EFFECT OF TEMPERATURE ON THE MECHANICAL PERFORMANCE OF JOINTS BONDED WITH ELECTRICALLY CONDUCTIVE ADHESIVE

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering

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DECLARATION

I declare that this report entitles “Effect of Temperature On The Mechanical Performance of Joints Bonded With Electrically Conductive Adhesive” is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

Signature : ....

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Date : ....

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Bachelor of Mechanical Engineering.

Signature : ....

Name : Dr. Mizah Binti Ramli

Date : ....

DEDICATION

This report work is dedicated to my beloved mother and father, whose has been support physically, emotionally and financially during the challenges to graduate school and life. I also truly thankful to my friends whose always helpful and been there to support and helped me. I am sincerely thankful for having you in my life.

ABSTRACT

An electrically conductive adhesive is glue which is used in method of joining and it's widely used in the electronic industry. An electrically conductive act as a medium for electric current to pass through them. The function of electrically conductive adhesive same as soldering process. However, due to the sensitivity of the electronic part to the temperature, the application of the electrically conductive adhesive is more compatible compared to the soldering process. There are a lot of factors that must be considered to design the adhesive joints. One of the factors is the effects temperature on the strength of the adhesive joints. In this study, the characteristic of the electrically conductive adhesive on the temperature was studied. In order to carry out this experiment, single lap joints of the specimen were used. The specimens were exposed to the room temperature, low temperature and high temperature. The specimens were tested using tensile test machine and the strength were of these three condition were compared. Then, the fractures of the specimens were examined using 3D Profilometer and the results of the degradation of the electrically conductive adhesive due to the temperature were compared.

ABSTRAK

"Electrically conductive adhesive" ialah sejenis gam yang mana digunakan dalam kaedah penyambungann dan digunakan secara meluas dalam industri elektronik. "Electrically conductive adhesive" akan bertindak sebagai satu medium untuk arus elektik lalu melepasi mereka. Fungsi "electrically conductive adhesive" adalah sama dengan proses pematerian. Walau bagaimanpun, disebabkan oleh bahagian elektonik yang sentsitif pada suhu, penggunaan "electrically conductive adhesive" dilihat lebih sesuai berbanding proses pematerian. Untuk mereka bentuk peyambungan gam, banyak faktor yang perlu dipertimbangkan. Salah satunya ialah kesan suhu keatas keatas penyambungan gam. Dalam pembelajaran ini, kesan suhu keatas ciri-ciri "electrically conductive adhesive" disiasat. Untuk menjalankan eksperimen ini, "single lap joints" specimen digunakan. Specimen-spesimen akan didedahkan kepada suhu bilik, suhu rendah dan suhu tinggi. Specimen-spesimen akan diuji menggunakan mesin ujian tegangan dan kekuatan specimen untuk ketiga- tiga keadaan akan dibandingkan. Selepas itu, pematahan spesimen akan diuji menggunakan "3D Profilometer" dan keputusan untuk kemerosotan "electrically conductive adhesive" akan dibandingkan.

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First and foremost, I would like to thankful to Allah s.w.t for giving me a blessing to finish my PSM. I also would like to express my appreciation to Universiti Teknikal Malaysia Melaka especially Faculty of Mechanical Engineering for giving me an opportunity to conduct my PSM.

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LIST OF ABBREVIATIONS

ICA	Isotropic Conductive Adhesive
SMD	Surface Monitoring Device
ACA	Anisotropic Conductive Adhesive
LCD	Liquid Crystal Display
PCB	Printed Circuit Board
RFID	Radio Frequency Identification
SLJs	Single Lap Joints
RT	Room Temperature
TAST	Thick Adherent Shear Test
RTV	Room Temperature-Vulcanizing
DMA	Dynamic Mechanical Analysis
GFRP	Glass Fibre Reinforced Polymer
AT	Ambient Temperature
DCB	Double Cantilever Beam
MW	Microwave
ACF	Anisotropic Conductive Film
DSC	Different Scanning Calorimetry
EDS	Energy Dispersive Spectroscopy
CFRP	Carbon Fibre Reinforced Polymer
DLJs	Double Lap joints

HTA	High Temperature Adhesive
LTA	Low Temperature Adhesive
CTE	Coefficient of Thermal Expansion
ABS	Acrylonitrile Butadiene Styrene
PLA	Polyactic Acid
ASTM	American Society for Testing and Materials
ECA	Electrically Conductive Adhesive

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

An electrically conductive adhesive is glue which is widely used in electronic industry. An electrically conductive adhesive will act as a medium for electric current to pass through them. There are a lot of advantages why conductive adhesive is widely used in the industry instead of soldering processes. Based on the research, some of electronic parts cannot be soldered due to the sensitivity of temperature. Therefore, conductive adhesive is the best problem solving for electronic parts that sensitive to the temperature because it proves that the temperature of the soldering process is higher than conductive adhesive [1]. In addition, ability of conductive adhesive to withstand vibrations is better compared to the solder. Besides, conductive adhesive is more flexible and easy to use compared to the solder. Electrically conductive adhesive is divided into two types which is isotropic and anisotropic. Isotropic conductive adhesive (ICA) is define as the electrically conductive in all directions. For an example, isotropic is used for a chip contacting and bonding electrically conductive surface mounting device (SMD). Anisotropic conductive adhesive (ACA) are electrically conductive only in one direction and it's contain special conductive particles in the µm range. For an example, liquid crystal display (LCD) connection, contacting flexible printed circuit board (PCB) and bonding antenna structures on radio-frequency identification (RFID) are used anisotropic because they contain sensitive structure on circuit boards [2].

Adhesion usually used in method of joining. Adhesion tends to suffer from the degradation of the joint at elevated temperature and in water compared to the other method of joining, such as welding, brazing, soldering, and fastening. There are a lot of factors must be considered to design the adhesive joints. One of them is the effects temperature on the strength of adhesive joints. Therefore, in order to improve the temperature of adhesive joints, a lot of work has been made. Cure shrinkage, the coefficient of thermal expansion (CTE) and different adhesive mechanical properties are the most important factors to measure the strength of adhesive joint when it applied under extreme temperature range. However, due to polymeric nature of adhesives, generally the most significant factor must be consider to design bonded joint is the variation of the mechanical properties of the adhesives with temperature. At low temperature the high thermal stresses and the brittleness of the adhesive are the origin of such behaviour, while at high temperature the adhesive strength is low [3].

1.2 PROBLEM STATEMENT

Temperature is a significant factor that must been considered while designing and manufacturing adhesive joint because temperature can contribute a major effect to the electric circuit and adhesive joint. High temperature and heat has always been a problem to the electric circuit because it can lead to the damage circuit components. For an example, high temperature will lead to the overheating of the chip and melted the plastic casing of the chip. In addition, damage of adhesive forces between substrate, damage of adhesive layer and changing mechanical properties of adhesive glue may occur if there are any changes in environmental condition.

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To investigate the mechanical properties of the adhesive joints under low temperature and high temperature.
2. To examine surface fracture of an adhesive joints taken by 3D Profilometer.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. This project is design according to the ISO standard of single lap joint. This project involved joining between two metals using an adhesive.
2. The changing of mechanical properties was observed and mechanical testing was conducted under high temperature and low temperature.

1.5 GENERAL METHODOLOGY

The actions that need to be carried out to achieve the objectives in this project are listed below.

1. Literature review

   Journals, articles, or any material regarding the project will be reviewed.

2. Design specimen

   Design specimen according to ISO standard of single lap joint.

3. Fabrication

   The fabrication process will conducted at Makmal 2 Bahan Termaju. This process involved joining an adhesive joint according to ISO standard of single lap joint.

4. Experiment

   Experiment will be presented on how the experiment of mechanical properties of an adhesive joint under high temperature and low temperature.

5. Analysis

   Analysis will be presented on how to analyse the problem of an adhesive joint under high temperature and low temperature.

6. Report writing

   A report on this study will be written at the end of the project.

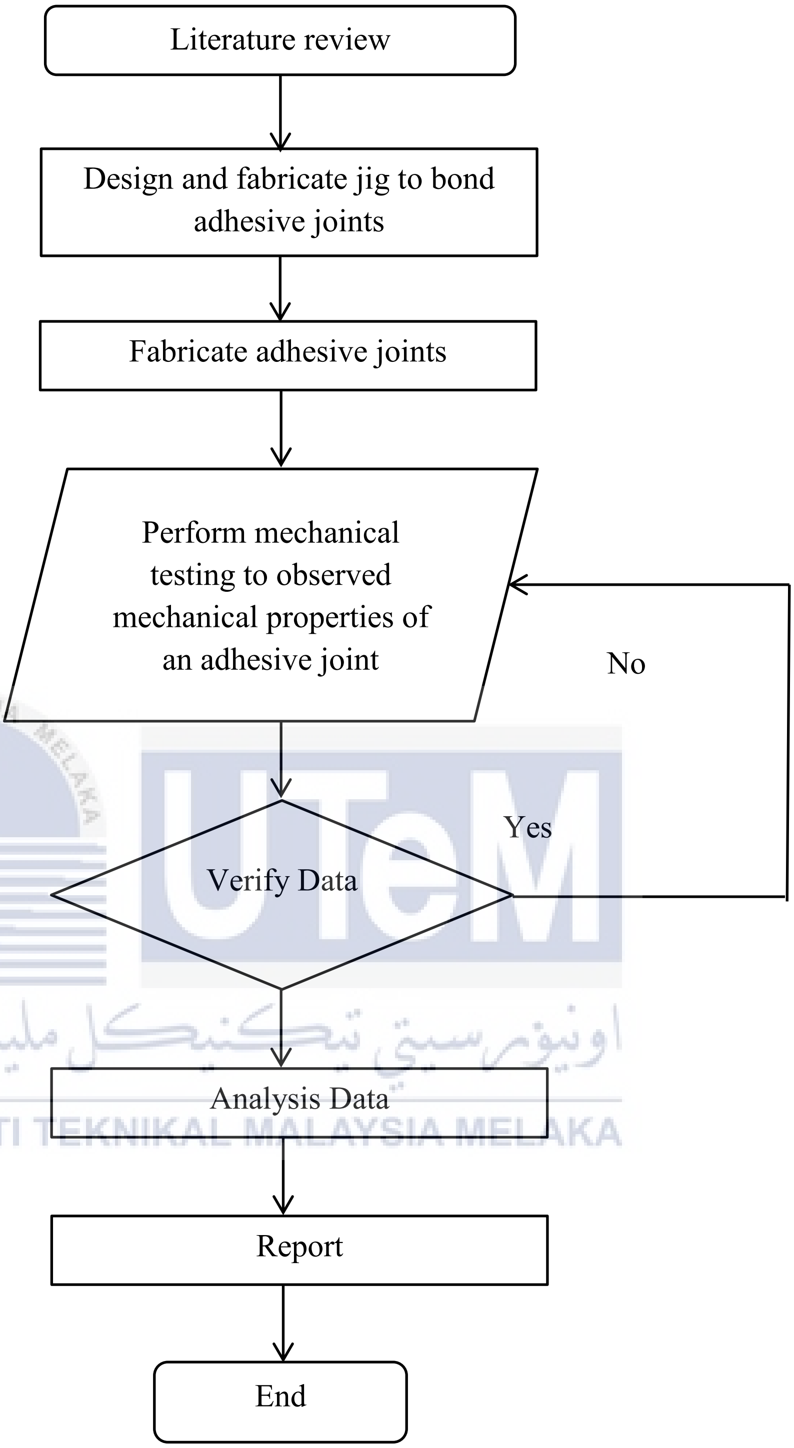


Figure 1.1: Flow chart of the methodology.

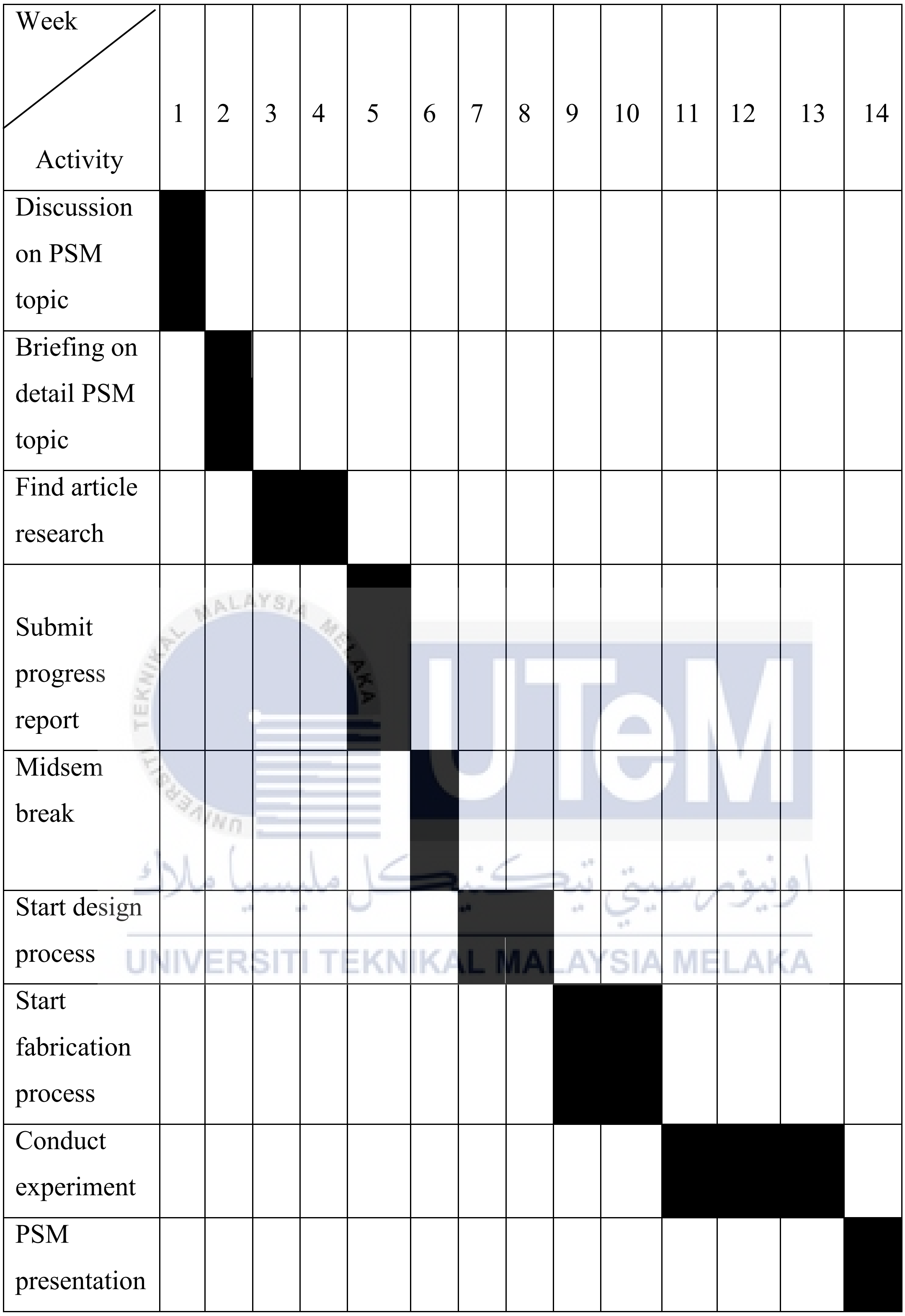


Figure 1.2: Gantt chart for PSM project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTODUCTION

This section discusses the previous study about the application of the adhesive at low and high temperature.

2.2 APPLICATION OF ADHESIVE AT HIGH AND LOW TEMPERATURE

An adhesively bonded joint is a growing requirement and widely used in engineering applications. Adhesively bonded joints provide a lot of advantages over conventional mechanical fastener such as lower structural weight, lower fabrication cost and improve damage tolerance. However, in order to design a bonded joint, there are a lot of factor that must been considered such as temperature. Temperature is one of the most important factors that must be highlight before start the designing process.

Some researcher investigates the behaviour and mechanical performance of bonded joints at high temperature. The performance of single lap joints (SLJs) with epoxy adhesives at low and room temperatures were investigated by Adams et al. and found that the stresses those generated by adherend thermal mismatch have more effect on the lap joint strength than the stresses that generated by adhesive shrinkage. SLJs test with a rigid and flexible epoxy adhesive at room temperature and at -40˚C in quasi-static conditions were conducted by Owens and Lee-Sullivan. Stiffness loss due to crack growth in composite to aluminium joints were investigated and found that, the modulus of thin adhesive layer have much less affected on the joint stiffness compared to the response of the adherends to the test temperature [4].

SLJs test with and epoxy adhesive at -40˚C, room temperature (RT) and 80˚C were conducted by Banea and da Silva and found that at temperature -40˚C and 80˚C, the lap shear strength of the adhesive joints decreased by approximately 10 % and 30 % than the specimens tested at RT [3]. Some researchers were investigating aluminium using SLJs method and it were test at room temperature (RT) and high temperature (100˚C, 125˚C, 150˚C and 200˚C). Researcher indicated that at 100˚C, the strength of SLJs tested increased by approximately 9% than at RT, while approximately 30% of shear lap strength were increased at 125˚C. The adhesive becomes more ductile and the overlap contributes more to the strength as the adhesive yields when the temperature closer to 155˚C and at 175˚C and 200˚C the strength of SLJs were decreased by approximately 54% and 75 % [3], [4].

