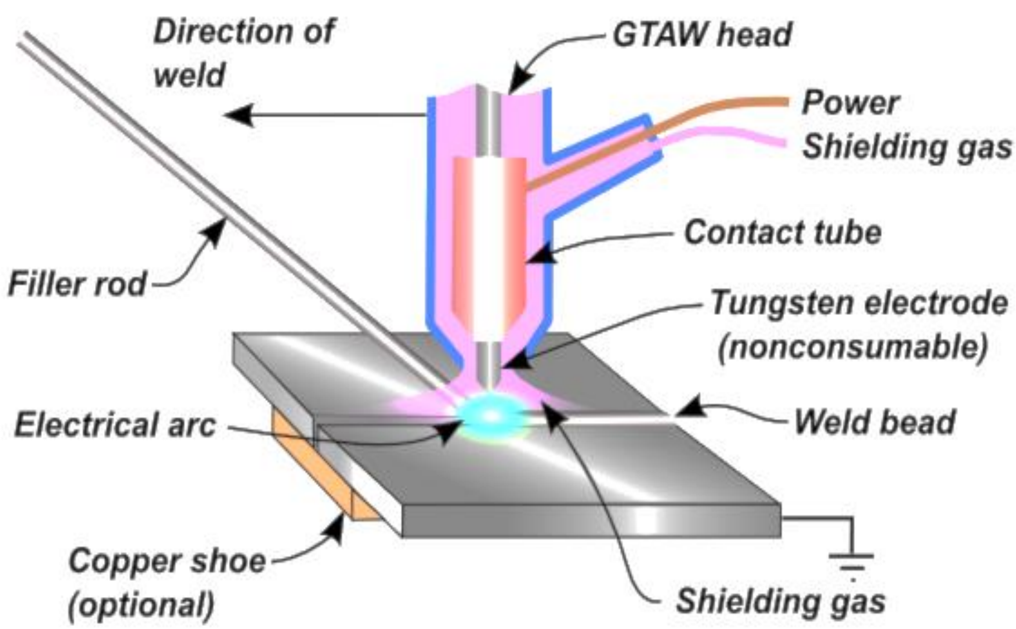


Figure 2: GTAW Equipment

There are advantages and disadvantages of using GTAW on aluminum. On the plus side, GTAW provides the highest-quality welds and offers a great deal of versatility, meaning that you can weld many material thicknesses and joint geometries. It also is easy to control and weld out of position. If an application has intricate welding requirements or uses thinner materials, GTAW usually is the process of choice.

On the downside, GTAW is a relatively slow process with a low deposition rate. It generally is not used for high-volume applications. In addition, the continuous high frequency associated with GTAW can interfere with robots, computers, and other sensitive equipment.

2.3 Weld Joint

Butt weld joint is formed when the two pieces to be welded are simply placed face to face and the welding head run over it. There many types of butt weld joint which is square groove, single-V, double-V, single bevel, double bevel and etc. The most common weld joint used in GTAW is square groove. But it is suitable for welding of thin metal plates only. Other types of weld joint are used in welding of thick metal plate to provide more penetration. The proposed weld joint geometries for this study is the single-V, single bevel and double bevel joint with the bevel angle of 45°. A. K. Lakshminarayanan et al[18], in their study on the effect of welding process on tensile properties of AA6061 joints used a single-V joint with a bevel angle of 30° for the sample with thickness of 6mm. For GTAW process, they have found that the tensile strength of the sample reduced by almost 50% of the base metal. E. Eltai et al [25] however did not specify how the weld is jointed in their study. They have found that the ultimate tensile strength of the sample is reduced by almost 40% of the base metal. A larger angle can allow for improved penetration through the joint [15]. Thus, for this study, the bevel angle will be 30°, 35° and 40° for the 3 butt weld joint. The thickness of samples will be 10mm to suit all the joint type since they have thickness limitation. If the sample is too thick, the volume for adding the filler metal will be large since the bevel angle is large.

2.4 Filler Metal 5356

5356 is an aluminum filler alloy with 5% magnesium added. 5356 filler has become the most commonly used of all aluminum filler alloys because of its good strength and its good feed-ability when used with 5XXX and 6XXX series aluminum alloy. However, one limitation is that 5356 is not suitable for service temperatures exceeding 150 degrees Fahrenheit (65°Celsius). This is because formation of Al_2Mg at elevated temperature will expose the alloy to stress corrosion cracking.

5356 filler is considered can produce more ductile and less crack sensitive weld compare to 4043 filler. High Mg content alloy is not suitable to be weld with 4043 filler because it major alloying element is Silicon and the weld structure may develop excessive magnesium-silicide (Mg_2Si). Mg_2Si cause the weld to be less ductile and sensitive to hot cracking. Aluminum alloy 6061 is an Al-Mg-Si base alloy and it is a crack sensitive alloy because it contains Mg_2Si. Therefore, using filler 5356 can decrease crack sensitivity of the alloy as well increasing the ductility of the weld. However, both filler can be used to be welded with aluminum alloy 6061 depending on the applications.

2.5 Mechanical Testing

A mechanical test shows whether a material or part is suitable for its intended mechanical applications by measuring elasticity, tensile strength, elongation, hardness, fracture toughness, impact resistance, stress rupture, and fatigue limit.

Tensile test

Tensile testing subjects a sample to uniaxial tension until it fails [10]. Machined samples with either circular or rectangular cross section are screwed into or gripped in jaws and stretched by moving the grips apart at a constant rate while measuring the load and the grip separation until fracture occur (samples failed).

Stress and strain relationship

When a specimen is subjected to an external tensile loading, the metal will undergo elastic and plastic deformation. Initially, the metal will elastically deform giving a linear relationship of load and extension. These two parameters are then used for the calculation of the engineering stress and engineering strain to give a relationship as shown below.

$$\sigma = \frac{P}{A_o}$$

$$\varepsilon = \frac{L_f - L_o}{L_o} = \frac{\Delta L}{L_o}$$

where :

σ is the engineering stress
ε is the engineering strain
P is the external axial tensile load
A_o is the original cross sectional area of the specimen
L_o is the original length of the specimen
L_f is the final length of the specimen

The unit of the engineering stress is Pascal (Pa) or N/m2 according to the SI Metric Unit whereas the unit of psi (pound per square inch) can also be used.

Young's modulus, E

During elastic deformation, the engineering stress-strain relationship follows the Hook's Law and the slope of the curve indicates the Young's modulus (E)

$$E = \frac{\sigma}{\varepsilon}$$

Young's modulus is of importance where deflection of materials is critical for the required engineering applications.

Yield strength

By considering the stress-strain curve beyond the elastic portion, if the tensile loading continues, yielding occurs at the beginning of plastic deformation. The yield stress(σ_y) can be obtained by dividing the load at yielding,(P_y) by the original cross-sectional area of the specimen,(A_o) as shown in equation below.

$$\sigma_y = \frac{P_y}{A_o}$$

Aluminum having a FCC crystal structure does not show the definite yield point in comparison to those of the BCC structure materials, but shows a smooth engineering stress-strain curve. The yield strength therefore has to be calculated from the load at 0.2% strain divided by the original cross-sectional area as follows

$$\sigma_{0.2\%y} = \frac{P_{0.2\%y}}{A_o}$$

The yield strength values can also be obtained at 0.5 and 1.0% strain. The determination of the yield strength at 0.2% offset or 0.2% strain can be carried out by drawing a straight line parallel to the slope of the stress-strain curve in the linear section, having an intersection on the x-axis at a strain equal to 0.002 as illustrated in figure below.

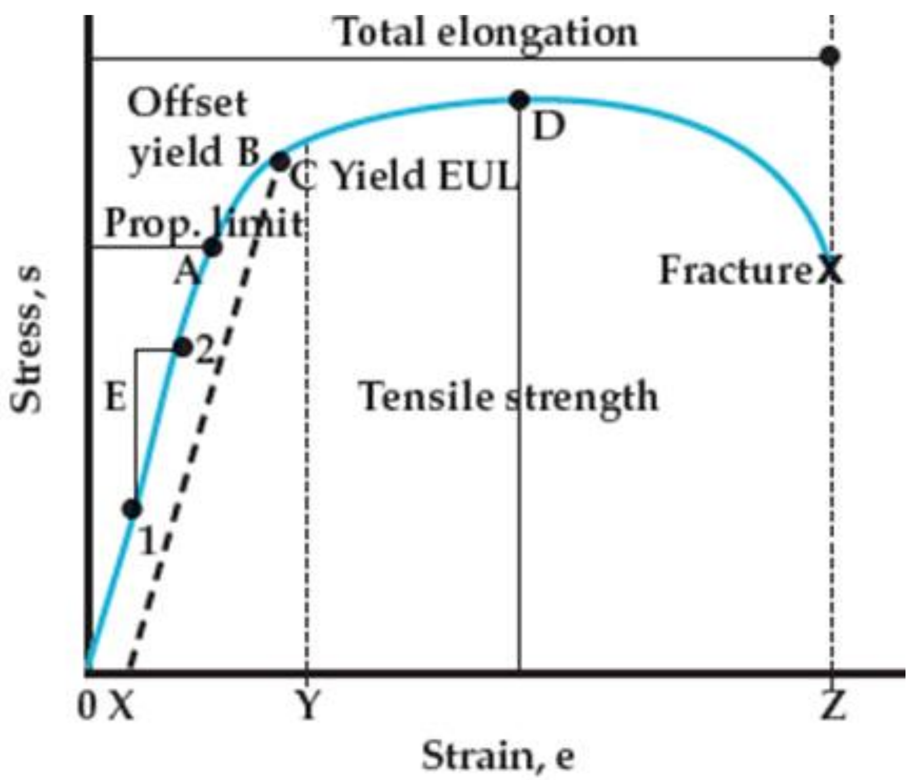


Figure 3: Determination of yield strength using 0.2% offset

Ultimate Tensile Strength

Beyond yielding, continuous loading leads to an increase in the stress required to permanently deform the specimen as shown in the engineering stress-strain curve. At this stage, the specimen is strain hardened or work hardened. The degree of strain hardening depends on the nature of the deformed materials, crystal structure and chemical composition, which affects the dislocation motion. FCC structure materials having a high number of operating slip systems can easily slip and create a high density of dislocations.