Moreover, there are researcher conducted the standard thick adherent shear test (TAST) to determine the performance of two different room temperature-vulcanizing (RTV) silicone adhesive and the fatigue behaviour [5], [6]. Researcher found that, as the temperature increases, there's a decline in lap shear strength [6]. Furthermore, the characteristic of seven different adhesive was investigated. Aluminium, titanium and invar were used as an adherends and were bonded using single lap joints (SLJs) method. The specimens were tested over temperature range from -150˚C up to 150˚ and their mechanical characteristic were compared. At the end of the study, researcher indicated that the performance of an adhesive affected by variation of temperature. Hysol 9494 or Hysol 9360 are suitable for application at high temperature while EC 2216, Hysol 9309.3 and Hysol 9361 are suitable for application at low temperature. Based on dynamic mechanical analysis (DMA) result, the modulus of the adhesive would be affected if there any change in ultimate strength [7].

Besides that, in order to degrease the adherend surface and followed by grit blasted to give a surface finish of 2.5μm of surface roughness, Grant et al has used acetone while Lucas et al has used #800SiC sandpaper. Next, in order to change the morphology and surface chemistry of adherends, Comyn showed that surface treatment was very important in removing contaminant and weak boundary layers. Tensile behaviour of adhesively bonded glass fibre reinforced polymer (GFRP) joints on the low and high temperature was proposed by Zhang et al. The surface treatment different mesh number of sandpaper 220, 400 and 600 and environmental temperature conditions ambient temperature (AT), 70˚C and 130˚C influenced the strength and failure modes of composite adhesive joint were investigated.

Table 2.1: Failure mode for specimen test

Failure Mode		
Cohesive Failure	Interfacial Failure	Mixed Failure
Without sanding (130˚C) #220* (130˚C) #400* (130˚C) #600* (130˚C) #400* (70˚C)	Without sanding (AT) #220* (AT) #600* (AT)	Without sanding (70˚C) #220* (70˚C) #600* (70˚C) #400* (AT)

From the table 2.1, * is indicate mesh number of sandpaper used for the surface abrasion. Cohesive failure means the separation is within the adhesive. Interfacial failure means separation appears to be at adhesive-adherend interface and mixed failure means a mixture of different classes. At the end of the experiment, researcher indicated that, at the temperature of 70˚C, a complete wetting of adhesive were observed uniformly over the surface of adherend and for all type of the specimen, joint strength were increase. Furthermore, researcher discovered the strength of the adhesive bonding and the stiffness were decreased at the temperature aboveT_g [8]. Figure 2.1 shows the SLJs specimen.

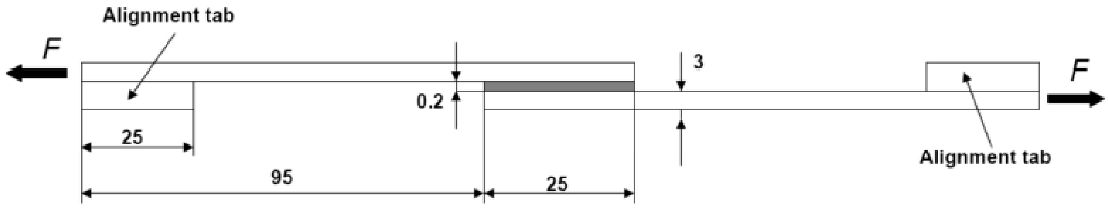


Figure 2.1: Single lap joints (SLJs) specimen [4].

Spingarn used developed data reduction schemes to evaluate the value of G_{Ic} of a nylon-modified epoxy adhesive. Aluminium alloy 2024 adherend, adhesive thickness and temperature were used as the parameter and the specimen was test in the Chevron-notched. Researcher found that there was drastically reducing when temperature up to the value of T_g. Furthermore, Chai found that the mode II fracture energy decreased in the region 0.7 < T/T_g < 1.0 when the investigation of influence of temperature on the fracture energy in shear was conducted. Furthermore, some researcher were investigate the effect of temperature on the adhesive strength and fracture toughness of high temperature (100, 150 and 200˚C) epoxy adhesive using tensile test and pure mode I double cantilever beam (DCB) adhesive fracture toughness (G_{Ic}). Researcher indicated that, at the temperature between 100 and 150, the ultimate stress decreased monotonically while the strain drastically reduced at the temperature 200˚C, as the temperature increased above $T_g = 155^{\circ}C$ of the adhesive [9]. Figure 2.2 shows the double cantilever beam (DCB) specimen.

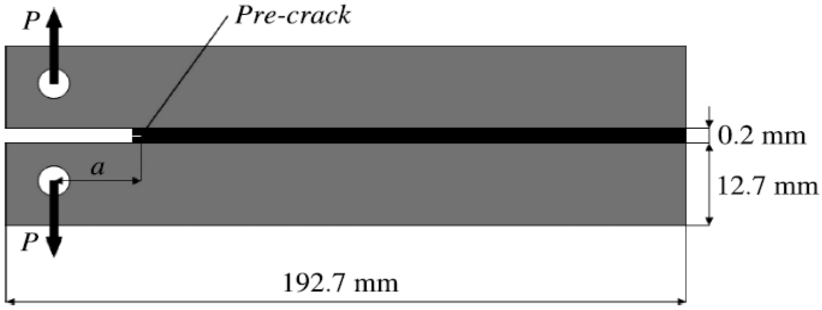


Figure 2.2: Double cantilever beam (DCB) specimen [9].

In addition, some researcher also studied the performance of flip chip on flex circuit with the effect of microwave (MW) preheating of anisotropic conductive film (ACF). The characteristic the electrical and mechanical performance of the bonding depends on the contact resistance and the shear force at breakage of the bond. In this study, 80 and 240W of the microwave power was used and 180˚C as the standard temperature for flip chip bonding. At the temperature of 180˚C the contact resistance is 0.017Ω and the shear forces at the breakage are (173.3 N). At the end of this study, researcher indicated that the temperature of 170˚C can be used instead of 180˚C because the contact resistance is low which in range of 0.015Ω -0.025Ω and the shear forces at the breakage even higher than a standard one which is in range of 125 – 176 N. The contact resistance at the temperature 160˚C is in the range of 0.022 – 0.032Ω and bond strength is in the range of 137.3 – 145 N and researcher concluded that the temperature at 160˚C also can be used instead of 180˚C because of the low contact resistance but the bond strength is smaller than a standard one [10]. Figure 2.3 shows the side view of a chip package.

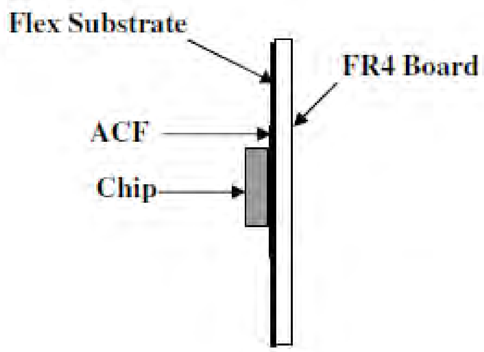


Figure 2.3: Side view of a chip package [10].

Afterwards, 40˚C and 98% of relative humidity was investigated on the quasi-static strength of the adhesive bonded aluminium alloys. SLJs method was used to fabricate aluminium alloys. In order to determine the degradation mechanism of adhesive bonded joints exposed to hot humid environment, different scanning calorimetry (DSC), contact angle measurement, surface free energy dispersive X-ray spectroscopy (EDS) and polarization corrosion test were conducted. From this study, the failure mode has changed from mixed cohesive and adhesive failure with failure being dominant to adhesive failure being dominant. Furthermore, researcher also found that there was a decrease in the joint strength when the specimen exposed to the hot humid. Researcher also concluded that the corrosion reaction of aluminium would be increased at high temperature and automatically influenced the degradation in joint strength of aluminium [11]. Double strap joints were used to bond CFRP and steel and the specimen were tested in tension at the temperature range from 27˚C up to 120˚C. Researcher discovered that, as the temperature increase, the rate of failure mode of specimens also increased. At the temperatures aboveT_g, researcher found that there's a decreasing in the initial stiffness and ultimate load of the specimens [12]. Figure 2.4 shows double strap joint specimen between CFRP and steel.

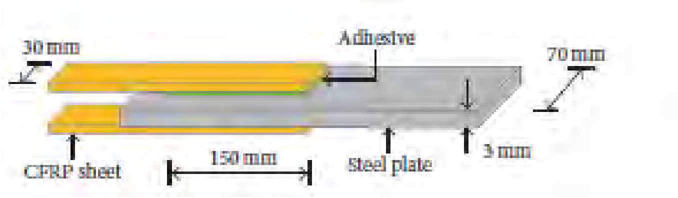


Figure 2.4: Double strap joint specimen between CFRP and steel [12].

Some researchers were investigated high temperature storage testing of conductive adhesive film (ACF) attached sensor structures. The test was carried on two different organic printed circuit board (PCB) materials which is FR-4 and Rogers and their performance and reliability were observed. After 2000 hours of testing, the failures started to occur at 200 ˚C and the interconnections were functional only for 400 hours at 240 ˚C. Researcher found that PCB material promising interconnection materials at elevated temperature, especially at 200 ˚C even though ACF were not designed for use in high temperature. Researcher also stated that reliability problem in long term high temperature exposure may be occurred due to material degradation [13].

Besides, some researcher investigates the behaviour and mechanical performance of bonded joints at low temperature. Researcher investigates the effect of heating on the structure of an adhesive joint, as indicated by electrical resistance measurement. Steel was used in this study as adjoining components. The surface roughness of the steel is 120 µm and the steel is heating from 20˚C up to a temperature as low as 25˚C. Researcher stated that, the partial reversibility upon subsequent cooling increased when the contact electrical resistivity of the joint is increased. A microstructural change which is decreased the extent of electrical contact of the adjoining surfaces occurred when the irreversible portion of observed resistivity increased while the reversible portion of the epoxy caused by thermal expansion [14]. Figure 2.5 shows the four electric contact A, B, C and D.

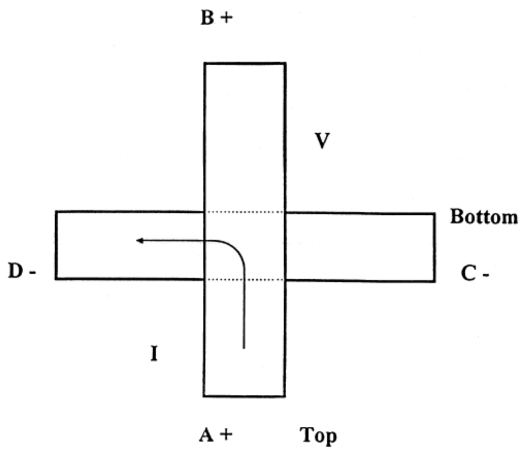


Figure 2.5: A, B, C and D represent four electrical contact. B and C are for voltage, measurement and A and D are for passing a current, I [14].

Furthermore, some researcher also investigated the temperature effect on the mechanical behaviour of adhesive bonded steel joints under short and long term loading. In this study, epoxy and acrylic were used to assemble the galvanized steel sheets and double shear by tension test were performed. For the short term test, two thickness of adhesive bond line at four temperatures which is -20, 0, 20 and 40˚C were used while long term test was applied at 40˚C with one thickness. Researcher found that adhesive behaviour, mechanical shear properties and failure modes were affected by increasing of temperature. Researcher concluded that, for the long term test, even when a constant shear stress of a joint was not exceed the short term ultimate shear strength, the probability of failure in shorter period was higher at the higher temperature [15]. Figure 2.6 and figure 2.7 show double lap shear joint for short term test and long term.

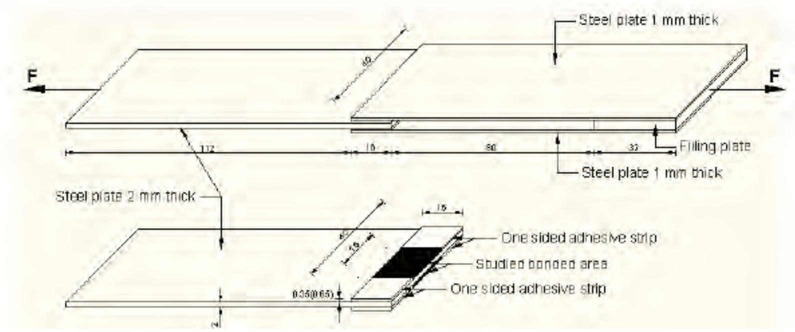


Figure 2.6: Double lap shear joint for short term test and the black areas indicate bonded areas [15].

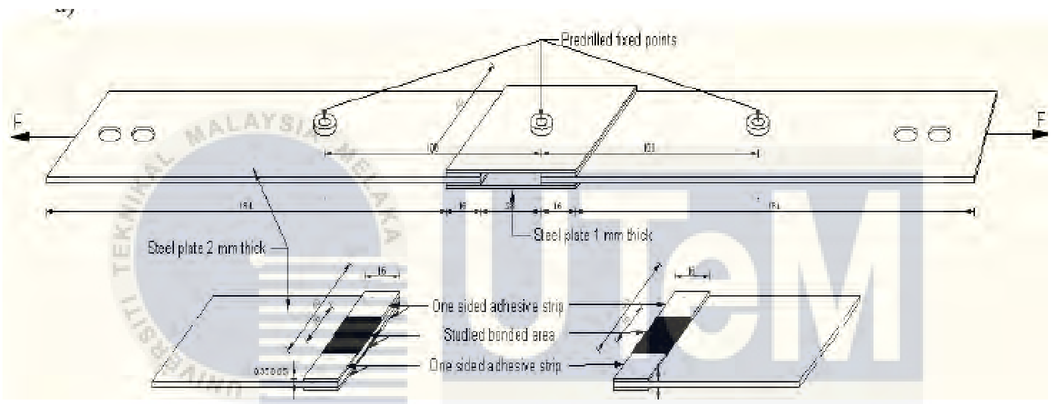


Figure 2.7: Double lap shear joint for long term test and the black areas indicate bonded areas [15].

Then, two dissimilar material which is 2024-T3 aluminium alloy and 6^{th} grade titanium alloy Ti6Al4v were tested at the temperature of 22, 10, 0, -10, -20, -30, -40, and -50˚C to determine their mechanical properties. Hysol EA-934 was used as an adhesive to bond two dissimilar materials and a single lap joints method was used. Researcher indicated that, at very low temperatures, effect from thermal loads below 0˚C caused a negative impact on the adhesive strength and micro-cracks formation. Researcher also concluded that stress states that exceed the adhesive lap shear strength may be occurs at low temperatures in dissimilar material bonded joints [16].

Furthermore, the specimen was tested under temperatures ranging between 21˚C and 70˚C and epoxy adhesive was used as an adhesive to make SLJs. Two different types of the overlap length were used in this study which is 12.5mm and 18.75mm. At the end of this study, researcher found that from temperature 30 to 50˚C, showed the higher shear strength loss. Furthermore, researcher also indicated that the shear strength increased when the overlap of the single lap joints increased and the failure mechanism was caused by an adhesive [17].

Moreover, bulk specimen was bonded using SLJs method and the performance of two different adhesives were investigated which is an epoxy and polyurethane. The specimens were tested at the room temperature (RT), -40˚C, 60˚C and 80˚C. Researcher concluded that as the temperature decreased at -40˚C, the adhesive becomes more brittle and has more apparent tensile strength, but less strain for epoxy adhesive while adhesive has a low strength and stiffness but sustains large displacement at room temperature of polyurethane adhesive [6], [18].

In addition, some researcher were investigated the effect of temperature on fatigue growth in epoxy adhesive. The specimen was test from temperature range -55 to 80˚C using DCB method. Power-law relationship between the amount of available energy and the applied cyclic work was found from previous work. Researcher stated the behaviour was affected by temperature at -55˚C and -20˚ as well as at 60˚C and 80˚ but did not show any change from temperature range 0˚C to 40˚C. Researcher also indicated that temperature was affected active mechanism but does not affect the crack growth [19].

Then, researcher also investigated tensile lap shear testing of adhesively bonded polyethylene pipe. The specimens were tested from temperature range of -10, -5, 0, 5 and 20˚C. Researcher found that, lap shear strength decrease as the testing temperature decrease to zero. At 20˚C, the lap shear strength performance is 2.72 MPa while at 0 ˚C was 1.15 MPa. The result showed a very low strength 0f 0.105 MPa at -10 ˚C [20]. Figure 2.8 shows the schematic diagram of electrofusion joint.

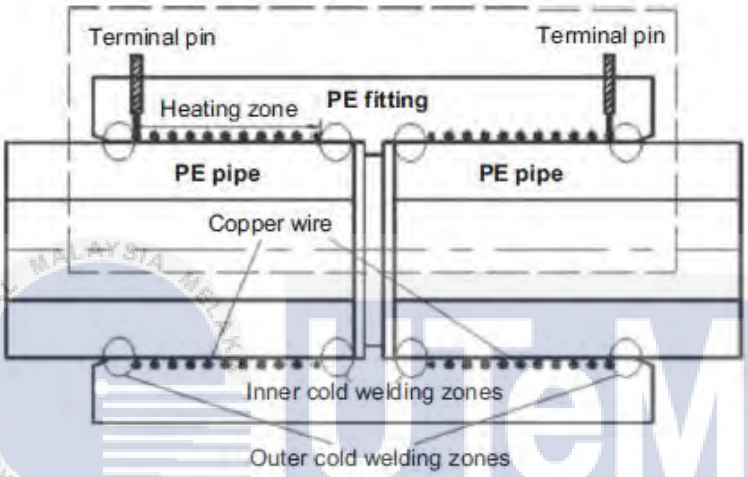


Figure 2.8: Electrofusion joint schematic diagram [20]

Some researcher also investigated effect of temperature and strain rate on SLJs with dissimilar lightweight adherend bonded with an acrylic adhesive. The adherends used for this study is unidirectional carbon fibre reinforced polymer (CFRP). The specimens were test at -30, 23 and 80˚C and the results were taken under quasi-static and impact loading test. Less strain rate dependency was found at low temperature because materials became stiffness and more brittle. The result from quasi-static loading showed the plastic behaviour on the adhesive at room temperature while at high temperature, softening of the adhesive caused the decreased on the joint strength [21].

Furthermore, similar (titanium/titanium) and dissimilar (titanium/composite) were investigated from temperature range from -55 to 200˚C. The experiment was conducted using double lap joints (DLJs) and high temperature adhesive (HTA) and low temperature adhesive (LTA) were used as an adhesive. High temperature adhesive (HTA) was located in the middle while low temperature adhesive (LTA) in the ends. Researcher indicated that, from low to high temperature, the strength of the joint is higher when used HTA. When using similar adherends, the strength of adhesive joint when used mixed adhesive was higher at low temperature compared to HTA alone. When using dissimilar adherends, if the difference of coefficient of thermal expansion (CTE) between the adherends is high, the mixed modulus concept is real improvement over a joint with HTA alone. At high temperature, the strength of the joint when used mixed adhesive was higher compared to the HTA alone at low temperature. In addition, the strength of the HTA alone at intermediate temperature is lower compared to the mixed adhesive [22]. Figure 2.9 and figure 2.10 show DLJs of the specimen.

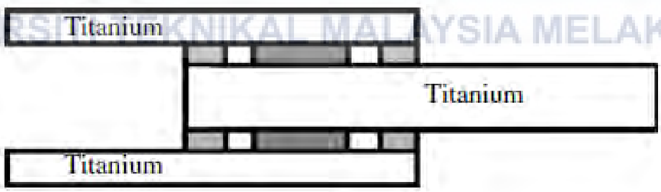


Figure 2.9: Double lap joints (DLJs) of the specimen [22].

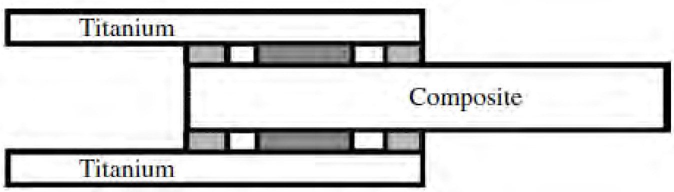


Figure 2.10: Double lap joints (DLJs) of the specimen [22].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is the method that has been used to achieve the main objective for this project. Besides, this methods acts as a guidelines to conduct and obtain result for this project.

3.2 DESIGNING JIG

The jig was designed according to the dimension and specification. In order to design the jig, CATIA software was used. The purpose of the jig was designed is to control the thickness of the adhesive which is 0.1 mm. Advanced technology of 3D printing has been use to fabricate the jig. Figure 3.1 shows the drawing and the dimension of the jig.

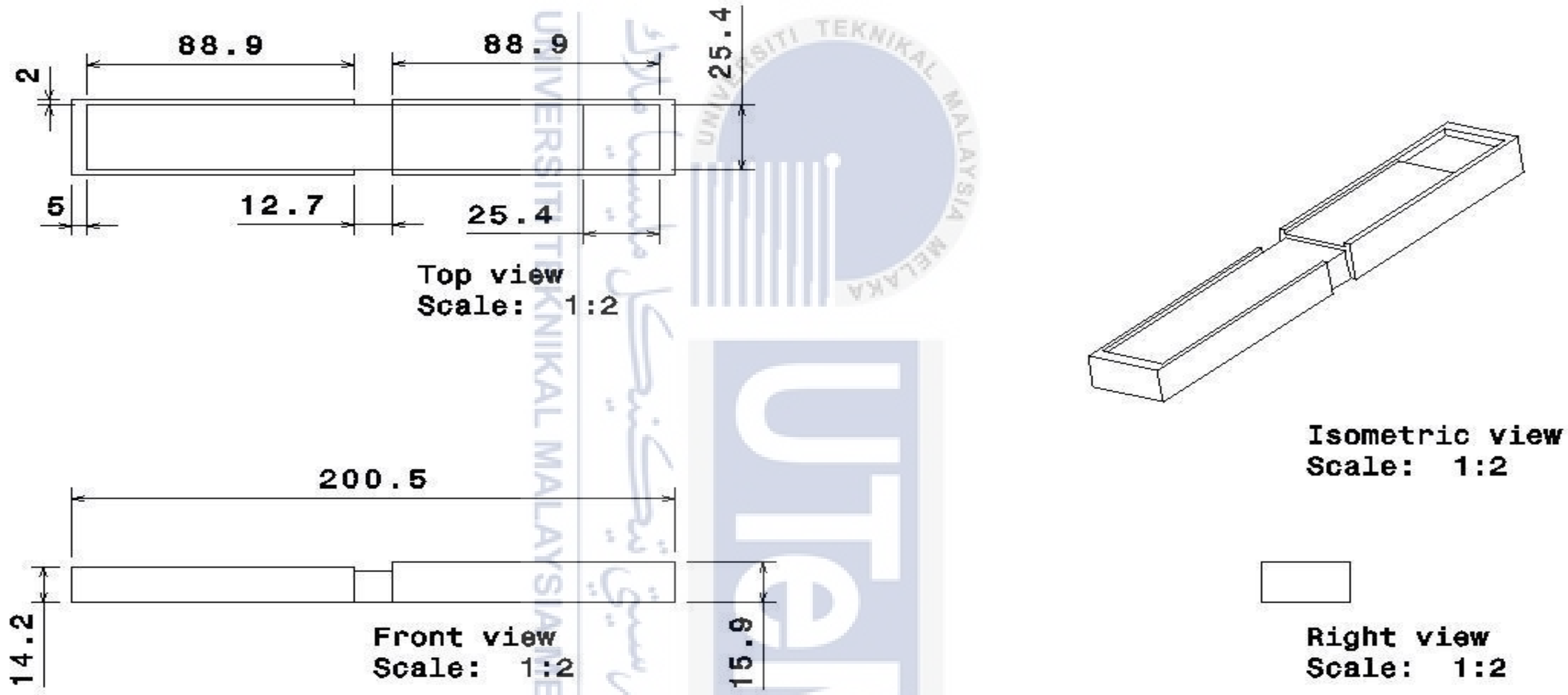


Figure 3.1: Drawing and dimension of the jig.

3.3 PRINTING PROCESS

CUBEPRO 3D printing machine was used to fabricate the jig. Acrylonitrile butadiene styrene (ABS) and polyactic acid (PLA) were used as a material for this process. Figure 3.2 shows the tools that have been used in the printing process. There were a few steps must be taken before and after using this machine. The steps as follows:

1. Convert files from format catpart to stl.
2. Transfer the files in stl format to CUBEPRO 3D printing machine.
3. Clean the glass bed.
4. Applied glue to the glass bed.
5. Start the process of the printing.
6. After the process of the printing was finished, cooling down the printing machine first.
7. Then, take out the glass bed from the machine and applied hot water to the surface that glue was applied.
8. In order to remove the jig, the surface of the glass bed must be scrap using a scraper.
9. Next, wash the surface of the glass bed until clean.
10. Wipe the surface of the glass bed until dry.
11. Placed the glass bed into the machine.

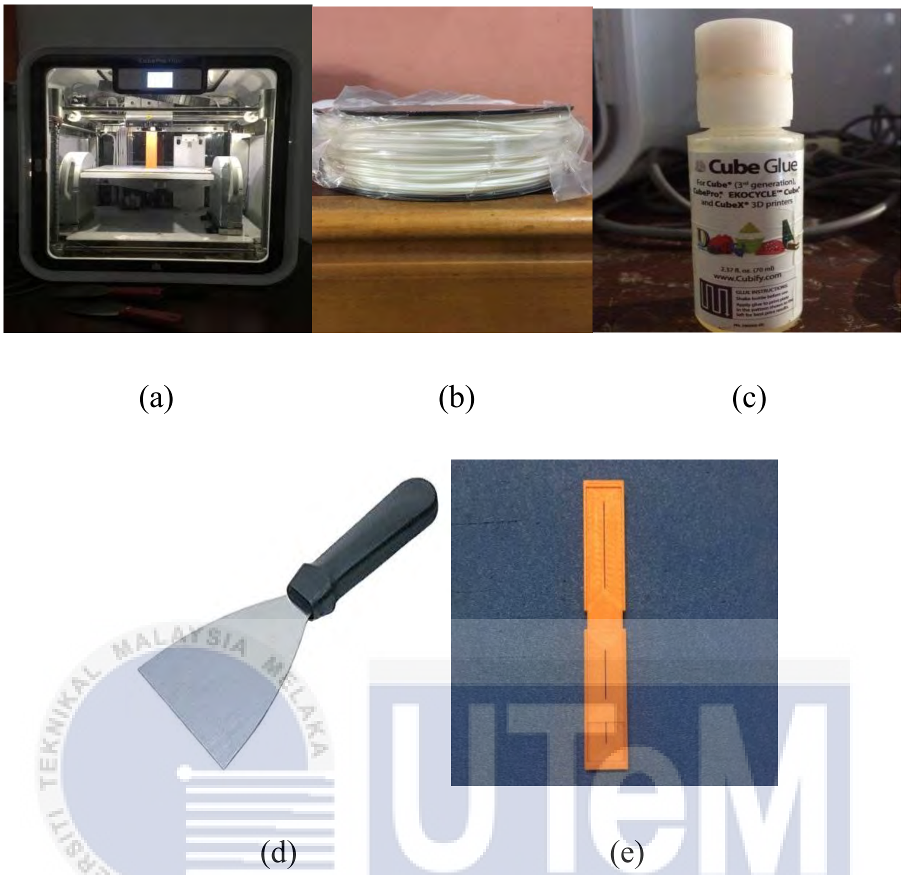


Figure 3.2: (a) CUBEPRO 3D printing machine (b) ABS filament (c) Glue

(d) Scraper (e) Jig

3.4 PREPARATION OF THE SUBSTRATE

In this experiment, aluminium is used as a material of the substrate. The substrate is design according to American Society for Testing and Materials (ASTM) D1002. The area of the substrate IS 101.6 mm x 25.4 mm. The selection of the steel based on the toughness, ductility, strength, weld ability and the durability of the material. The details dimension of the substrate as shown in Figure 3.3.

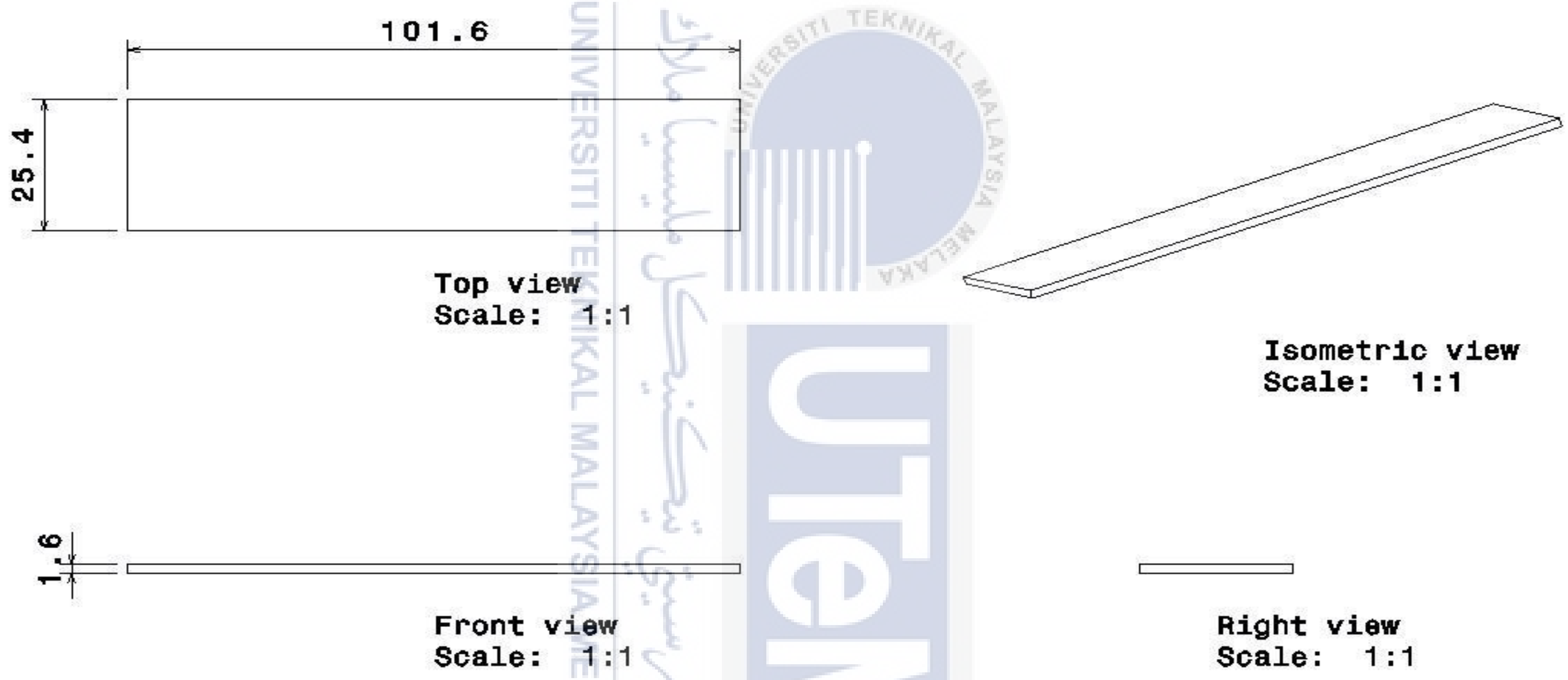


Figure 3.3: Details dimension of the substrate.

3.5 PREPARATION OF THE SPECIMEN

Before bonded the specimen, acetone was used to clean unwanted particle on the surface of the substrate. Then, dry the substrate in 2 minutes before bonded. Salotape was applied to the specimen to avoid any ECA exceed the lap shear as shown in the figure 3.4. Next, applied the ECA onto the surface of the substrate as shown in figure 3.5. Razor blade was used to ensure the thickness of the ECA is equal to 0.1mm as shown in figure 3.6. Figure 3.7 showed that details drawing of the bonded specimen and the thickness of the ECA applied to the surface of the specimen is 0.1mm.