$$\sigma_{UTS} = \frac{P_{max}}{A_o}$$

Tangling of these dislocations requires higher stress to uniformly and plastically deform the specimen, therefore resulting in strain hardening. If the load is continuously applied, the stress-strain curve will reach the maximum point, which is the ultimate tensile strength (UTS). At this point, the specimen can withstand the highest stress before necking takes place. This can be observed by a local reduction in the cross-sectional area of the specimen generally observed in the center of the gauge length.

Fracture Strength

After necking, plastic deformation is not uniform and the stress decreases accordingly until fracture. The fracture strength can be calculated from the load at fracture divided by the original cross-sectional area.

$$\sigma_{fracture} = \frac{P_{fracture}}{A_o}$$

Tensile ductility

Tensile ductility of the specimen can be represented as % elongation or % reduction in area as expressed in the equations given below

$$\%Elongation = \frac{\Delta L}{L_o} x\ 100$$

$$\%RA = \frac{A_o - A_f}{A_o} x\ 100 = \frac{\Delta A}{A_o} x\ 100$$

Where : A_o is the cross-sectional area of specimen at fracture.

The fracture strain of the specimen can be obtained by drawing a straight line starting at the fracture point of the stress-strain curve parallel to the slope in the linear relation. The interception of the parallel line at the x axis indicates the fracture strain of the specimen being tested.

Basic procedure from previous studies

Figure 2 below shows various types of specimen shoulder. A, B and C are specimens with round cross section while D and E are specimens with rectangular cross section.

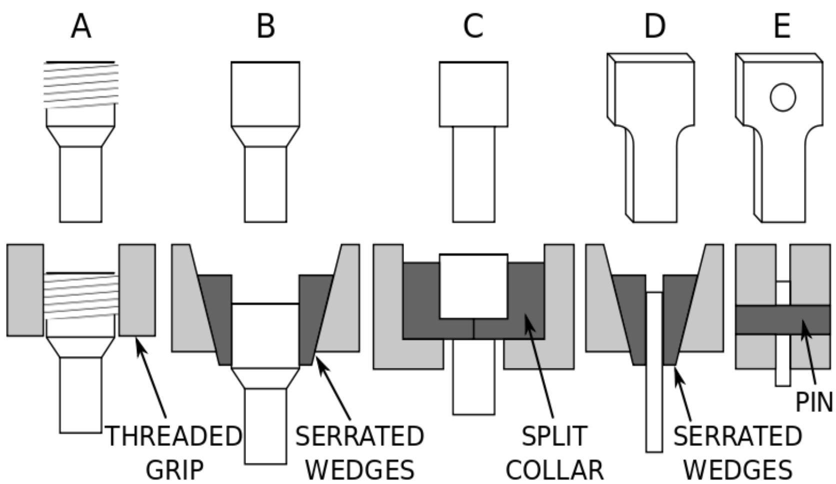


Figure 4: Specimen shoulder types for tensile testing [11]

- A - threaded shoulder for use with a threaded grip
- B - round shoulder for use with serrated grips
- C - butt end shoulder for use with a split collar
- D - flat shoulder for used with serrated grips
- E - flat shoulder with a through hole for a pinned grip

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines [11]. The machine must have the proper capabilities for the test specimen being tested. There are three main parameters: force capacity, speed, and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to accurately and precisely measure the gauge length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing [10].

For this project, samples for tensile testing will be machined into dog bone shape with specific dimension. Comparing to study done by E. Eltai et al [25], specimens for tensile testing were machined to ASTM E8-04 standards. Then the samples are machined with conventional milling machine into specific dimension. A. K. Lakshminarayanan et al[18], used flat shoulder to be used with serrated grip as shown in figure 3 (D) followed the ASTM E8M-04 standard.

2.6 Previous Studies

Currently there are no research has been made about the effect of weld joint geometry on the tensile properties of material. But several research papers have been collected and the method that the researchers used in their studies and also the results obtained has been compared.

Table 6: Research papers and results obtained from studies

Author	Title	Remarks
S. Missori et al (2000) [17]	Mechanical behavior of 6082-T6 aluminum alloy welds	• Using GMAW • Sample thickness of 10mm • Used single-V joint with 40° bevel angle • Ultimate tensile strength (UTS) of sample is 150-180MPa (base metal: 280MPa)
A.K Lakshminaryan et al (2007) [18]	Effect of welding process on tensile properties of AA6061 aluminum alloy joints	• Using GTAW (voltage: 20V, current: 175A) • Sample thickness of 6mm • Single-V joint with 30° bevel angle • UTS of sample is 211Mpa (base metal: 334MPa) • Yield strength (YS) of sample is 188Mpa (base metal: 302Mpa)

M. Sivashanmugan et al (2009) [19]	Investigation of microstructure and mechanical properties of GTAW and GMAW joints of AA7075 aluminum alloy	• Using GTAW • Sample thickness of 4mm • Used single-V joint with 35° bevel angle • UTS of sample is 550MPa (base metal: 570MPa) • YS of sample is 414Mpa (base metal: 537Mpa)
R.K Shukla et al (2010) [20]	Comparative study of friction stir welding and tungsten inert gas welding process (AA6061)	• Using GTAW (voltage: 18V, current: 90A) • Sample thickness of 4mm • Used square groove joint • UTS of sample is 140MPa (base metal: 313.6MPa)
S. Malarvizhi et al (2010) [21]	Effect of welding processes on AA2219 aluminum alloy joint properties	• Using GTAW (voltage: 30V, current: 150A) • Sample thickness of 5mm • Used square groove joint • UTS of sample is 242MPa (base metal: 470MPa) • YS of sample is 220MPa (base metal: 390MPa)

K. Mutombo et al (2011) [22]	Fatigue Behavior of Aluminum Alloy 6061-T651 Welded Using Fully Automatic Gas Metal Arc Welding and ER5183 Filler Alloy	• Using GTAW • Sample thickness of 6.35mm • Used square groove joint • No tensile test • He found that the fatique life of sample reduced significantly
M.R. Indira et al (2012) [23]	Effect of Pulsed Current TIG Welding Parameters on Mechanical Properties of J-Joint Strength of AA6351	• Using GTAW (pulse current applied) • Sample thickness of 6mm • Used J-groove joint with bevel angle of 45° • UTS of sample is 170MPa (base metal: 178.4MPa) • YS of sample is 104MPa (base metal: 169.8MPa)
J.M. Samer (2012) [24]	Comparative Investigation of FSW and TIG of 6061-T651 Aluminum Alloy on Mechanical Property and Microstructure	• Using GTAW (voltage: 10V, current: 157-158A) • Sample thickness of 6mm • Used single-V joint with bevel angle of 35° • UTS of sample is 125MPa (base metal: 340MPa)

E. Eltai et al (2013) [25]	The Effects of Gas Tungsten Arch Welding on the Corrosion and Mechanical Properties of AA 6061 T6	• Using GTAW • Sample thickness of and joint type is not specified • UTS of sample is 193.1MPa (base metal: 357.7MPa) • YS of sample is 146MPa (base metal: 321.3MPa)

Analysis from research papers

Based on studies done, we can conclude that welding process reduce the mechanical properties of materials. But there might be some ways to minimize the reduction in mechanical properties.

Studies done by A.K. Lakshminaryan et al (2007), E.Eltai (2013) and J.M. Samer (2012) are quite similar in terms of welding and material used. By comparing the study done by A.K. Lakshminaryan et al and J.M. Samer, both of them used AA 6061 and sample thickness of 6mm. The differences are on the welding parameters and the bevel angle of the single-V joint.

A.K. Lakshminaryan et al used a voltage of 20V and current of 175A while J.M. Samer used lower voltage and current (10V and 158A respectively). The result obtained by A.K. Lakshminaryan et al is about 40% reduction of UTS while J.M. Samer obtained about 60% reduction of UTS compare to base metal.

The bevel angle and the welding parameters might affect the weld strength in terms of depth of penetration which is critical to avoid porosity and cracking. These types of defects can easily cause failure below the material ultimate strength limits. Besides that, volume of filler metal also can affect the weld strength because it changes the structure of element in the weld area.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

For this project, 6 pieces of aluminum alloy 6061 plates will be welded using gas tungsten arc welding (GTAW) process. The sample will undergo preparation process before GTAW. After welding, these samples will be tested for tensile properties. Details about the procedures, equipment and standards used will be explained below.