Figure 3.4: Salotape was applied

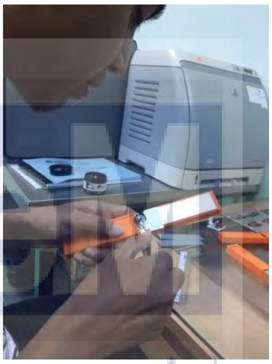


Figure 3.5: ECA was applied to the surface of the substrate

Figure 3.6: Razor blade was applied

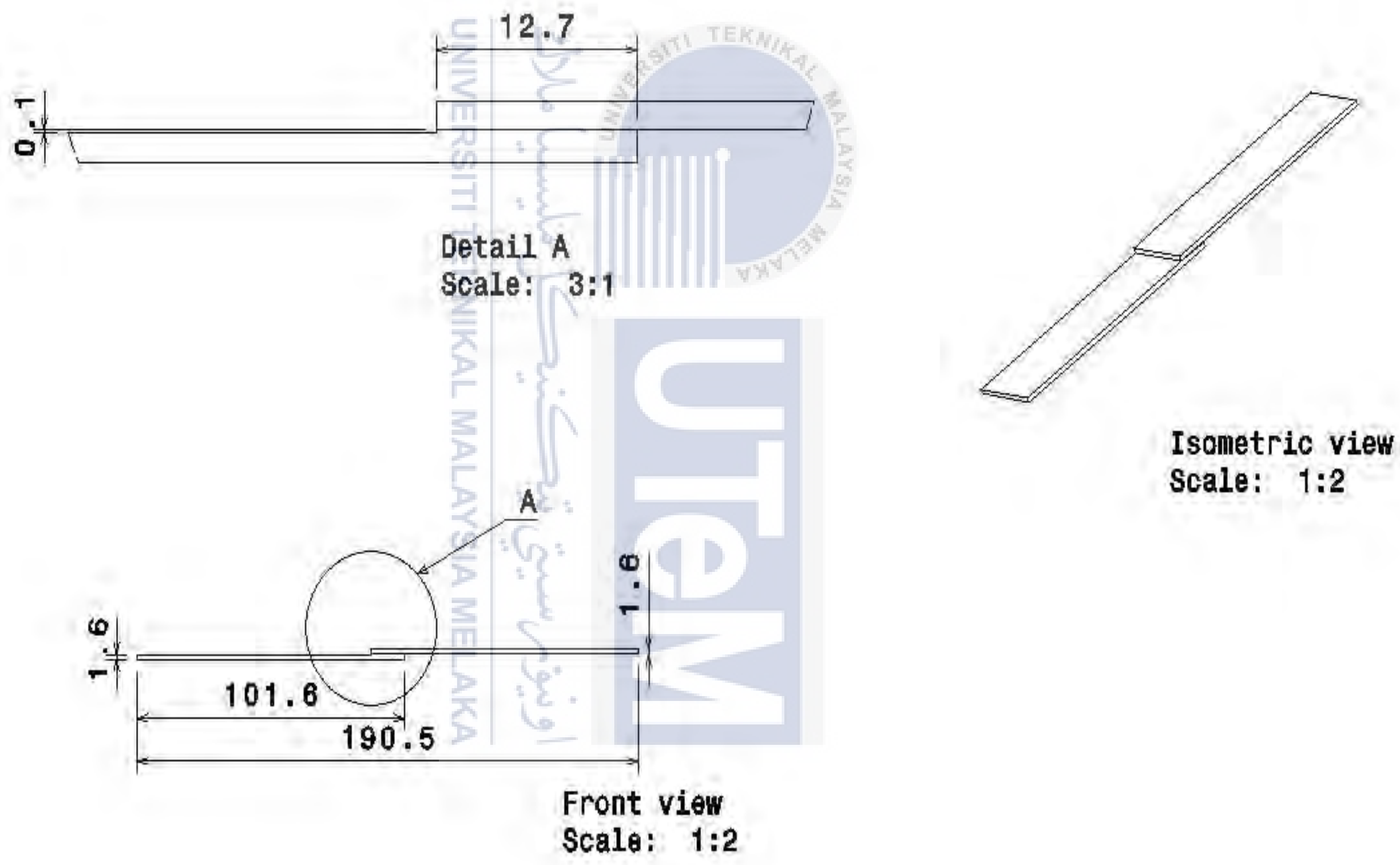
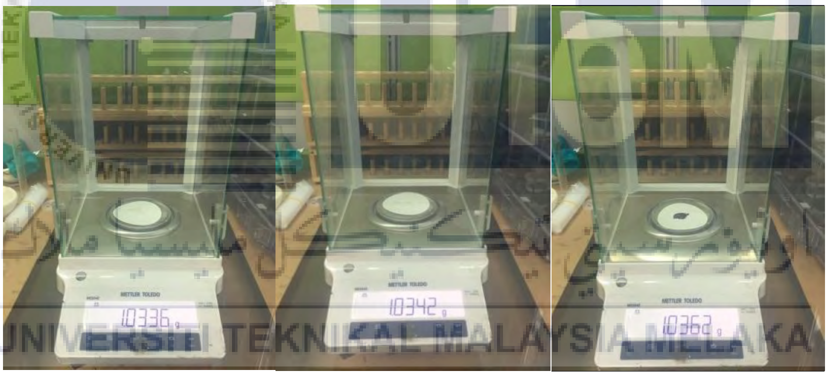


Figure 3.7: Bonded joints of the specimen.

3.6 CHARACTERISTIC OF ELECTRICALLY CONDUCTIVE ADHESIVE (ECA)

In this section, araldite epoxy adhesive which is consist of resin and hardener and electrically conductive ink were used and formulated to bond the specimen. The ratio 1:1:1 was used to formulate the adhesive and electrically conductive ink. There were a few steps must be taken to formulate the adhesive. First, weighing the resin, hardener and electrically conductive ink with the same weight using a digital weight as shown in figure 3.8. Second, put the resin, hardener and electrically conductive ink into a beaker and mixed them in 2 minutes. Figure 3.9 shows the mixing process of resin, hardener and electrically conductive ink.



(a) (b) (c)

Figure 3.8: (a) Resin (b) Hardener (c) Electrically conductive ink

Figure 3.9: Mixing process of resin, hardener and electrically conductive ink

3.7 TESTING METHOD

In this experiment, there are two methods to test the strength and detect the fracture of the substrate. The methods are:

i. Tensile test machine

The specimen will be test using tensile test machine. The purpose of this testing is to determine the strength of the adhesive. The specimen tested at three conditions which are high temperature, room temperature and low temperature. At high temperature, the specimens were exposed to the temperature at 85˚C using an oven while at low temperature, the specimens were exposed to the temperature at 6˚C using a refrigerator. The results in room temperature condition will be a benchmark or reference to low and high temperature. After the specimens were bonded, the specimens were cured at room temperature in one day. Then, the specimens were cured again inside oven in 30 minutes with 100˚C of temperature. During the testing shear strength is important parameters that must be concern. The strength of the specimens for each condition were recorded and compared. Figure 3.5 shows that tensile test machine that was used in this experiment.

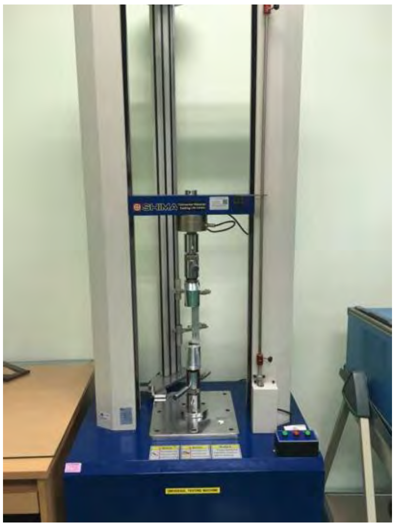


Figure 3.10: Tensile test machine

ii. 3D Profilometer

The specimen will be exposed to the high and low temperature and will be tested using tensile machine. The process to examine the fracture on the surface of the specimen will be conducted after the tensile test. In order to detect the fracture on the surface of the specimen, 3D profilometer was used. The topography and the peak value of the specimen were define and compared.

Figure 3.11: 3D Profilometer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This section will be discussed the results obtained from the experiments. All failures occurred during jig fabrication and the solutions will be explained.

4.2 DESIGN JIG TO BOND ADHESIVE JOINTS

In order to design a jig, the dimension and specification of the substrate need to be determined. In this project, ASTM D1002 has been use. The purpose of this jig is to control the thickness of adhesive joints which is 0.1 mm. Figure 4.1 shows the dimension and specification of the specimen used for this project.

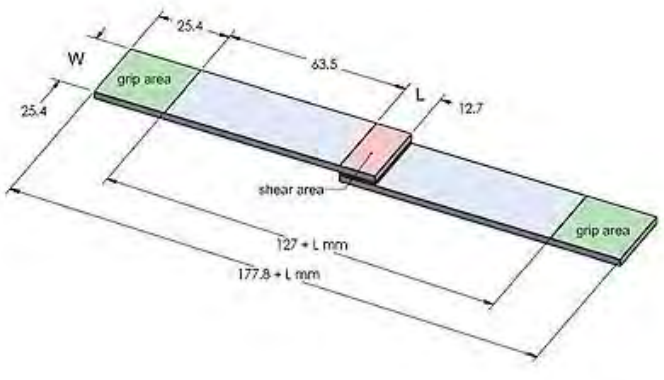


Figure 4.1: The dimension and specification of the specimen [16].

The jig was designed according to the dimension and specification. In order to design the jig, CATIA software was used. Latest technology of 3D printing has been use to fabricate the jig and ABS and PLA were used as a material for this process. In this section, there are two different designs which are design 1 and design 2.

Design 1:

Design 1 was designed according to the dimension and specification in the Figure 4.2. Cube Pro 3D printing machine was used for this process and was assist by technician at the lab. ABS was used as the first attempt fabrication of the jig.

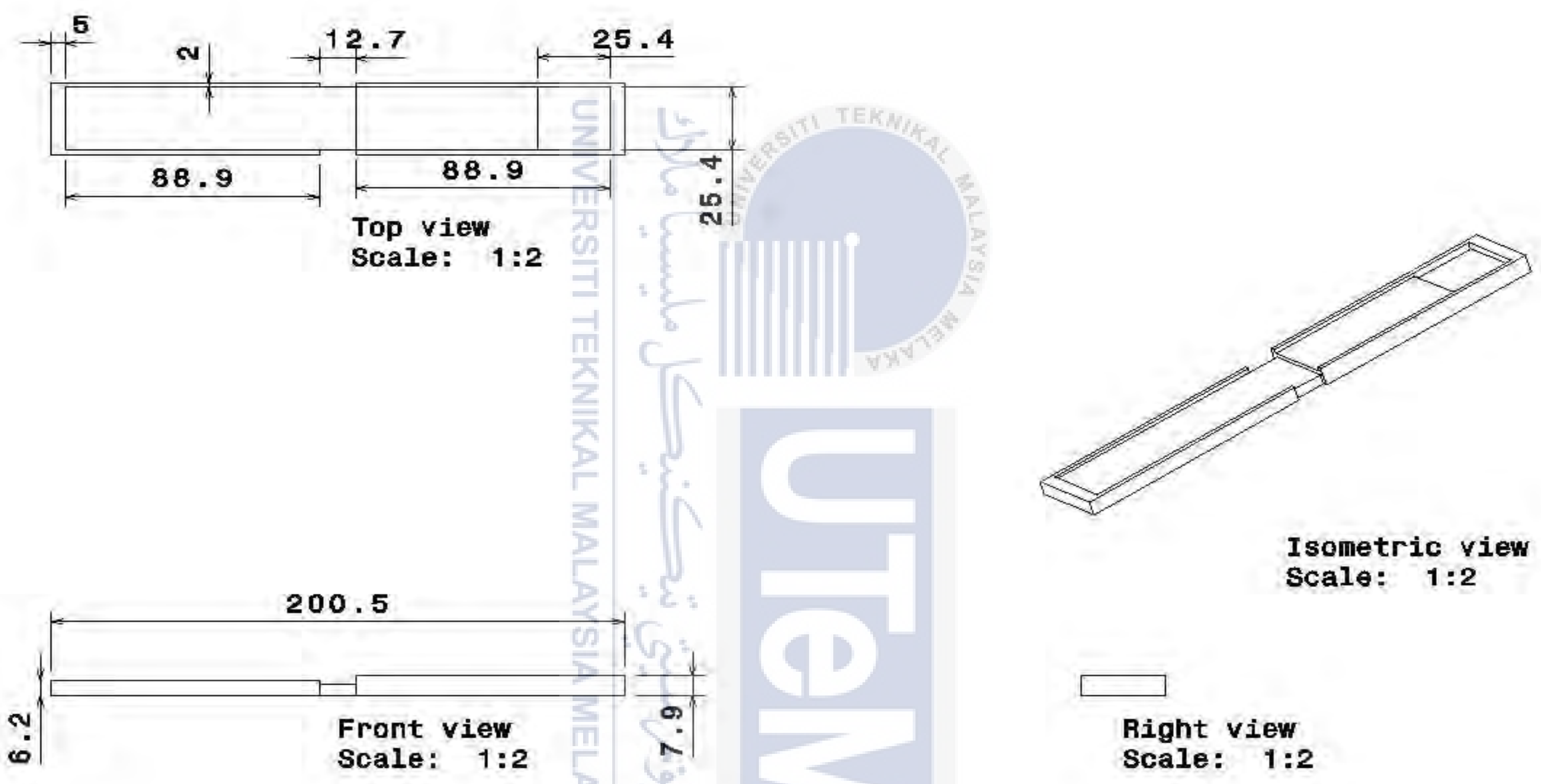


Figure 4.2: Design 1

After the jig was fabricated, it is noticed that the jig was not in the perfect condition. Below, is the list of jig's failure:

i. The jig was broken

Based on the Figure 4.3, ABS was use d as a material and it showed that the jig was broken due to the weak strength. Weak strength of the jig caused by the wrong orientation used during the 3D printing process. When used y-orientation as Figure 4.4, the surface area becomes small therefore, it does not support the height of the object. It was recommended to use x-orientation to support the length of the jig besides increase the strength of the jig.

Figure 4.3: Broken jig

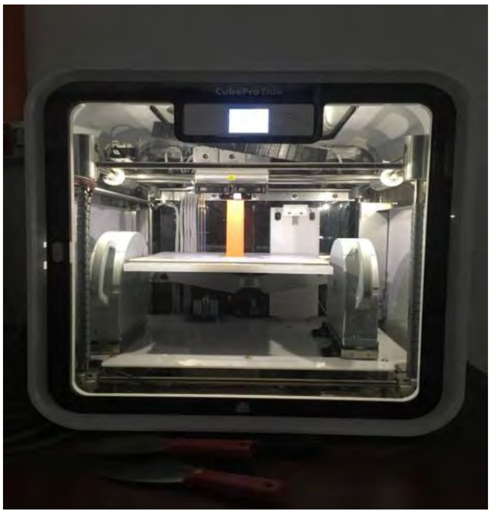


Figure 4.4: y-orientation of the jig

ii. The jig was bending

Figure 4.5 showed the bending jig due to the small dimension of the thickness and failure in scarping process. ABS was used as the material and the jig above was printed in the x-orientation but the failure happened during the scraping process. The purpose of the scraping process is to separate between the jig and the board of the machine. The strength needed during the scraping process. Due to the small thickness, the jig was bending due to the forced exerted in the scraping process.

Figure 4.5: Bending jig

iii. Wrong material used

Figure 4.6 shows the x-orientation with PLA as the material. As a result, it shows that the surface was unsmooth due to the PLA material. In order to product perfect shape of the jig, some improvement was made in the design of the jig. The improvement design as shown in the Design 2.

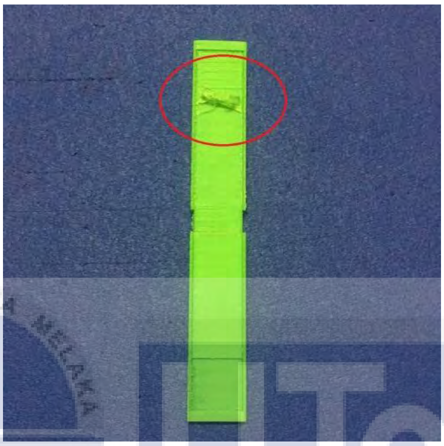


Figure 4.6: PLA material of the jig

Design 2:

In order to overcome all the failure in Design 1, some improvement were made. The thickness of the jig was increase by 8 mm to avoid the jig from bending during the scraping process. Furthermore, the jig was printed in the x-orientation and ABS was used as the material to produce a good shape of the jig. Figure 4.7 shows the dimension and specification of design 2 and Figure 4.8 showed that the perfect shape of the jig manufactured by the 3D printer machine.

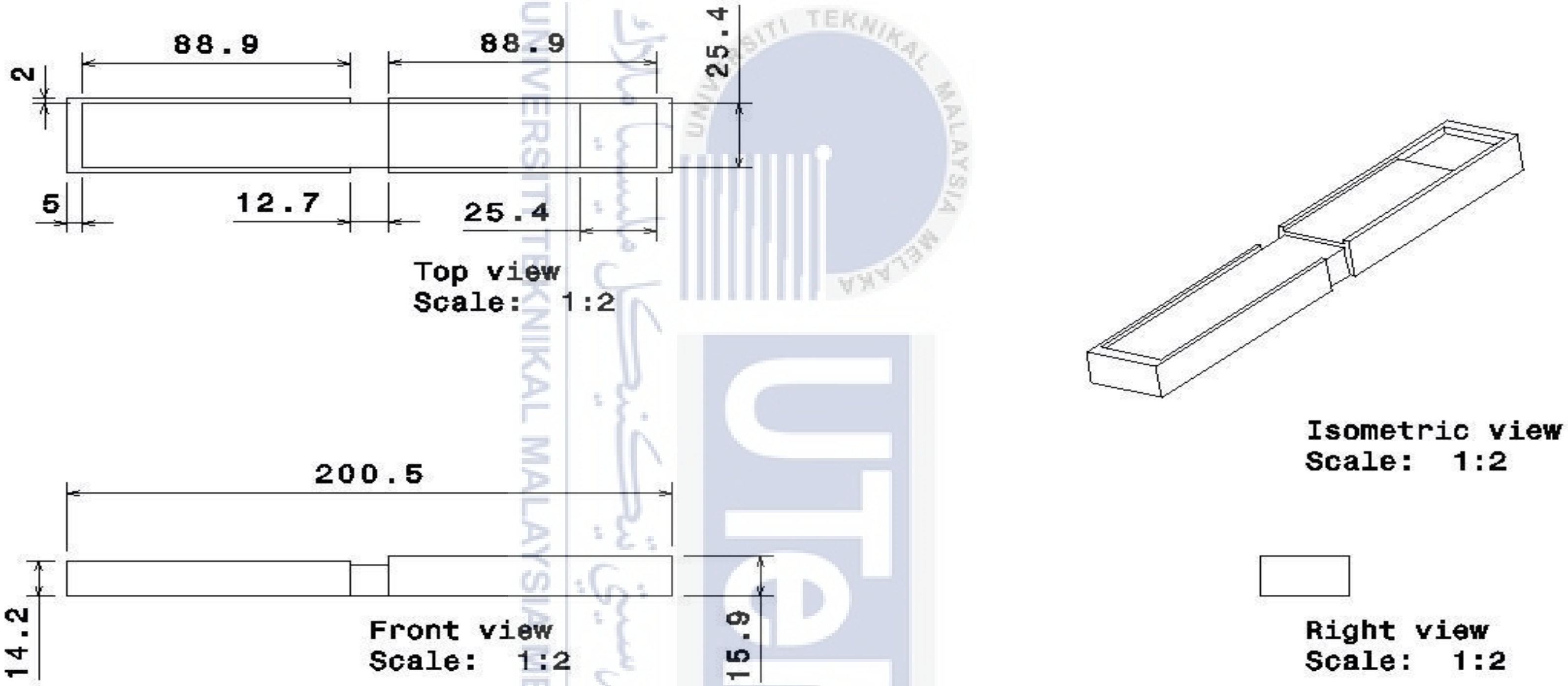


Figure 4.7: Design 2.