3.1.1 Sample Preparation (GTAW)

7 pieces of aluminum alloy 6061 with dimension of 100mmx100mmx10mm is required for this project. 6 pieces of of aluminum alloy were cut into required dimension for GTA welding. There will be 3 pairs of aluminium alloy 6061 for the welding. One piece of the alloy will be the reference (base metal) and it will directly be tested for tensile properties after prepation process. The 3 pairs of aluminium alloy 6061 then were cut using abrasive cutter for correction of allignment since there are some defects in dimension. Then, the bevel angle of 30°, 35° and 40° were formed using milling machine for each pair respectively.

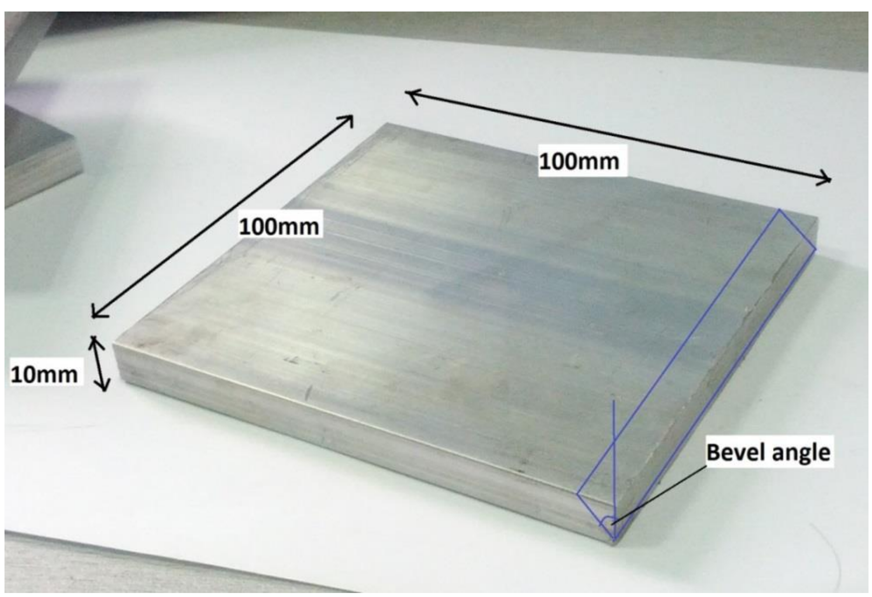
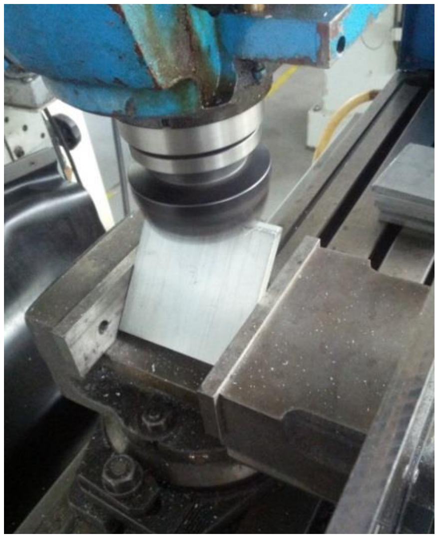
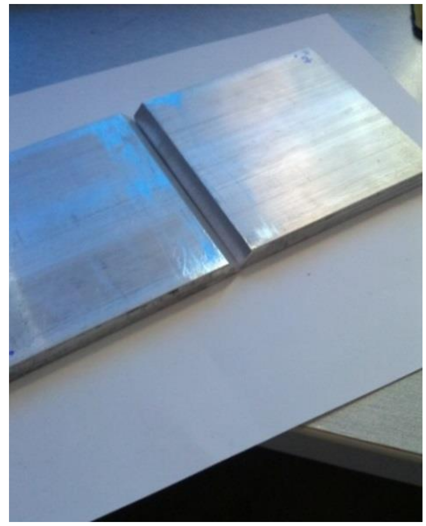


Figure 5: Aluminum Alloy 6061 Plate with Dimensions

After the dimensions are perfectly acquired, the samples then undergo cleaning process. First, the oxide layer on the surface is removed by using stainless steel wire brush. Oil, grease, and water vapor are removed using an organic solvent such as acetone or a mild alkaline solution like a strong soap [13]. The samples must be kept dry before welding.

a) 

b) 

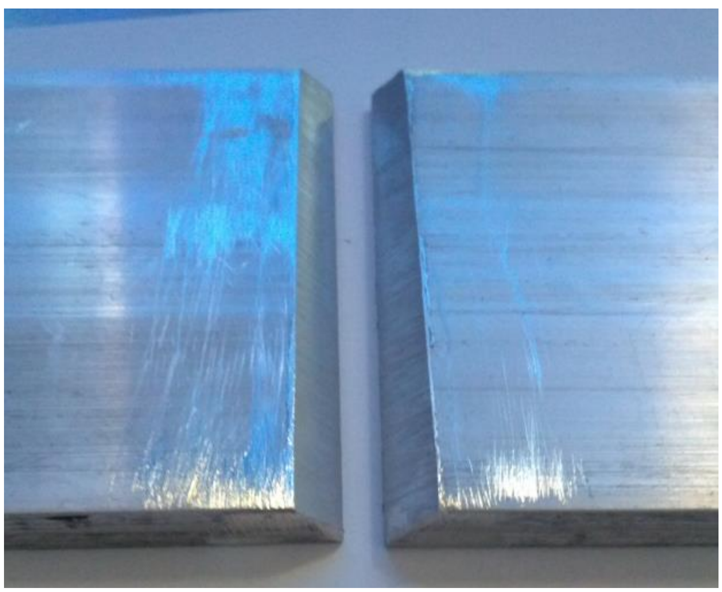
c) 

Figure 6: (a)Forming the Bevel Angle using Conventional Milling Machine. (b)&(c) Aluminum Alloy Plates After Milling Process

3.1.2 GTAW

Firstly, the size and type of tungsten electrode is selected. Pure tungsten is suitable for aluminium and is typically used with ball-end preparation on alternating current. Diameter of the electrode will be around 4-6mm and the ball-end diameter is 1-½ of the electrode diameter [14]. For the shielding gas, the mixture of argon and helium is desired as the samples are quite thick. Aluminum alloy 6061 cannot be weld without adding filler metal as it will exposed to surface cracking [27]. 5356 filler is more suitable for this project as it can produced stronger weld with higher ductility than adding any other filler metal.

a)

b)

c)

Figure 7: (a) GTAW Equipment. (b)&(c) Aluminum Alloy Plates After GTA Welding Process

3.1.3 Sample Preparation (Tensile Test)

Samples for tensile testing will be machined according to ASTM E8-04 standards. A conventional milling machine is used to cut the samples into the specified dimension. Standard dimension is 0.5 inches in diameter, gage length of 2.0 inches and 3/8 inches minimum fillet radius [26]. Since the samples for this project have a thickness of 10mm (approximately 0.4 inches), it is not possible to machine them into standard dimension. However, there is a small-size sample proportional to standard dimension in ASTM E8-04. So, the samples in this project will be machined into dog-bone shape with diameter of 0.25 inches (approximately 6.35mm), and gage length of 1 inches with tolerances of ±0.005. The fillet radius is 3/16 inches [26]. For each pair, 2 samples are cut into dog-bone shape. So, there will be 8 samples for tensile test.

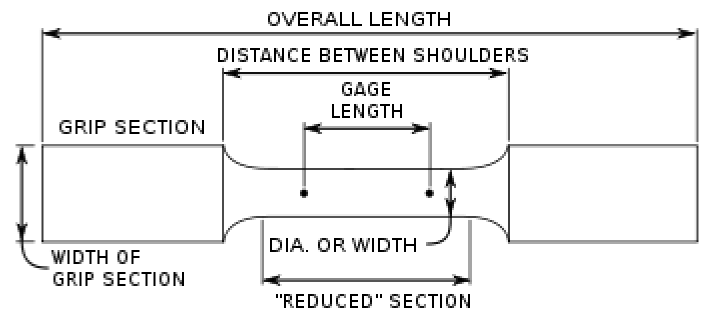


Figure 8: Dimensions in tensile sample

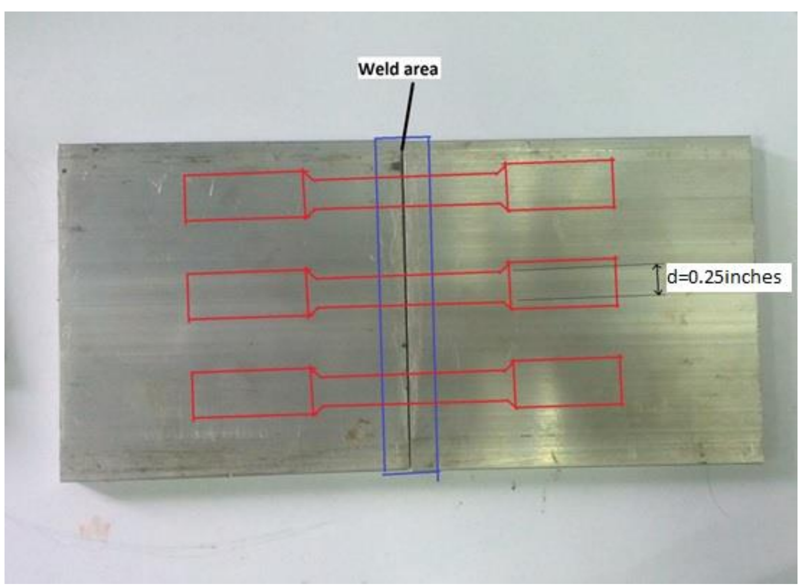


Figure 9: Tensile Samples from Welded Plates

3.1.4 Tensile Test

Materials and equipment:

- Tensile samples
- Micrometer or vernia calipers
- Universal testing machine (50kN)

Procedure:

- Measure and record specimen dimensions (diameter and gauge length) for the calculation of the engineering stress and engineering strain. Marking the location of the gauge length along the parallel length of each specimen for subsequent observation of necking and strain measurement
- Fit the specimen on to the universal Testing Machine (UTM) and carry on testing. Record load and extension for the construction of stress-strain curve of each tested specimen.
- Calculate Young's modulus, yield strength, ultimate tensile strength, fracture strain, % elongation and % area of reduction of each specimen

Figure 10: Tensile Sample

3.1.5 Data Analysis

Data from tensile test, sample dimensions and tensile properties are analyzed and the calculations are made to obtain the Young's modulus, yield strength, UTS, fracture strain, %elongation and %reduction area of each of the sample. The results are presented with stress-strain curve and comparison is made to identify which sample has the highest tensile properties.

3.2 Project Flow Chart

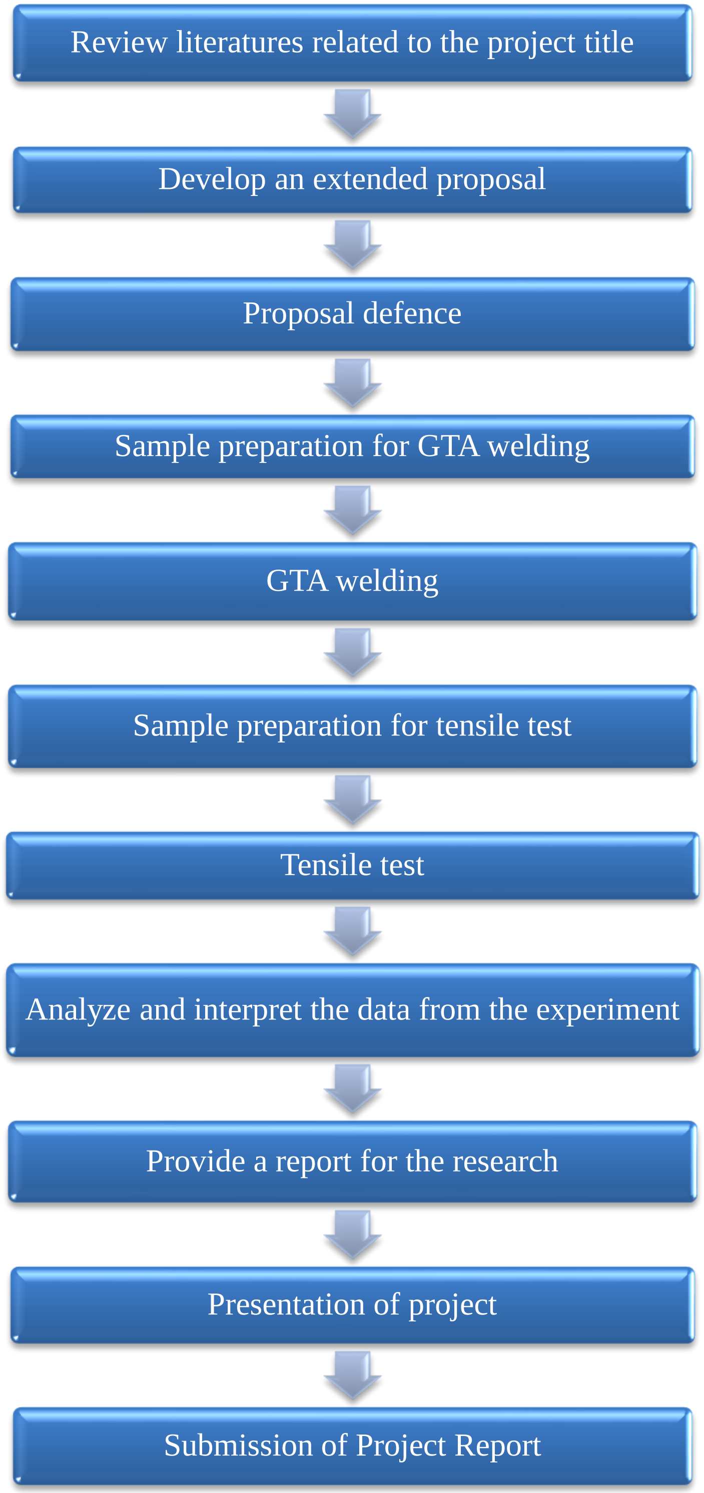


Figure 11: Project flow diagram

3.2.1 Literature Review

Literature Review of the topic taken "*Study on the effects of butt weld joint bevel angles on the tensile properties of aluminum alloy 6061*" is done after the project was selected. Several journal and research paper is studied as references to get tight understanding about the welding process and how this experiment is conducted to achieve the objectives.

3.2.2 Extended Proposal

Extended proposal is prepared for deeper study on the title selected. It contains background of study, literature reviews and project planning.

3.2.3 Sample Preparation

Samples for the experiment will be prepared for welding and mechanical testing in terms of finding the right material and also planning the required number of samples and the dimensions.

3.2.4 Conducting Experiment

GTAW and tensile test is conducted. Samples will be welded and shaped into specific dimension. For each tensile test, specific sample dimension is required. Therefore, sufficient number of sample must be prepared.

3.2.5 Data Analyzing

Data collected from the experiments is being analyzed to study the effects of different weld geometry on the tensile properties of aluminum alloy 6061.

3.2.6 Research Report

Preparing final report based on the study that has been carried out.

3.2.7 Project Presentation

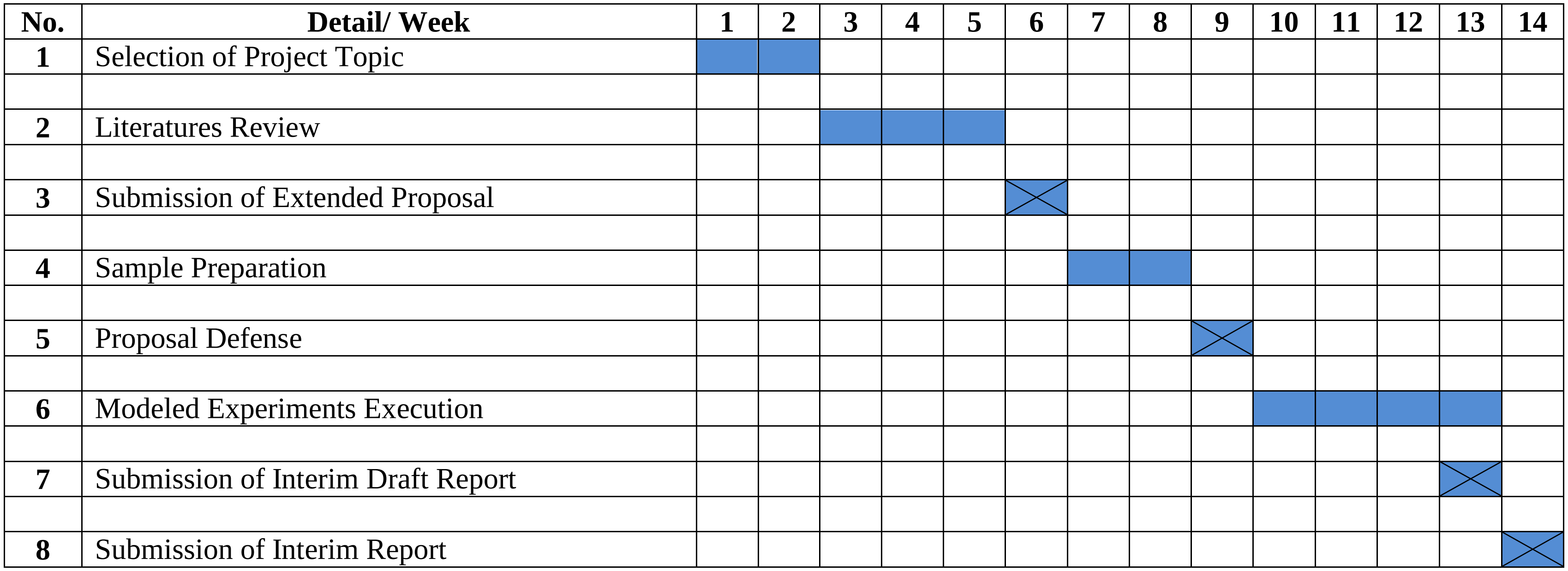
Presentation of the project to the examiner

3.2.8 Final Report

Submission of final report for evaluation and mark distributions.

3.3 Gantt Chart and Project Milestones

Several targets have been set for FYP I and FYP II. Figure 12 and Figure 13 shows the project activities and key milestones for FYP I and FYP II respectively.