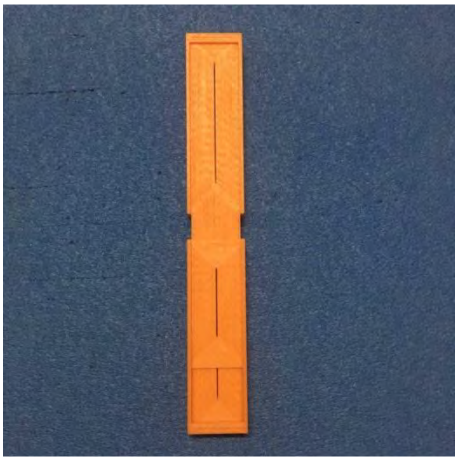


Figure 4.8: Perfect shape of the jig

4.3 ANALYSIS OF THE TENSILE TEST

The specimens were tested in three conditions which are low temperature, room temperature and high temperature using tensile test machine. The specimen that test at room temperature will be a benchmark of reference to the low temperature and high temperature. Three specimens for each condition were test to get the average of the data.

4.3.1 ROOM TEMPERATURE CONDITION WITHOUT SURFACE TREATMENT

Table 4.1 shows the result of the shear strength for room temperature condition before the process of surface treatment. Three specimens were tested to get the average of the data.

Table 4.1: Shear strength of room temperature condition before surface treatment

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	195.84	1.01	0.61
2	322.58	220.36	0.76	0.68
3	322.58	172.99	1.07	0.54

Figure 4.9 shows the result of the tensile test for three specimens for room temperature condition before the process of the surface treatment. The average of the shear strength for this condition is 0.61 MPa which means the strength of the specimen is low. After the test, the result of the ECA showed that it does not attached between two surface of the specimen which means there’s an absent of mechanical interlocking.

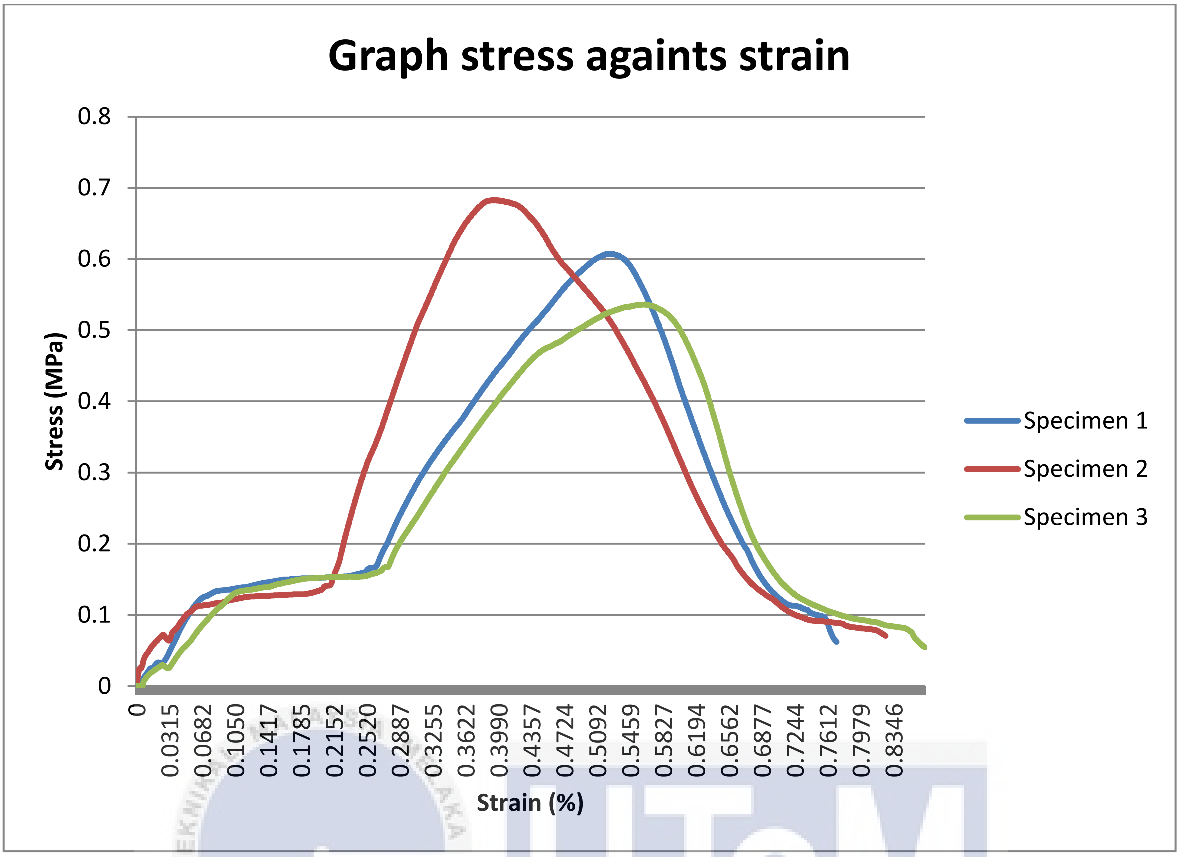


Figure 4.9: Shear strength of three specimens for room temperature condition before the process of surface treatment.

Table 4.2 shows the result of the surface roughness of three specimens before the process of the surface treatment. 3D profilometer was used to find the surface roughness and average data of surface roughness is calculated.

Table 4.2: Surface roughness (Ra) value without surface treatment

Roughness (Ra) / Sample	Ra_1 (μm)	Ra_2 (μm)	Ra_3 (μm)	Ra_4 (μm)	Ra_5 (μm)	Average (μm)
1	0.9010	0.6825	0.5928	0.3837	0.6673	0.6455
2	0.7183	0.7279	0.4748	0.5341	0.7157	0.6342
3	0.4875	0.2299	0.5587	0.5155	0.4977	0.4579

Figure 4.10 shows the result of the topography of the lap joint taken by using 3D Profilometer. The result showed that, the surface of the specimen before process of surface treatment not constantly smooth. There's high peak and low peak on the surface of the specimen and it contributed to the different strength on the different area. Furthermore, it also leads to low strength of mechanical interlocking. In order to overcome this problem, surface treatment process was conducted.

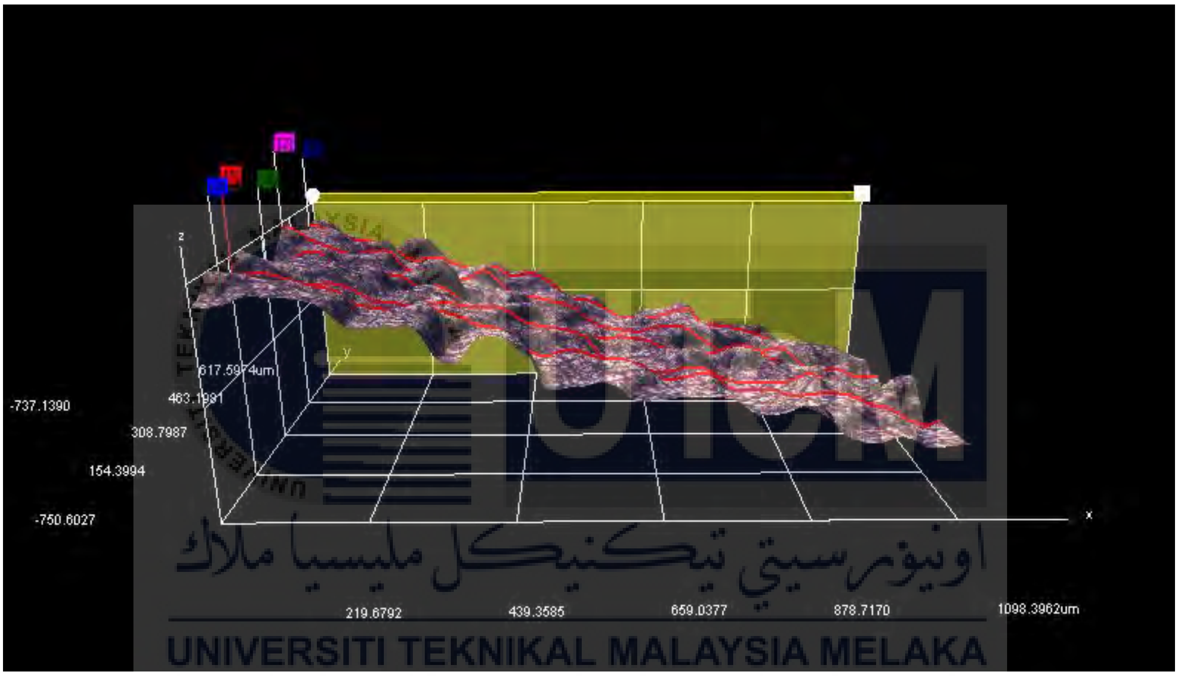


Figure 4.10: Topography of the specimen for room temperature condition before the process of surface treatment.

4.3.2 ROOM TEMPERATURE CONDITION WITH SURFACE TREATMENT

Table 4.3 shows the result of the shear strength for room temperature condition with the process of surface treatment. Three specimens were test to get the average of the data.

Table 4.3: Shear strength of room temperature condition with surface treatment

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	513.57	0.96	1.59
2	322.58	344.61	1.07	1.07
3	322.58	352.45	0.84	1.09

Average: 1.25 MPa

Figure 4.11 shows the result of the tensile test for three specimens for room temperature condition after the process of the surface treatment. The result showed that the shear strength of the specimen 1 is higher compared to specimen 2 and specimen 3. The reason for this problem may come from the curing temperature for specimen 1. Specimen 1 was cured in the room without the air conditioner on before the specimen was cured again in the oven. It means that the curing temperature of the specimen 1 is higher compared to the specimen 2 and specimen 3. The average of the shear strength for this condition is 1.25 MPa. After the test, the result of the ECA showed that it attached to both surface of the substrate which means the surface treatment is necessary to increase the strength of the shear strength and to increase the strength of the mechanical interlocking of the specimen.

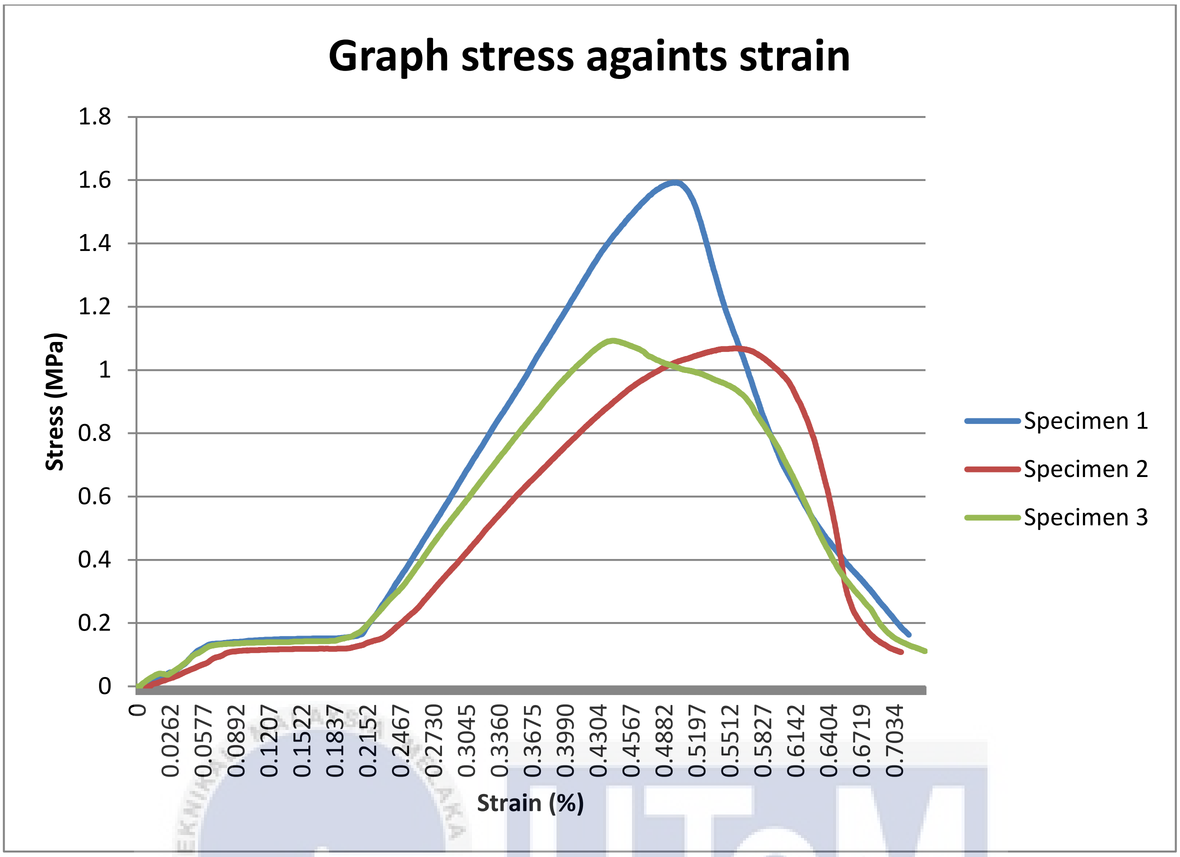


Figure 4.11: Shear strength of three specimens for room temperature condition after the process of surface treatment.

Table 4.4 shows the result of the surface roughness of three specimens after the process of the surface treatment. 3D profilometer was used to find the surface roughness and average data of surface roughness is calculated.

Table 4.4: Surface roughness (Ra) value with surface treatment

Roughness (Ra) / Sample	Ra_1 (µm)	Ra_2 (µm)	Ra_3 (µm)	Ra_4 (µm)	Ra_5 (µm)	Average (µm)
1	1.1357	1.0064	0.6776	0.7989	1.0166	0.9270
2	1.1665	0.9876	0.7275	0.5630	1.0255	0.8940
3	0.8303	0.6578	0.9765	0.8192	0.7661	0.8099

Figure 4.12 shows the result of the topography of the lap joint taken by using 3D profilometer. Sand paper was used in order to conduct the surface treatment. The result showed that, the peak of the lap joint of the specimen produce same peak in area of the lap joint which means it produced same strength to all the area. Moreover, it also produced higher strength in mechanical interlocking. Higher strength in mechanical interlocking produced higher in shear strength. Thus, the results of shear strength after the surface treatment is selected as a benchmark to the low and high temperature.

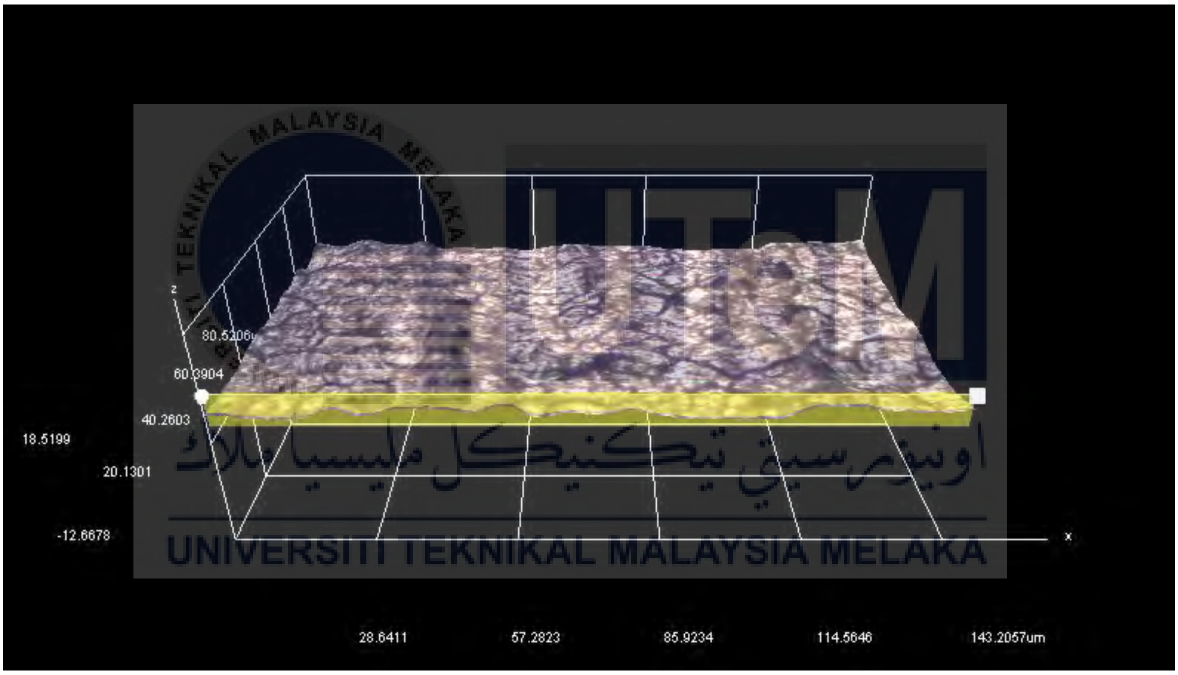


Figure 4.12: Topography of the specimen for room temperature condition after the process of surface treatment.