Notes:

Project Activity

Key Milestone

Figure 12: Project activities and key milestones for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Modeled Experiments Execution and Optimization														
2	Preparing Progress Report														
3	Submission of Progress Report														
4	Data Analysis														
5	Pre-SEDEX														
6	Preparing Final Report and Technical Report														
7	Submission of Dissertation (soft bound)														
8	Submission of Technical Paper														
9	Oral Presentation														
10	Submission of Project Dissertation (Hard Bound)														

Notes:

Project Activity

Key Milestone

Figure 13: Project activities and key milestones for FYP II

CHAPTER 4

RESULT AND DISCUSSION

4.1 Welding Parameters

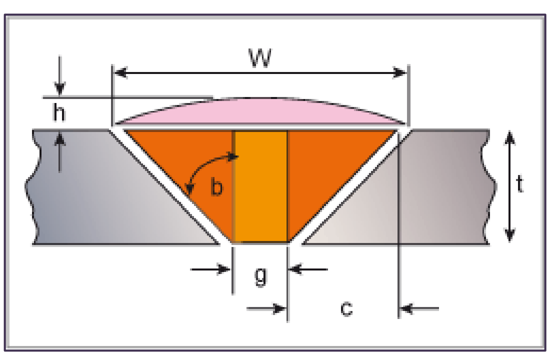
Welding parameters such as current, voltage and welding speed for each sample is different because of the difference butt weld bevel angle which effect the depth of penetration. Table 7 below shows data for welding parameters for each sample.

Table 7: Welding Parameters for each sample

Parameters	Samples		
	30° bevel angle	**35° bevel angle**	**40° bevel angle**
Thickness (mm)	10	10	10
Filler diameter (mm)	3	3	3
Current (Amps)	180	175	165
Voltage (V)	30	28	24
Welding speed (mm/min)	Appr. 125	Appr. 115	Appr. 105

The results from welding shows that the current and voltage used is increased for smaller bevel angle. This is because smaller angle need deeper penetration so that it can be welded completely. Larger opening gives better penetration but need more time to complete the welding process as larger volume of weld area is required. These parameters were set before welding process to make sure the weld produced is strong there is no defects for example porosity or hot cracking.

4.2 Volume of Filler Metal



W = 2(tan b x t) + g
c = tan b x t
Area provided by gap (A) = g x t
Area of excess weld metal (B) = (W x h)/2
Area of 2 dark orange areas (C) = t x c
Volume = (A+B+C) x length of weld, L

Where,

g= 0.2cm
t= 1cm
b= 30°, 35°, 40°
L= 10cm

Sample Calculation:

30° bevel angle, h=0.14cm, t=1cm, g=0.2cm, L=10cm

$W = 2(\tan b \text{ x } t) + g$
$= 2(\tan 30° \text{ x } 1) + 0.2$
$= 1.355cm$

$c = \tan b \text{ x } t$
$= \tan 30° \text{ x } 1$
$= 0.577cm$

Area provided by gap (A) $= g \text{ x } t$
$= 0.2 \text{ x } 1$
$= 0.2cm^2$

Area of excess weld metal (B) $= (W \text{ x } h)/2$
$= (1.355 \text{ x } 0.14)/2$
$= 0.094cm^2$

Area of 2 dark orange areas (C) $= t \text{ x } c$
$= 1 \text{ x } 0.577$
$= 0.577cm^2$

Total area = A + B + C
$= 0.87cm^2$

Total volume = total area x L
$= 0.87 \text{ x } 10$
$= 8.71cm^3$

Volume/tensile sample $= \pi t^2(c + g)$
$= \pi(0.5)^2(0.577 + 0.2)$
$= \underline{0.610cm^3}$

Table 8: Volume of Filler Metal in Each Sample

Dimension	**Samples**		
	30° bevel angle	**35° bevel angle**	**40° bevel angle**
Height, h (cm)	0.14	0.17	0.15
Width, W (cm)	1.355	1.600	1.878
Total area, (cm^2)	0.87	1.04	1.18
Volume, (cm^3)	8.71	10.36	11.79
Volume per tensile sample, (cm^3)	Appr. 0.610	Appr. 0.707	Appr. 0.848

The filler metal used is 5356 filler. From the table, we can see that the larger bevel angle resulted in higher volume of filler metal needed. This result is theoretical value of filler metal volume used and the actual value might be slightly higher.

4.3 Tensile Properties

Before tensile test is carried out, the dimensions of each sample are measured and recorded. The initial diameter, initial cross-sectional area and initial gauge length is measured using vernier calipers. The final diameter, final cross-sectional area and final gauge length are measured after tensile test when the samples are fractured. Displacement of length for each load applied is measured by extensometer because the change is very small. Thus for each load applied, the engineering stress and strain can be calculated and the engineering stress versus engineering strain curve can be plotted. From the results obtained, we can see that the diameter and cross-sectional area of the samples are decreased because of necking of the samples. The gauge length is increased because of load applied causing the samples to stretch, undergo necking and then failed. The details of the samples dimensions before and after tensile test are shown in table 9.

Table 9: Samples Dimensions

Details	Samples							
	Base metal		30° bevel angle		35° bevel angle		40° bevel angle	
	1	2	1	2	1	2	1	2
Initial diameter (m)	0.00636	0.00639	0.00635	0.00637	0.00638	0.00636	0.00635	0.00637
Initial cross-sectional area ($10^{-5}\ m^2$)	3.1769	3.2069	3.1669	3.1869	3.1969	3.1769	3.1669	3.1869
Initial gauge length (m)	0.0254	0.0254	0.0255	0.0254	0.0253	0.0254	0.0255	0.0254
Final diameter (m)	0.00486	0.00485	0.00536	0.00520	0.00510	0.00502	0.00510	0.00498
Final cross-sectional area ($10^{-5}\ m^2$)	1.8551	1.8475	2.2564	2.1237	2.0428	1.9792	2.0428	1.9478
Final gauge length (m)	0.0282	0.0285	0.0270	0.0270	0.0270	0.0272	0.0272	0.0272

Tensile properties of each samples are then calculated using the equations. Ultimate tensile strength, %elongation, %reduction area, Young's modulus and fracture strenght are calculated based on data obtained. Maximum load and load at yield point are obtained from data shown in the universal tensile testing machine from the engineering stress-strain curves.

To determine the engineering stress, the load at each point is divided by the original cross-sectional area of the sample. Engineering strain is calculated by dividing the change in gauge length by the original gauge length.

$$\textbf{Engineering stress, } \boldsymbol{\sigma = \frac{P}{A_o}}$$

$$\textbf{Engineering strain}, \boldsymbol{\varepsilon = \frac{L_f - L_o}{L_o} = \frac{\Delta L}{L_o}}$$

These equations are the main equation to generate the engineering stress-strain curve. From the curve, we can obtained ultimate tensile strength, the yield strength, Young's modulus and the load at yield point of the aluminum alloy. The yield strength is determined by drawing a straight line parallel to the slope of the stress-strain curve in the linear section, having an intersection on the x-axis at a strain equal to 0.002 at 0.2% offset or 0.2% strain.

Tensile ductility, %elongation or %reduction area calculated using equations below. For %elongation, it shows how much the sample is stretched based on its original gauge length. It is actually the maximum strain of the samples before fracture times 100%. %Reduction area shows how much the cross sectional area of the samples changed, with respect to changes in diameter of the samples. Necking caused the sample diameter become smaller thus the cross sectional area also reduced.

$$\%\boldsymbol{Elongation = \frac{\Delta L}{L_o} x\ 100}$$

$$\%\boldsymbol{RA = \frac{A_o - A_f}{A_o} x\ 100 = \frac{\Delta A}{A_o} x\ 100}$$

Sample Calculation:

30° bevel angle, d_0=0.00635m, d_f=0.00536m, A_o=3.1669E-5m^2, A_f=2.0428E-5m^2, l_o=0.0255m, l_f=0.0270m

At P=1kN,

Engineering stress, $\sigma = \frac{P}{A_o}$

$$\sigma = \frac{1kN}{3.1669\text{E}-5m^2}$$

$$\boldsymbol{\sigma = 31.576MPa}$$

Engineering strain, $\varepsilon = \frac{L_{f@1kN} - L_o}{L_o}$

$$= \frac{25.5184 - 25.5000}{25.5000}$$

$$\boldsymbol{= 0.000722mm/mm}$$

Ultimate Tensile Strength $= \frac{\text{Max load}}{A_o}$

$$= \frac{6.0\text{kN}}{3.1669\text{E}-5m^2}$$

$$\boldsymbol{= 189.5MPa}$$

Fracture strength $= \frac{\text{Load @fracture}}{A_o}$

$$= \frac{5.8\text{kN}}{3.1669\text{E}-5m^2}$$

$$\boldsymbol{= 183.1MPa}$$

$\%Elongation = \frac{\Delta L}{L_o} x\ 100\%$

$$= \frac{27.00 - 25.50}{25.50} x\ 100\%$$

= **5.88%**

$\%RA = \frac{A_o - A_f}{A_o} x\ 100\%$

$$= \frac{3.1669\text{E}-5 - 2.0428\text{E}-5}{3.1669\text{E}-5} x\ 100\%$$

= **28.75%**

By calculating the data at all load, the stress-strain curve can be plotted. The yield strength is determined by finding the intersection of the stress-strain curve with a line parallel to the initial slope of the curve and which intercepts the curve at 0.2% offset. Young’s modulus is determined by the gradient of the slope at elastic region (straight line curve). Fracture strain is calculated at maximum displacement before fractured measured by the extensometer.

The tensile properties of all the samples are shown in **table 10.**

Table 10: Tensile Properties of the Samples

Details	Samples							
	Base metal		30° bevel angle		35° bevel angle		40° bevel angle	
	1	2	1	2	1	2	1	2
Young's Modulus (GPa)	67.40	69.67	59.44	51.06	60.02	53.91	61.2	60.02
Load at yield point (kN)	8.7	9.1	5.0	5.2	5.1	5.3	5.2	5.4
Yield strength (MPa)	274.3	268.8	118.8	114.5	116.5	126.0	131.2	147.6
Maximum load (kN)	9.8	10.1	6.0	6.2	6.4	6.5	6.3	6.7
Ultimate Tensile Strength (MPa)	308.5	314.9	189.5	194.5	200.2	204.6	198.9	210.2
% Elongation	11.02	12.20	5.88	6.30	6.72	7.10	6.67	7.09
% Area reduction	41.20	42.40	28.75	33.36	36.10	37.70	35.50	38.88
Fracture strength (MPa)	283.3	286.9	183.1	185.1	190.8	192.0	195.8	204.0
Fracture strain (mm/mm)	0.1197	0.1193	0.0571	0.0615	0.0682	0.0691	0.0652	0.072

Engineering stress versus engineering strain curves for each sample are shown in figure 14-22 below.

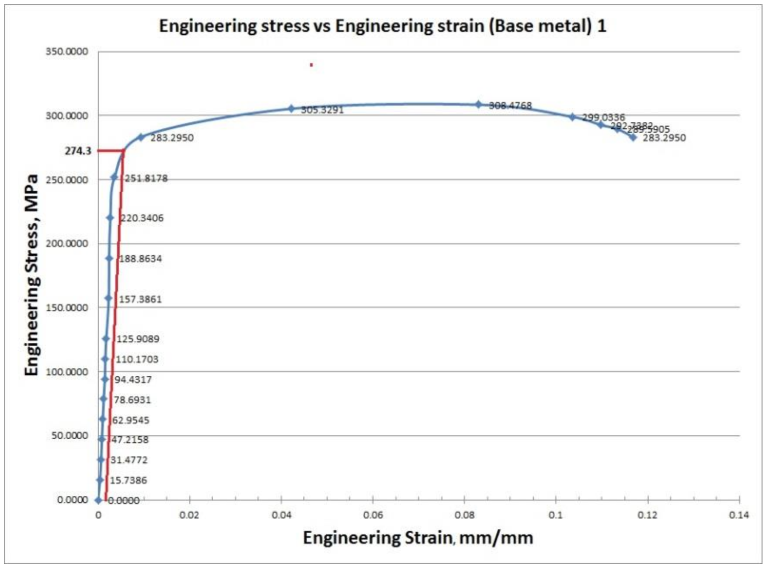


Figure 14: Engineering Stress Vs Engineering Strain Curve for Base Metal Sample #1

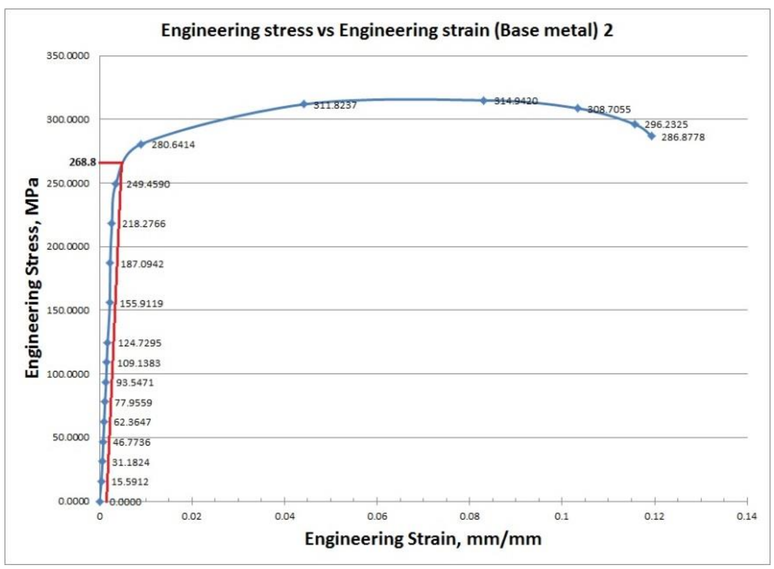


Figure 15: Engineering Stress Vs Engineering Strain Curve for Base Metal Sample #2

The unwelded samples of aluminum alloy 6061 show a normal stress-strain curve pattern. The value of UTS and yield strength for both sample have a slight difference and around the theoretical value. Sample #2 has higher UTS and yield strength than sample #1. Both samples failed at the center of the gauge.

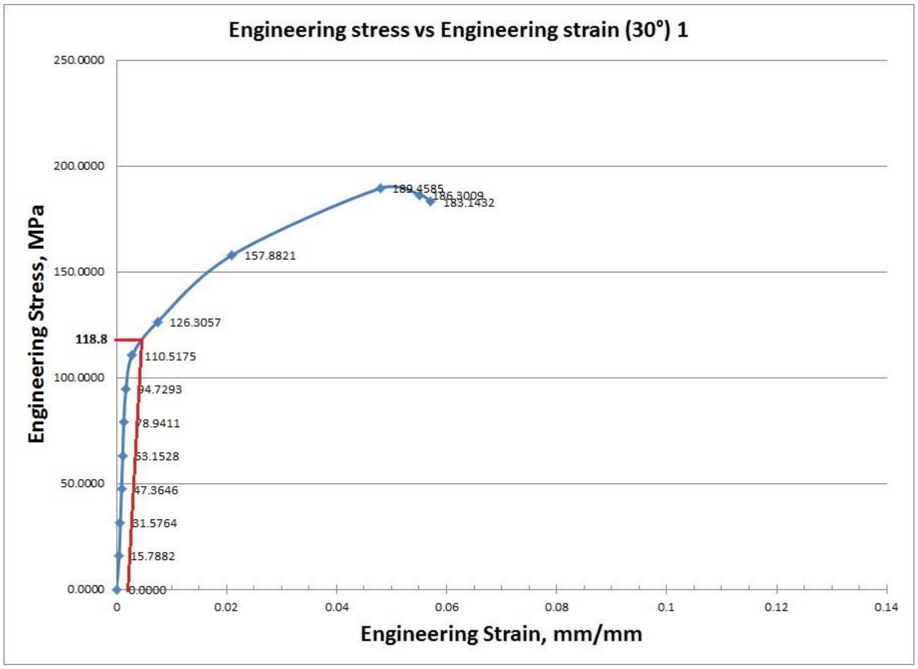


Figure 16: Engineering Stress Vs Engineering Strain Curve for 30° Sample #1

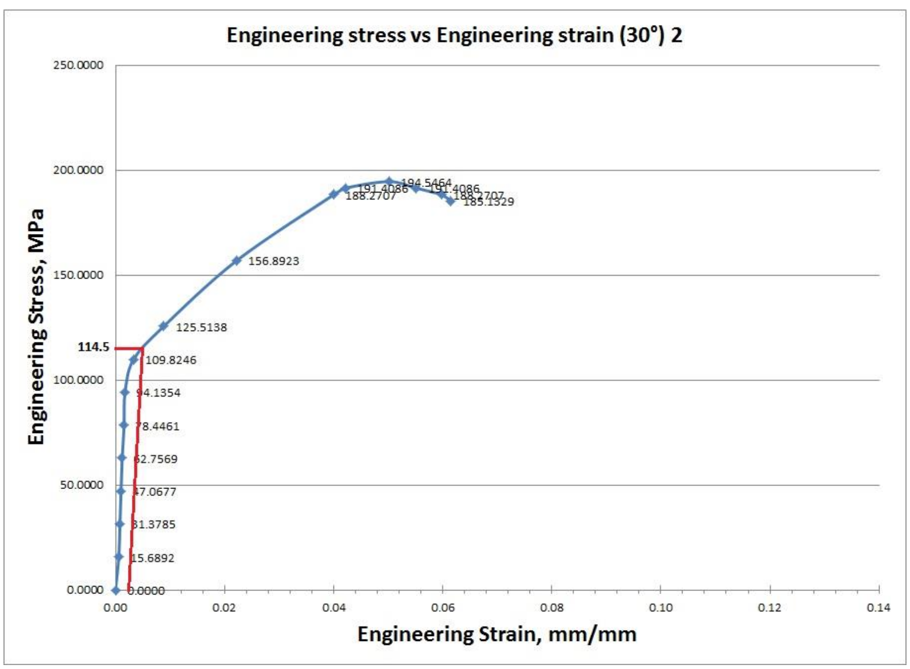


Figure 17: Engineering Stress Vs Engineering Strain Curve for 30° Sample #2

For samples with 30° bevel angle, the stress-strain curves show a dissimilar pattern from that of normal aluminum alloys. The necking occur in a small range of stresses before failed. The yield strength for sample #1 is 118.8MPa and for sample #2 is 114.5. UTS for sample #1 is 189.5MPa and for sample #2 is 194.5. The yield strength and UTS are decreased by almost 40% from the base metal. Samples with 30° bevel angle have lowest yield strength and UTS. The curves also show that the elastic region for the samples decreased and both samples started to yield at applied load of 5.0 and 5.2 kN respectively. %Elongation and %area reduction of sample #1 is 5.88% and 28.75% respectively. For sample #2, . %elongation and %area reduction is 6.30% and 33.36% respectively. Sample #1 failed at stress of 183.1MPa and sample #2 failed at stress of 185.1MPa. For sample #1, failure occured at the fusion zone while for sample #2, failure occured at the weld area.