4.3.3 LOW TEMPERATURE CONDITION

I. Low temperature for 10 hours

Table 4.5 shows the result of the shear strength for the low temperature application at 6 ˚C for 10 hours. Three specimens were test to get the average of the data.

Table 4.5: Shear strength of low temperature application at 6 ˚ for 10 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	173.28	0.68	0.54
2	322.58	613.50	1.38	1.90
3	322.58	255.06	0.76	0.70

Average: 1.05 MPa

Figure 4.13 shows the result of the tensile test for three specimens for low temperature application at 6 ˚C for 10 hours. The result showed that the shear strength of the specimen 2 is higher compared to specimen 1 and specimen 3. The reason for this problem may come from the curing temperature for specimen 2. Specimen 2 was cured in the room without the air conditioner on before the specimen was cured again in the oven. It means that the curing temperature of the specimen 1 is higher compared to the specimen 1 and specimen 3. The average of the shear strength for this condition is 1.05 MPa which is 16% lower than a benchmark.

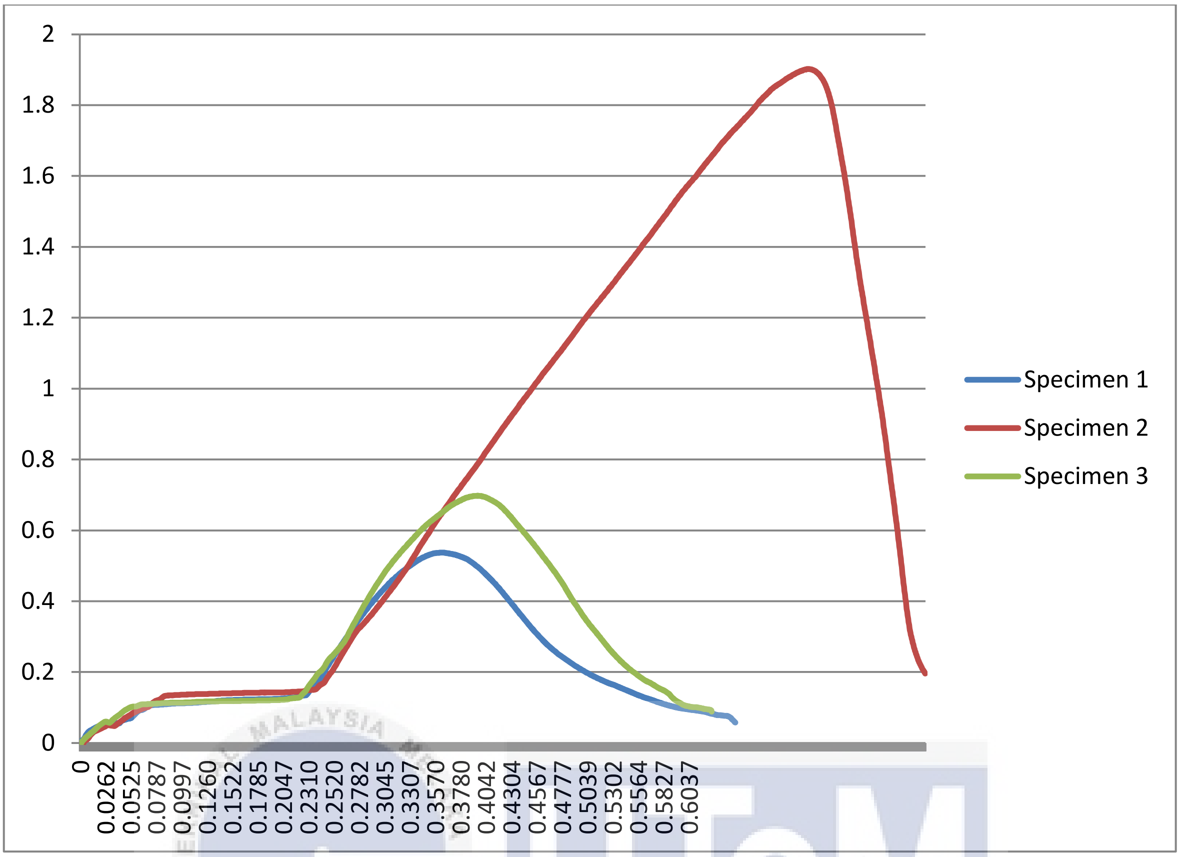


Figure 4.13: Shear strength of three specimens for low temperature application at 6˚C for 10 hours

Figure 4.14 shows that the topography of the lap joint for low temperature application at 6˚C for 10 hours. The result showed that the highest peak of the specimen is 539.5570 µm and the lowest peak is -550.1797 µm. The lowest peak is representing the degradation of the ECA caused by low temperature application. Furthermore, the more the number of lowest peak contributed the low mechanical interlocking which means degrade the shear strength of the lap joint. Besides that, the deformation of ECA will produced the surface becomes more ductile.

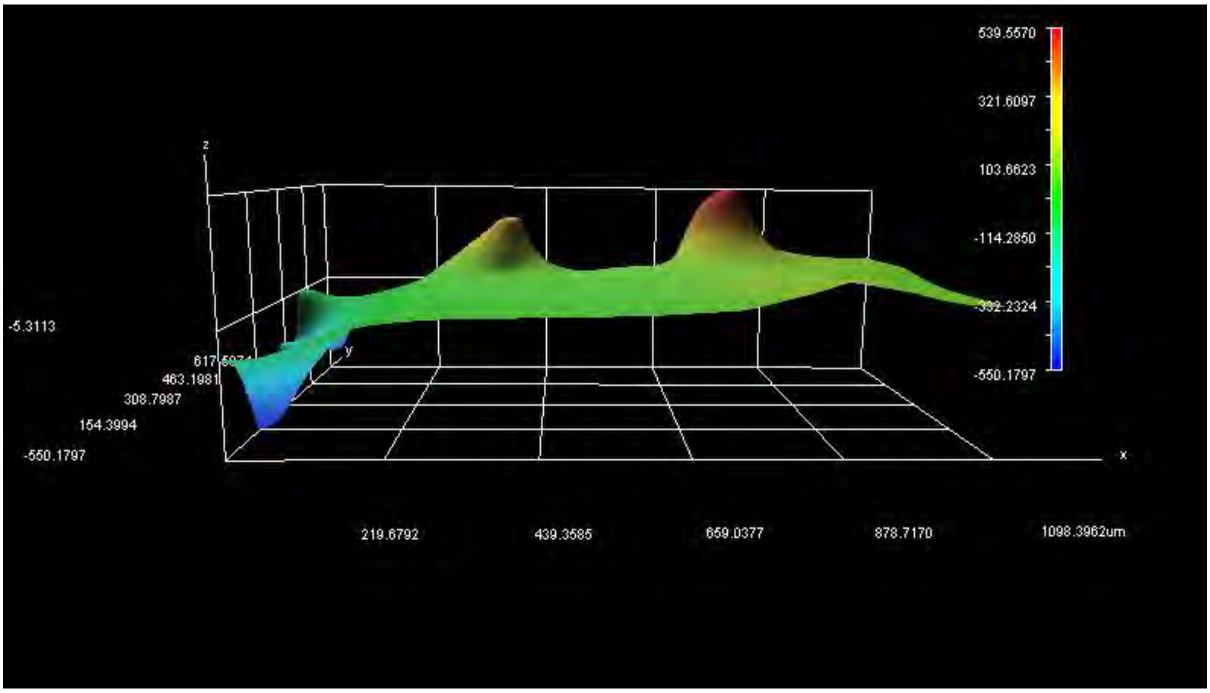


Figure 4.14: Topography of the specimen for low temperature application at 6˚C for 10 hours

II. Low temperature for 30 hours

Table 4.6 shows the result of the shear strength for the low temperature application at 6 ˚C for 30 hours. Three specimens were test to get the average of the data.

Table 4.6: Shear strength of low temperature application at 6 ˚ for 30 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	134.25	0.59	0.42
2	322.58	210.06	1.00	0.65
3	322.58	361.87	0.86	1.12

Average: 0.73 MPa

Figure 4.15 shows the result of the tensile test for three specimens for low temperature application at 6 ˚ for 30 hours. The results showed that the shear strength of specimen 3 is higher than specimen 1 and specimen 2. The reason of this fault is due to the exposure of ECA in specimen 1 and specimen 2 to the air for a long period during mixing process. Thus, it will harden the ECA before applied to the specimen. The average shear strength for this condition is 0.73 MPa which is 41.6% lower than a benchmark.

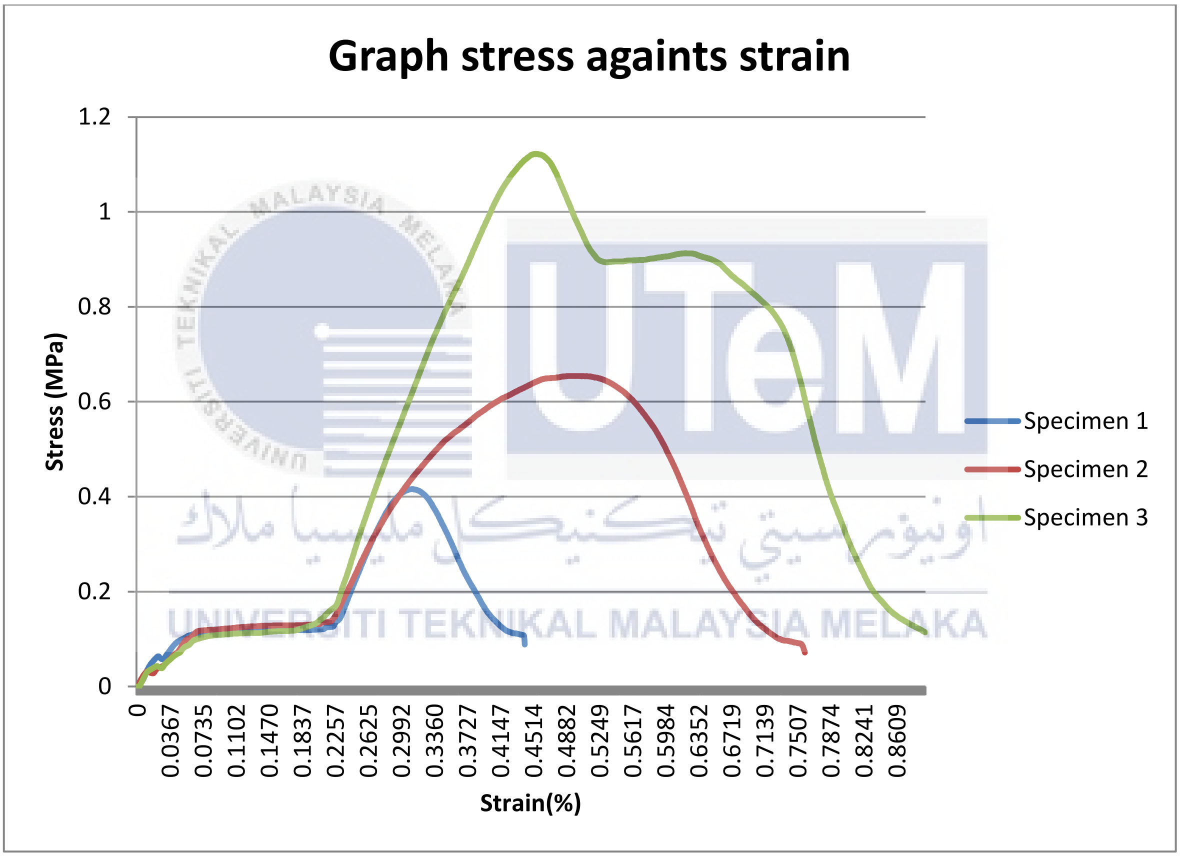


Figure 4.15: Shear strength of three specimens for low temperature application at 6˚C for 30 hours

Figure 4.16 shows that the topography of the lap joint for low temperature application at 6˚C for 30 hours. The result showed that the highest peak of the specimen is 364.3978 µm and the lowest peak is -703.6143 µm. The lowest peak for low temperature application at 6˚C for 30 hours is higher than 10 hours. Thus, it will degrade the shear strength of the lap joint which is 0.73 MPa for 30 hours and 1.05 MPa for 10 hours. Furthermore the mechanical interlocking for 30 hours is lower than 10 hours. Besides that, the surface of the lap joint becomes more ductile due to deformation of ECA.

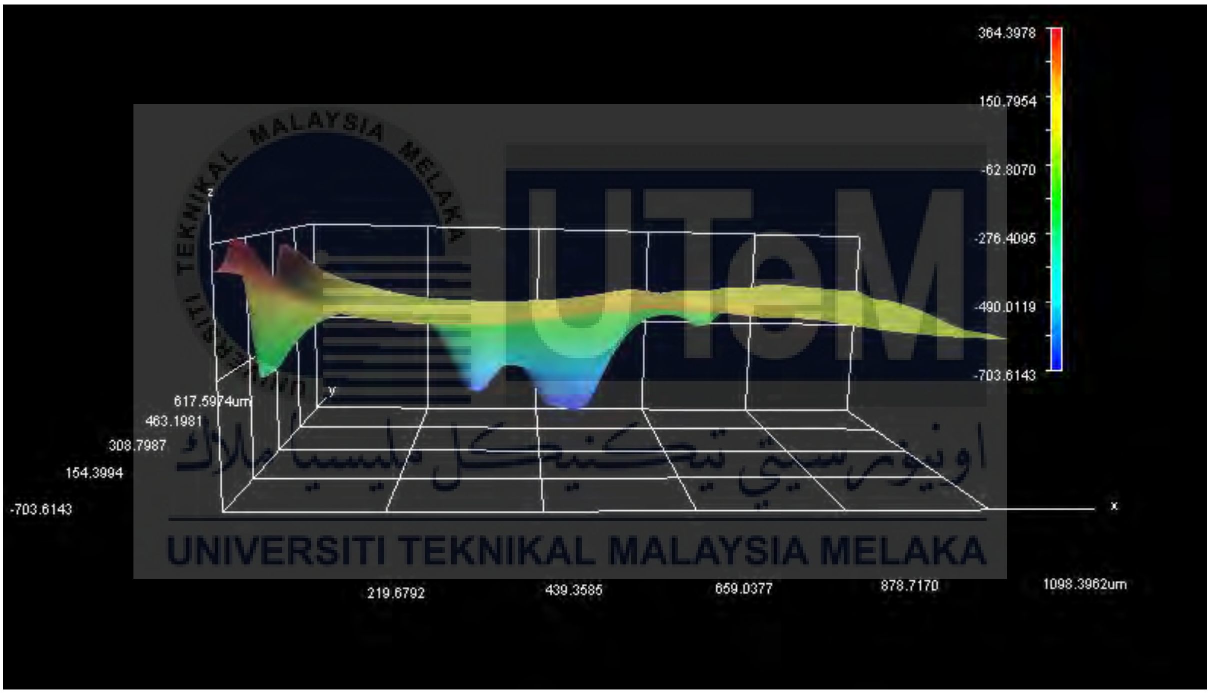


Figure 4.16: Topography of the specimen for low temperature application at 6˚C for 30 hours

III. Low temperature for 50 hours

Table 4.7 shows the result of the shear strength for the low temperature application at 6 ˚C for 50 hours. Three specimens were test to get the average of the data.

Table 4.7: Shear strength of low temperature application at 6 ˚ for 50 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	134.55	0.52	0.42
2	322.58	95.52	0.46	0.30
3	322.58	87.18	0.59	0.27

Average: 0.33 MPa

Figure 4.17 shows the result of the tensile test of three specimens for low temperature application at 6˚C for 50 hours. All the three specimens were cured with same duration and temperature. Furthermore, the exposure of the ECA to the air is taken carefully to avoid the ECA becomes harden. The average of shear strength of the specimen is 0.33 MPa which is 73.6 % lower than a benchmark.