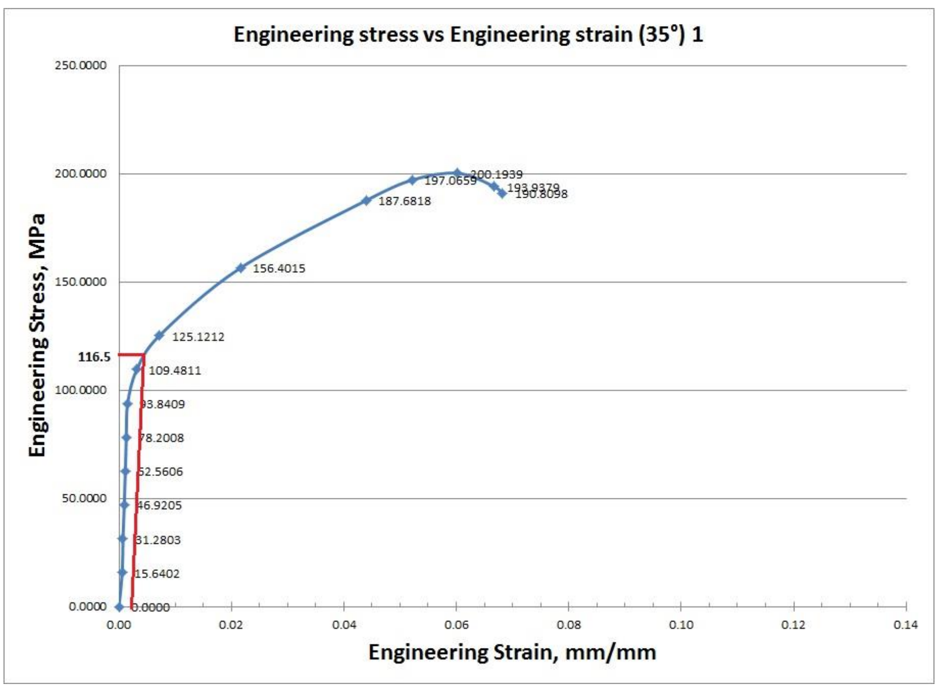


Figure 18: Engineering Stress Vs Engineering Strain Curve for 35° Sample #1

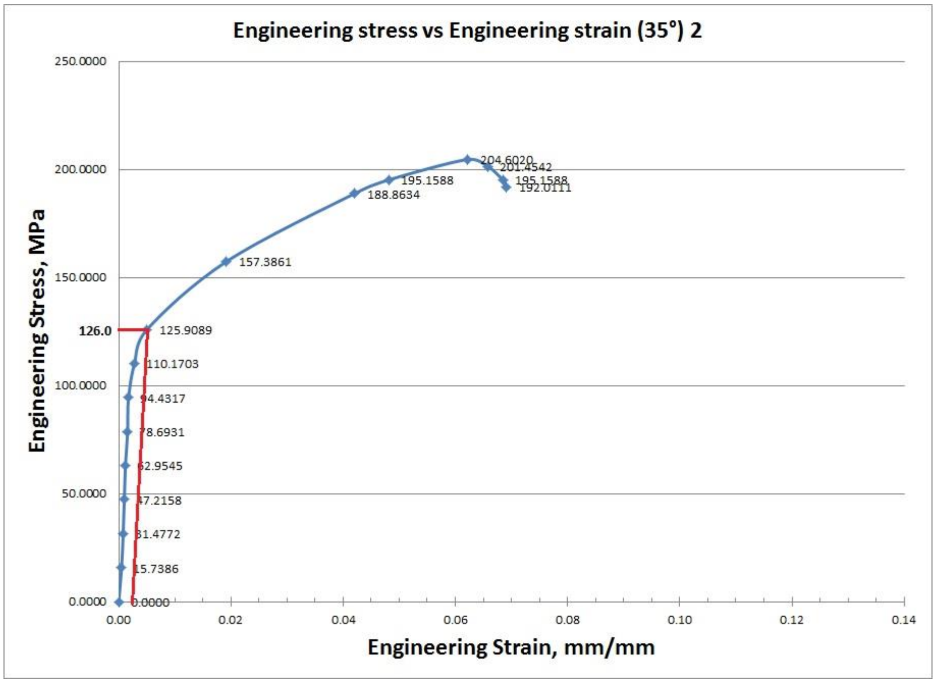


Figure 19: Engineering Stress Vs Engineering Strain Curve for 35° Sample #2

For samples with 35° bevel angle, the stress-strain curves show a similar pattern as the samples with 30° bevel angle. The yield strength for sample #1 is 116.5MPa and for sample #2 is 126.0MPa. UTS for sample #1 is 200.2MPa and for sample #2 is 204.6MPa. The yield strength and UTS are decreased by almost 35% from the base metal.The curves also show that the elastic region for the samples decreased and both samples started to yield at applied load of 5.1 and 5.3 kN respectively. %Elongation and %area reduction of sample #1 is 6.72% and 36.10% respectively. For sample #2, . %elongation and %area reduction is 7.10% and 37.70% respectively. Sample #1 failed at stress of 183.1MPa and sample #2 failed at stress of 185.1MPa. Both samples failed at the weld area.