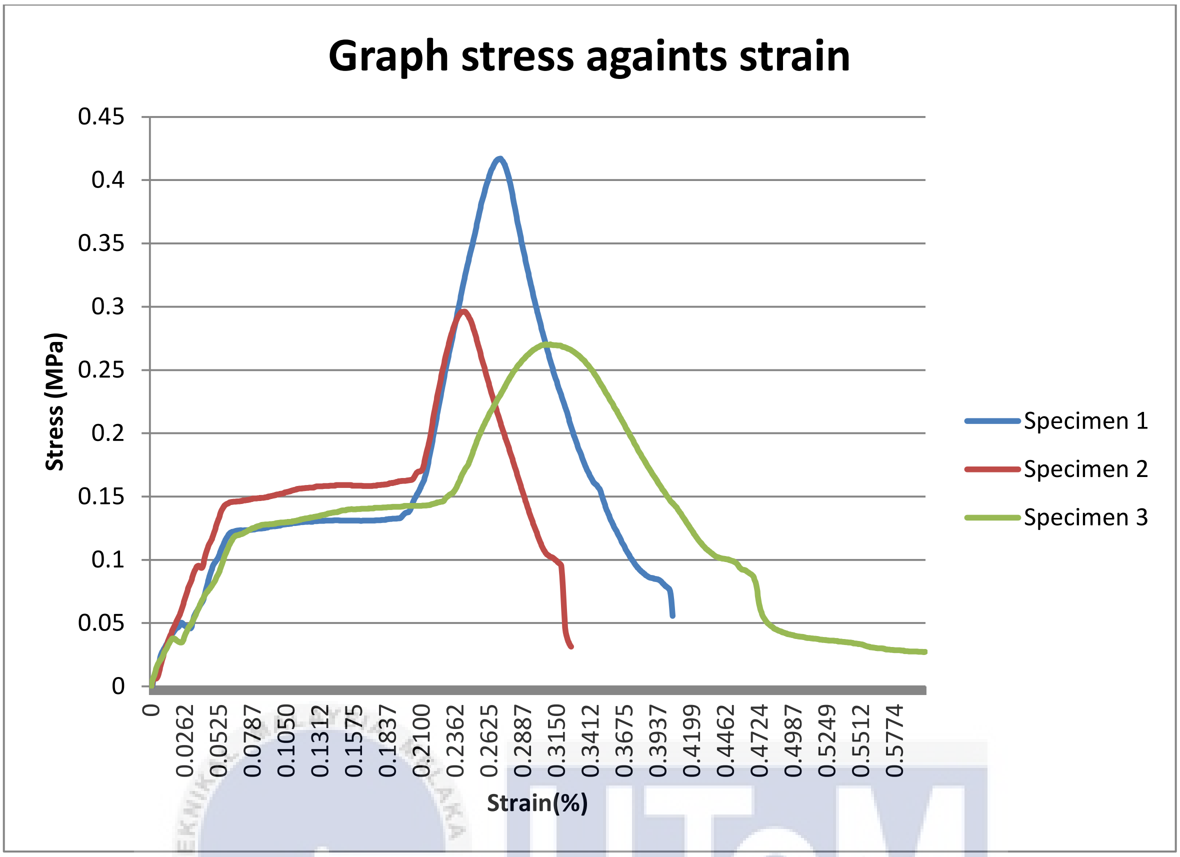


Figure 4.17: Shear strength of three specimens for low temperature application at 6˚C for 50 hours

Figure 4.18 shows that the topography of the lap joint for low temperature application at 6˚C for 50 hours. The result showed that the highest peak of the specimen is 263.5396 µm and the lowest peak is -398.6759 µm. The number of the lowest peak for 50 hours is higher compared to the 10 hours and 30 hours. Thus, it contribute to the low in mechanical interlocking and low in shear strength of lap joint. Besides that, the surface of the lap joint becomes more ductile due to deformation of ECA.

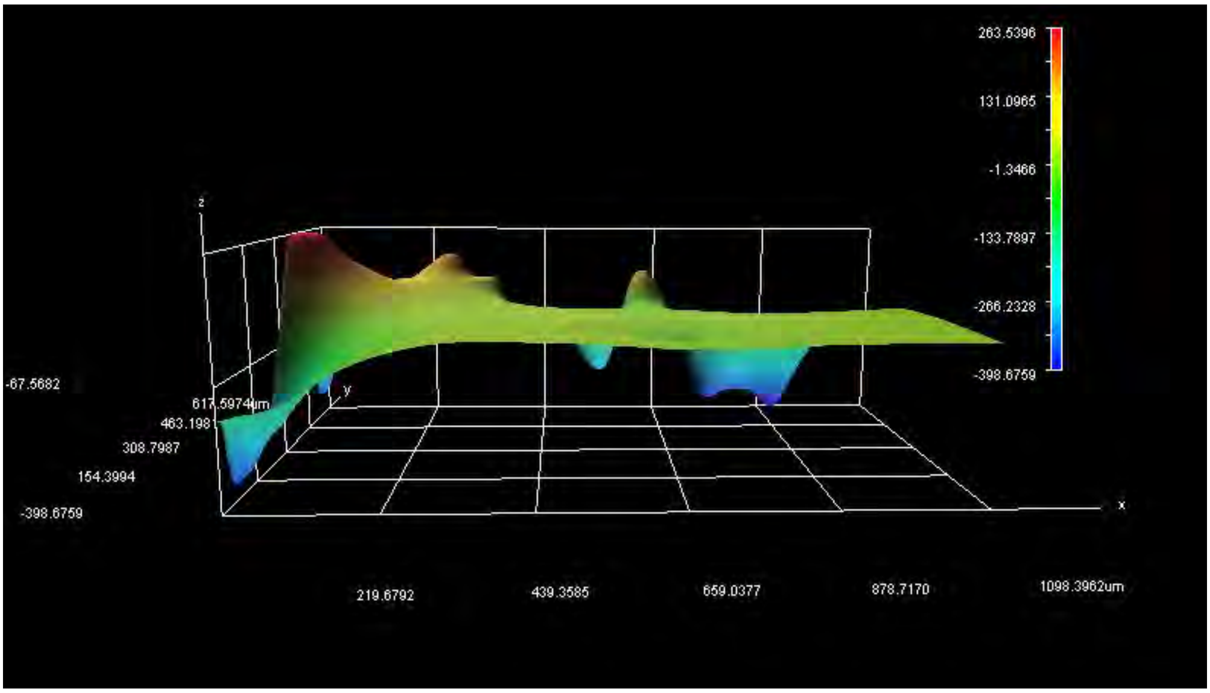


Figure 4.18: Topography of the specimen for low temperature application at 6˚C for 50 hours

4.3.4 HIGH TEMPERATURE CONDITION

I. High temperature for 10 hours

Table 4.8 shows the result of the shear strength for the high temperature application at 85 ˚C for 10 hours. Three specimens were test to get the average of the data.

Table 4.8: Shear strength of high temperature application at 85 ˚ for 10 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	323.03	0.77	1.00
2	322.58	420.12	0.80	1.30
3	322.58	668.91	1.64	2.07

Average: 1.46 MPa

Figure 4.19 shows the result of the tensile test of three specimens for high temperature application at 85˚C for 10 hours. The process of the bonding the specimen was conducted carefully to avoid any possibility than can influence the results of the specimen. The average of the shear strength of the specimen is 1.46 MPa which is 16.8% higher than a benchmark.

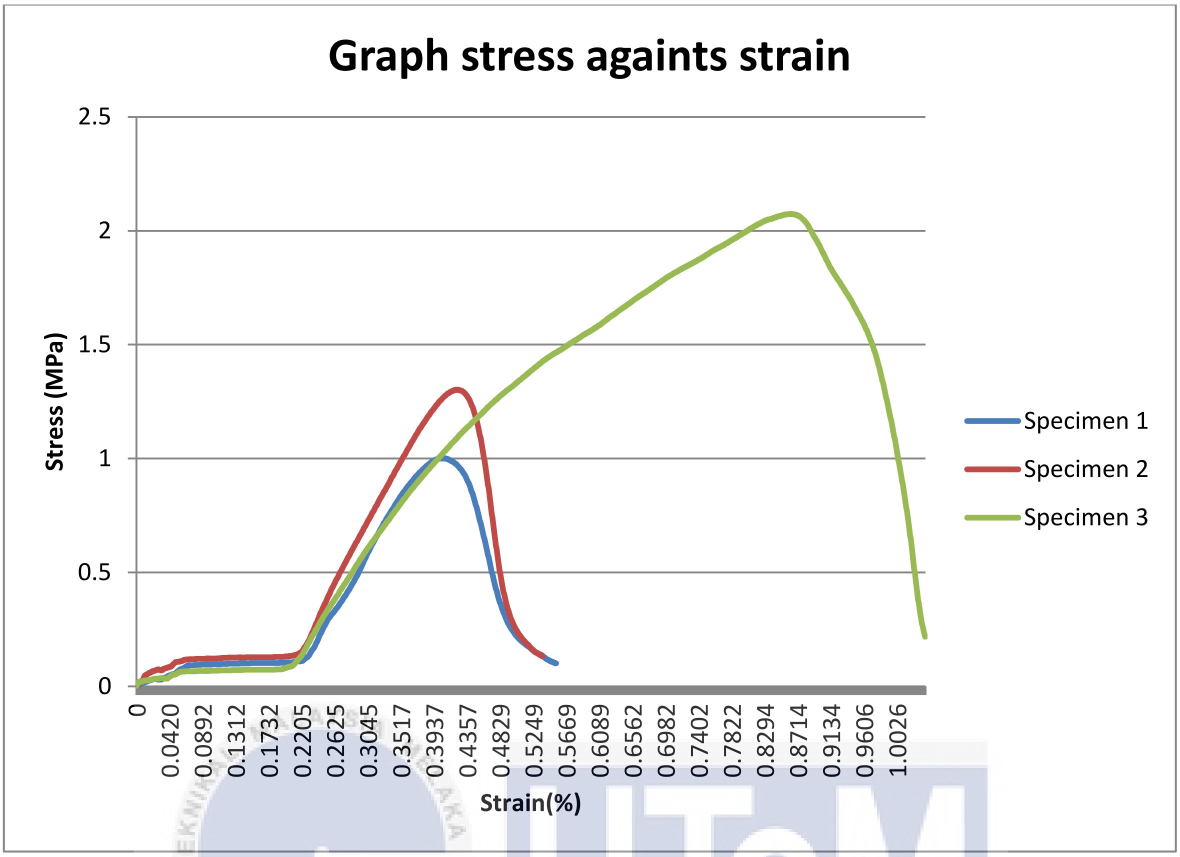


Figure 4.19: Shear strength of three specimens for high temperature application at 85˚C for 10 hours

Figure 4.20 shows that the topography of the lap joint for high temperature application at 85˚C for 10 hours. The result showed that the highest peak of the lap joint is 379.7470 μm and the lowest peak is -777.1209 μm. The higher the number of higher peak, the higher the strength of mechanical interlocking. Thus, it will automatically increase shear strength of the lap joint. Furthermore, the surface of the lap joint becomes more brittle because there's no degradation of the ECA when it was exposed to the high temperature at 85 ˚C for 10 hours. Besides, the topography of the lap joint showed that the number of higher peaks is higher compared to the lowest peak.

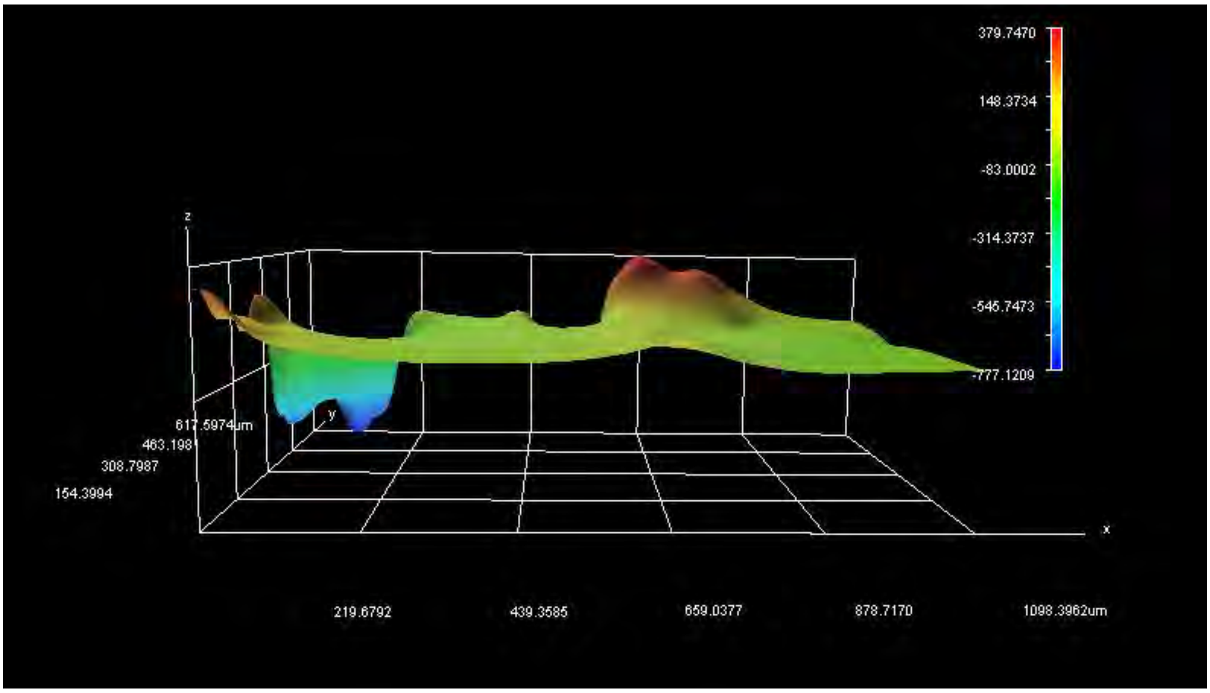


Figure 4.20: Topography of the specimen for low temperature application at 85˚C for 10 hours

II. High temperature for 30 hours

Table 4.9 shows the result of the shear strength for the high temperature application at 85 ˚C for 30 hours. Three specimens were test to get the average of the data.

Table 4.9: Shear strength of high temperature application at 85 ˚ for 30 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	1387.35	1.18	4.30
2	322.58	1662.82	1.32	5.15
3	322.58	1005.67	1.23	3.12

Average: 4.19 MPa

Figure 4.21 shows the result of the tensile test of three specimens for high temperature application at 85˚C for 30 hours. The lap shear strength of the specimen 3 is the highest for this condition which means the ECA is fully attached between two surfaces of the substrate. The average of the shear strength of the specimen is 4.19 MPa which is 235.2% higher than a benchmark.

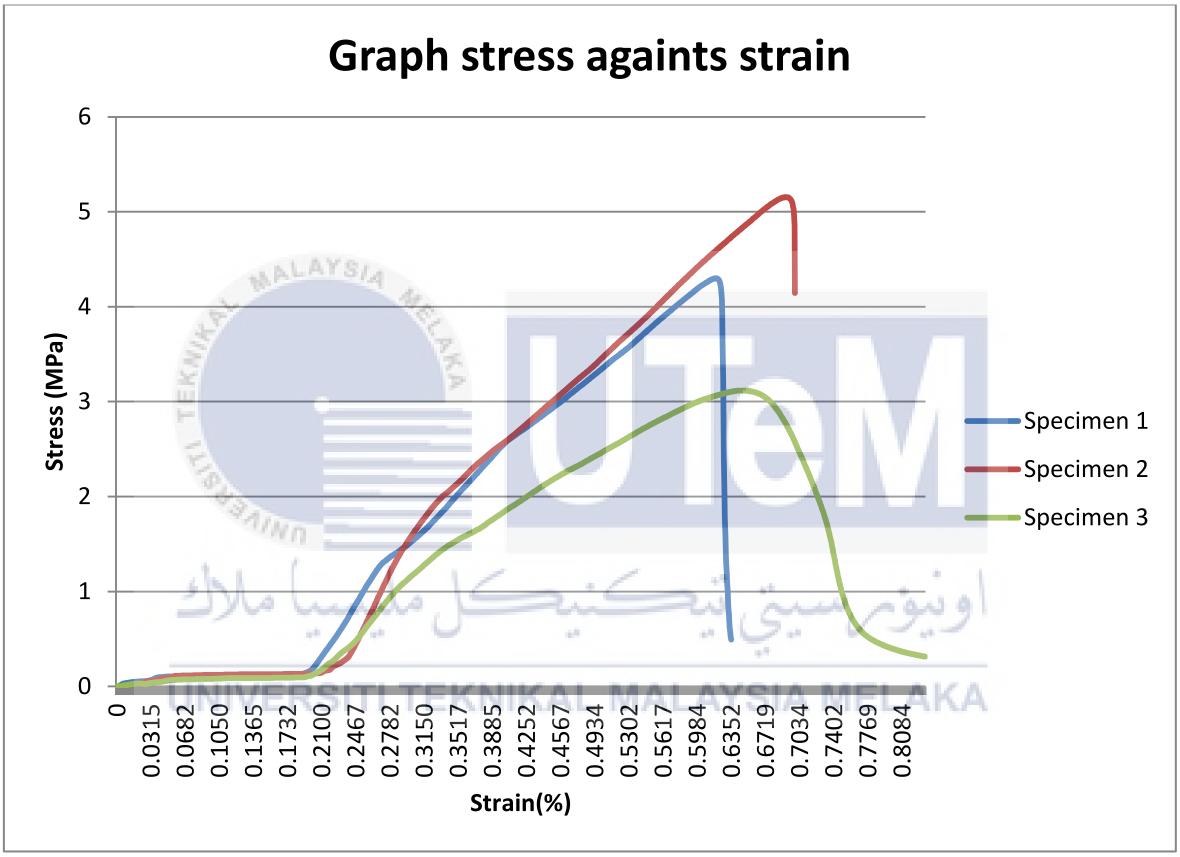


Figure 4.21: Shear strength of three specimens for high temperature application at 85˚C for 30 hours

Figure 4.22 shows that the topography of the lap joint for high temperature application at 85˚C for 30 hours. The result showed that the highest peak of the lap joint is 664.3529 µm and the lowest peak is -484.0392 µm. The number of highest peak for this application is much higher than 10 hours application. Thus, the strength of the mechanical interlocking for this application is better compared to the 10 hours application. The surface of the topography also shows the surface becomes more brittle because the frequency of lowest peak is low.