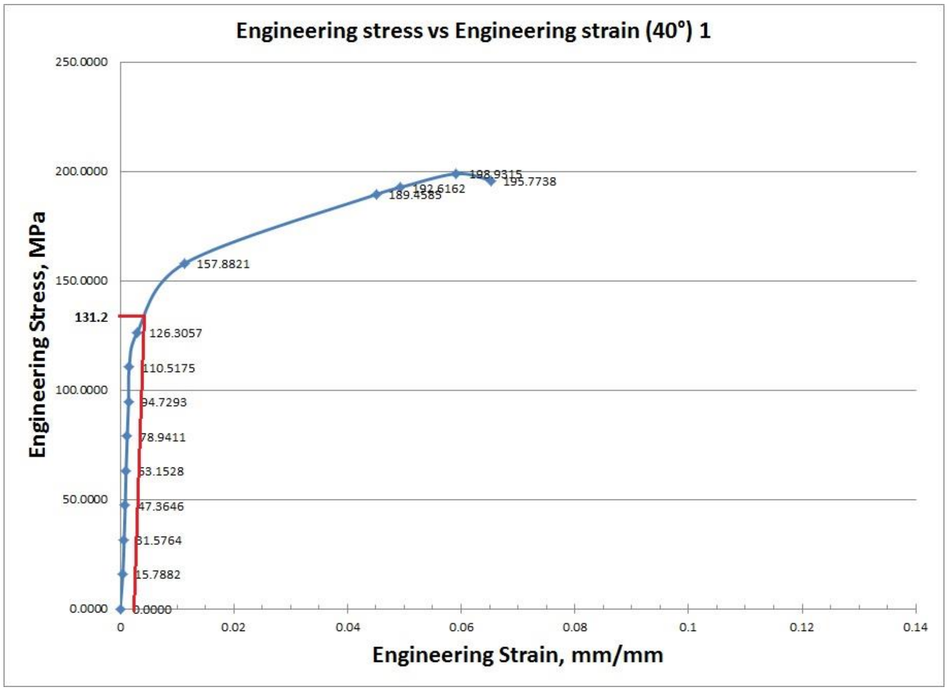


Figure 20: Engineering Stress Vs Engineering Strain Curve for 40° Sample #1

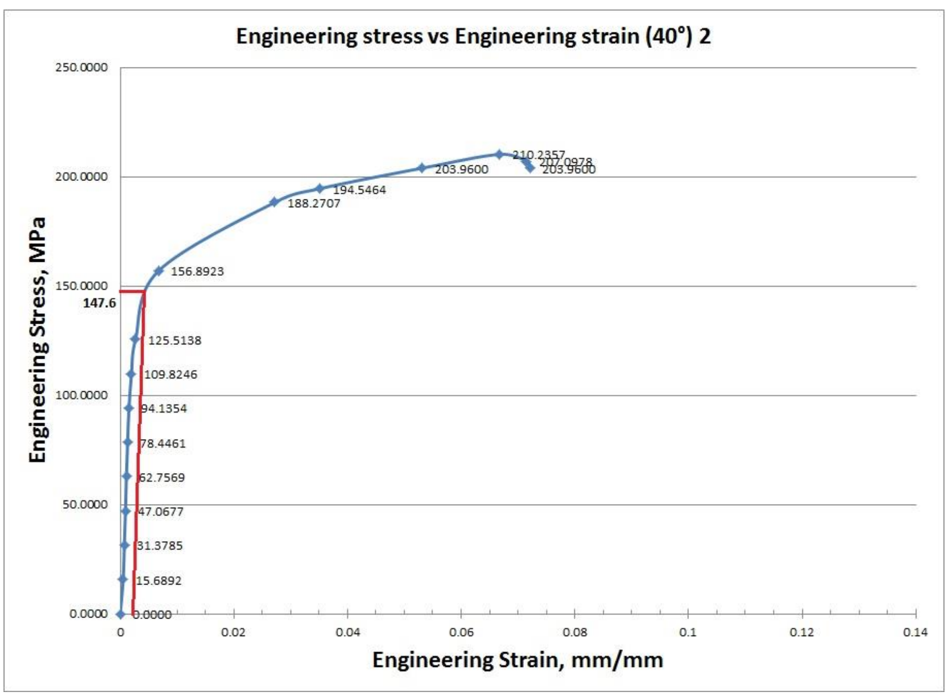


Figure 21: Engineering Stress Vs Engineering Strain Curve for 40° Sample #2

For samples with 40° bevel angle, the stress-strain curves show a similar pattern as the samples with 30° and 35° bevel angle. The yield strength for sample #1 is 131.2MPa and for sample #2 is 147.6MPa. UTS for sample #1 is 198.9MPa and for sample #2 is 210.2MPa. Sample #2 has the highest yield strength and UTS but for sample #1, the yield strength is higher than that of samples with 30 bevel angle but has lower UTS. The yield strength and UTS are decreased by almost 35% from the base metal.The curves also show that the elastic region for the samples decreased and both samples started to yield at applied load of 5.2 and 5.4 kN respectively. %Elongation and %area reduction of sample #1 is 6.67% and 35.50% respectively. For sample #2, . %elongation and %area reduction is 7.09% and 38.88% respectively. Sample #1 failed at stress of 183.1MPa and sample #2 failed at stress of 185.1MPa. Both samples failed at the weld area.

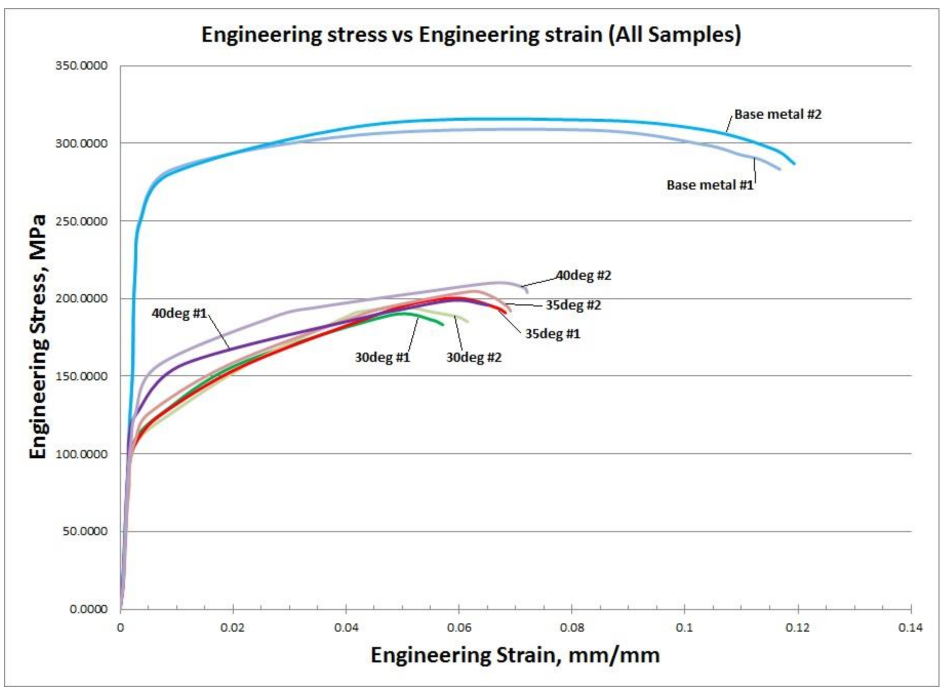


Figure 22: Engineering Stress Vs Engineering Strain Curve – Base metal vs Welded Samples

Welded samples lose their UTS by around 35-40% and yield strength by around 45-50% compared to base metal (unwelded samples). Welded samples also show an increasing yield point, a region where the material deforms plastically. This means that higher load is needed for the samples with larger bevel angle to make it deform plastically or to make it starts to yield. This is shown in the stress-strain curve in figure 23 where we can observe that the proportional limit of the welded samples is increasing with increasing bevel angle. Proportional limit is where the stress is proportional to strain and the curve is in straight line. This proportional limit shows the elasticity of the material.

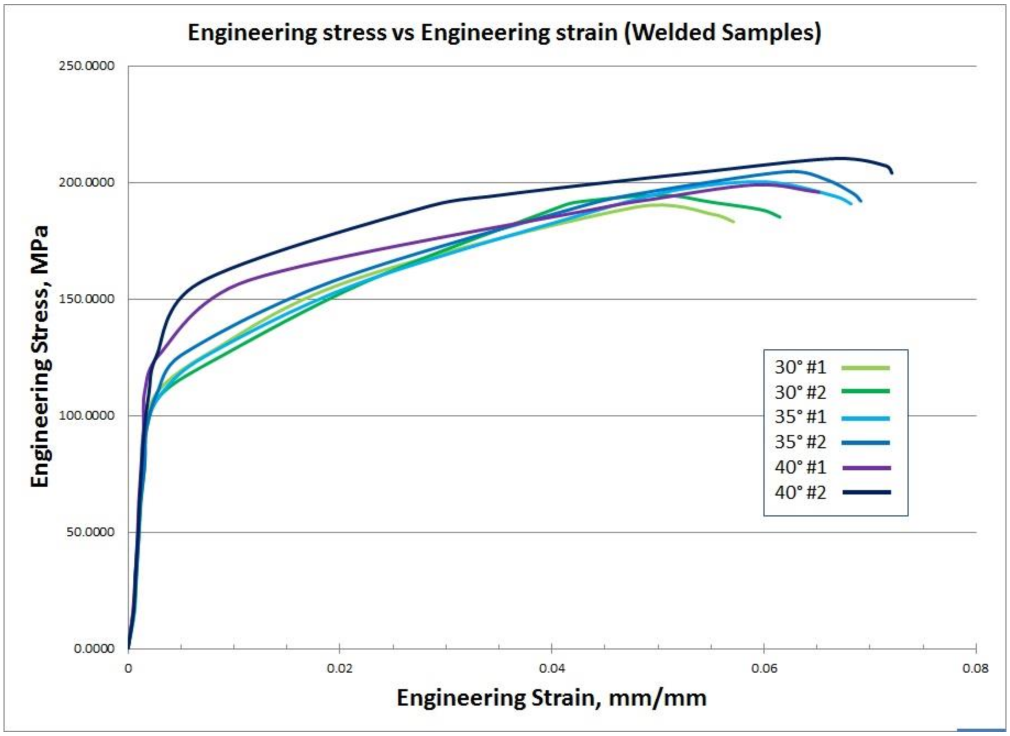


Figure 23: Engineering Stress Vs Engineering Strain Curve –Welded Samples

From the curves, we can observe that higher bevel angle resulting in higher yield point, yield strength and UTS. However, both sample #1 with 30° and 40° bevel angle show a lower UTS value. This might be because of defects in welding or the samples may have internal defects such as porosity or internal cracks. From the graph, we also can observe that the fracture strains for the welded samples are increased with the increasing bevel angle. Sample #1 with 40° bevel angle has the highest fracture strain. %Elongation and %reduction area also increased with increasing bevel angle.

From the data collected and observed, we can say that the amount of filler metal may have effects on the tensile properties of welded aluminum alloy 6061. Filler metal 5356 is (Mg-Si) based alloy. It contains magnesium and silicon as the major element. The present of this element can improve the strength as well as the ductility of the samples.

From this experiment, higher bevel angle have more filler metal added in welding process to fill the gap and space created by the angle. Sample with 40° bevel angle has the highest yield strength and UTS compared to other samples. It also has the highest yield point and fracture strain suggesting that the filler metal added had improved the ductility and strength of the welded samples. The proportionally limit also increased with increasing bevel angle, which means that more filler metal added will increase the elasticity of the samples. However, the difference in tensile properties of each samples is slight but still it is significant. Samples with 40° bevel angle have the best tensile properties compared to other samples.

Welding parameters only affected the weld quality. If the welding parameters are not set correctly, it will cause defects in the samples. It is essential to get the ideal depth of penetration for each bevel angle to avoid defects and lose of strength in weld area.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

For the conclusion, the bevel angle affected the tensile properties of material by the volume of filler metals added in welding. The larger bevel angle needs more volume of filler metal to fill the space. From this experiment, the largest bevel angle (40°) shows the best tensile properties; with highest UTS, yield strength, yield point and ductility. Samples with 30° bevel angle show the lowest tensile properties. Volume of filler metal 5356 influenced the tensile properties, by increasing strength and ductility. It is suggested by the increased of UTS, yield strength, elasticity region and %elongation as well as %reduction area of the samples as the bevel angle is increased. Welding parameters seems to have no effects to the tensile properties and it only essential to acquire ideal depth penetration.

However, the value of bevel angle must have the limitations and the range in which the strength of material is acceptable for industrial applications. The recommendations for future works are to study the effects of difference filler metal, with larger range of bevel angle so that we can find the limitations. Besides that, other experiment to find other properties of materials for example fatigue limit, corrosion resistant and etc. also should be included in the study.

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