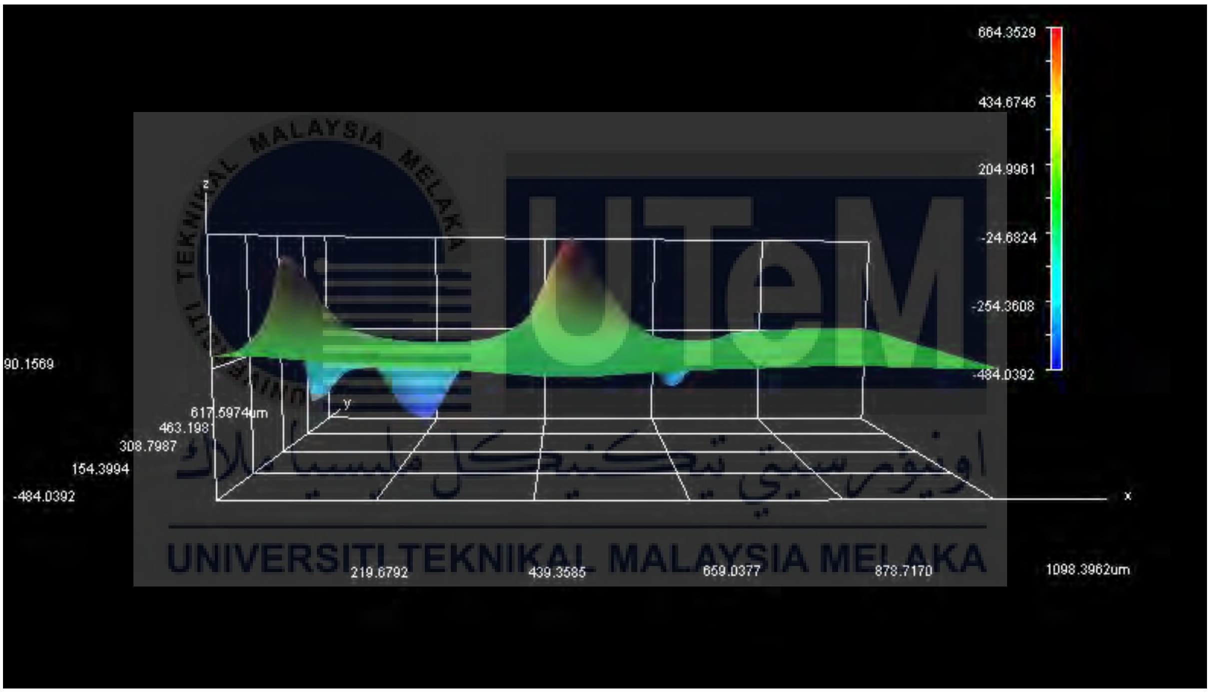


Figure 4.22: Topography of the specimen for low temperature application at 85˚C for 30 hours

III. High temperature for 50 hours

Table 4.10 shows the result of the shear strength for the high temperature application at 85 ˚C for 50 hours. Three specimens were test to get the average of the data.

Table 4.10: Shear strength of high temperature application at 85 ˚ for 50 hours

Specimen No.	Area (mm^2)	Maximum Force (N)	Maximum Elongation (mm)	Lap Shear Strength (MPa)
1	322.58	1042.35	1.40	3.23
2	322.58	1118.35	1.17	3.47
3	322.58	1280.95	1.35	3.97

Average: 3.56 MPa

Figure 4.23 shows the result of the tensile test of three specimens for high temperature application at 85˚C for 50 hours. The average of the shear strength of the specimen is 3.56 MPa which is 184.8 % higher than a benchmark. The average of the shear strength for this condition is lower than 30 hours condition because the ECA shows the degradation if it exposed to the heat for a long duration.

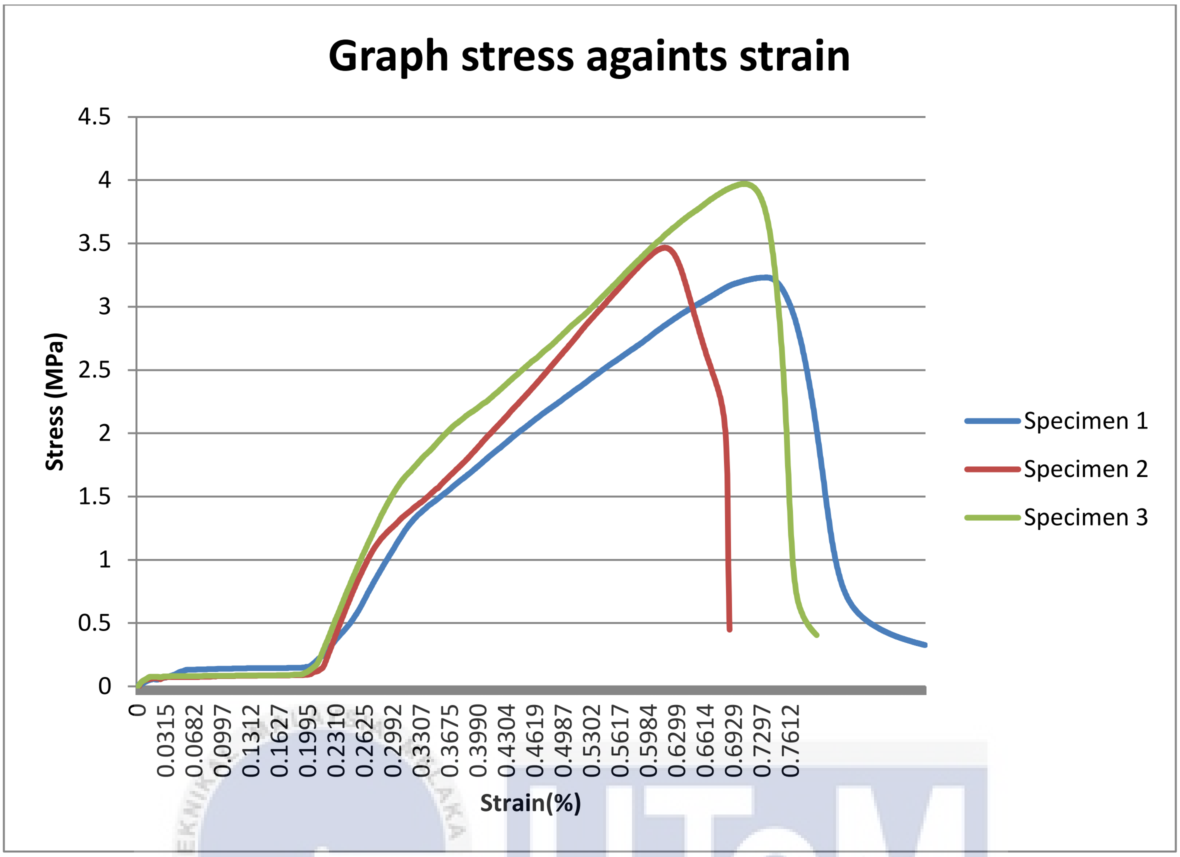


Figure 4.23: Shear strength of three specimens for high temperature application at 85˚C for 50 hours

Figure 4.24 shows that the topography of the lap joint for high temperature application at 85˚C for 50 hours. The result showed that the highest peak of the lap joint is 547.8532 µm and the lowest peak is -692.0973 µm. The number of the highest peak for this application is lower than 30 hours which means if the specimen was exposed to the high temperature for long duration, it will degrade the characteristic of ECA and the surface becomes more to ductile. Besides that, the mechanical interlocking for this condition is lower than 30 hours. Thus, the shear strength will degrade if the specimen was exposed to the high temperature for long duration.

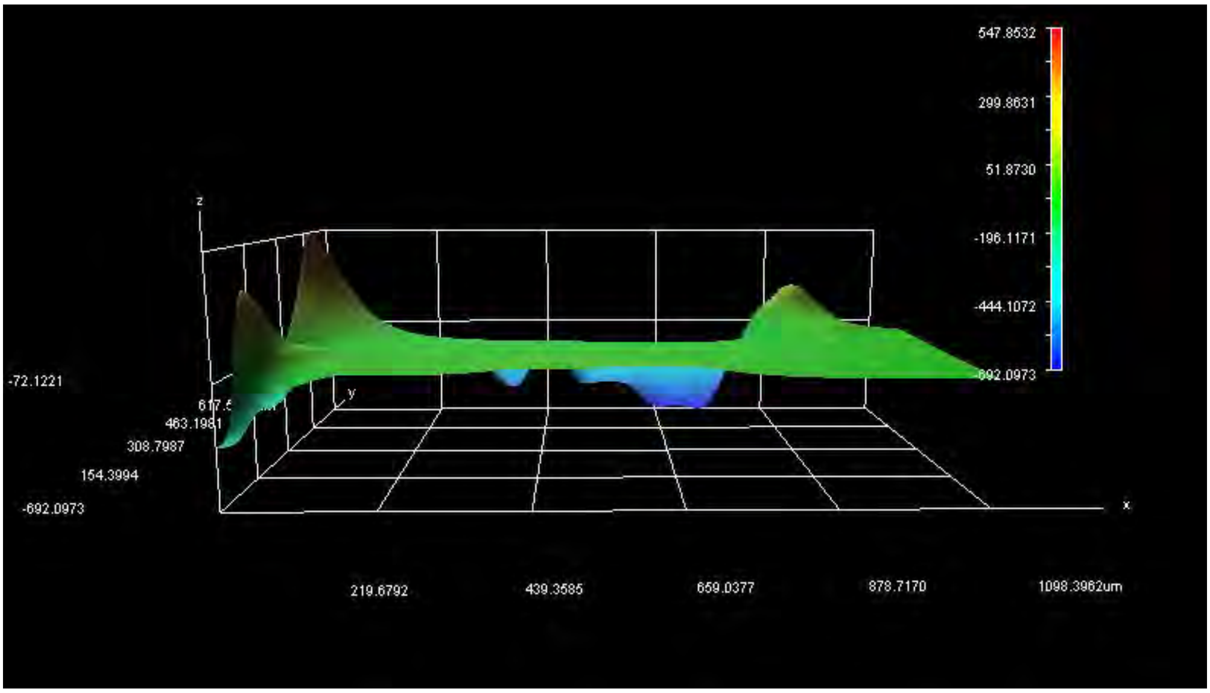


Figure 4.24: Topography of the specimen for low temperature application at 85˚C for 50 hours

4.3.5 AVERAGE DATA OF THE SPECIMEN

I. **Average data of specimen for low temperature**

Figure 4.25 showed that the average data of lap shear strength for RT, 10, 30 and 50 hours of specimen at 6 ˚C. The specimen were exposed at the temperature of 6 ˚C for 10, 30 and 50 hours and it showed that there are drastically decrease in the lap shear strength of the joints compared to the room temperature. It can be explained that, when the specimens were exposed to the temperature at 6 ˚C, it increased the moisture content in adhesive layer which degraded the lap shear strength. Furthermore, the number of lower peak and the frequency of lower peak occur has an important role in this section. The higher the number of lower peak and the higher the frequency of lower peak will degrade the mechanical interlocking between the surfaces. Thus, it also contributed to the low of shear strength. Furthermore, the higher the number of lower peak and the higher the frequency of lower peak occur will result in ductility of the surface. Table 4.11 shows average of the data and the standard deviation for low temperature condition.

Table 4.11: The average of the data and standard deviation for low temperature condition

Condition (Hours)	Average of the data (MPa)	Standard deviation
Room Temperature	1.25	0.2946
10	1.05	0.7433
30	0.73	0.3568
50	0.33	0.0794

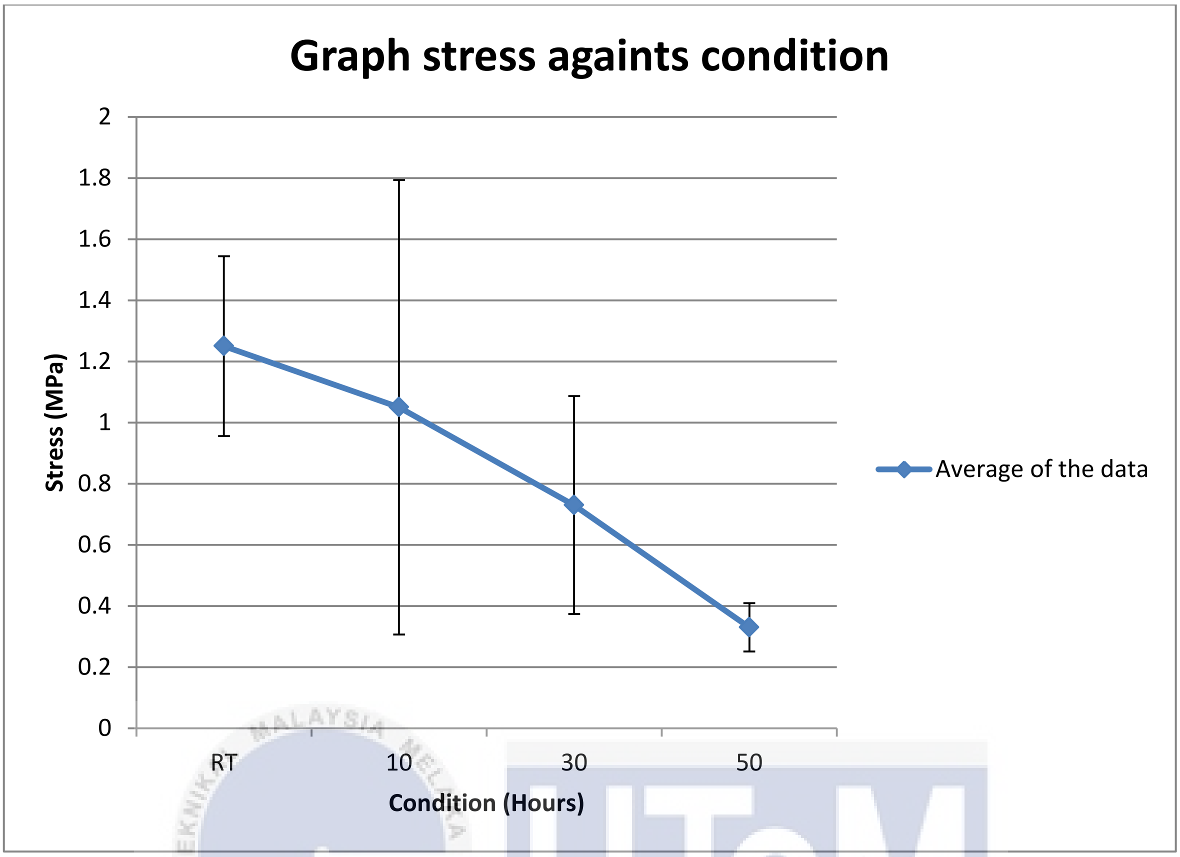


Figure 4.25: Average data of lap shear strength for RT, 10, 30 and 50 hours of specimen at 6 ˚C

II. Average data of specimen for high temperature

Figure 4.26 showed that the average data of lap shear strength for RT, 10, 30 and 50 hours of specimen at 85 ˚C. The specimen were exposed at the temperature of 85 ˚C for 10, 30 and 50 hours and it showed that there are drastically increase in the lap shear strength of the joints compared to the room temperature. When the specimens were tested for 10 to the 30 hours, it showed that there are increases in the lap shear strength. However, there are decreases in the temperature when the specimens were tested for 30 to the 50 hours. It can be explained that, the adhesive becomes more ductile and the overlap contributes more to the strength as the adhesive yields when the specimens were exposed at 85 ˚C for 50 hours. Furthermore, it also can be explain by, if the specimen was exposed to the heat for a long duration, it will degrade the characteristic of ECA. Based on topography of the lap joint, it show that the higher the number of high peak and the higher the frequency of high peak occur will contribute to the high in mechanical interlocking. Thus, it will increase the shear strength of lap joint. Table 4.12 shows average of the data and the standard deviation for high temperature condition.

Table 4.12: The average of the data and standard deviation for high temperature condition

Condition (Hours)	Average of the data (MPa)	Standard deviation
Room Temperature	1.25	0.2946
10	1.46	0.5520
30	4.19	1.0195
50	3.56	0.6153

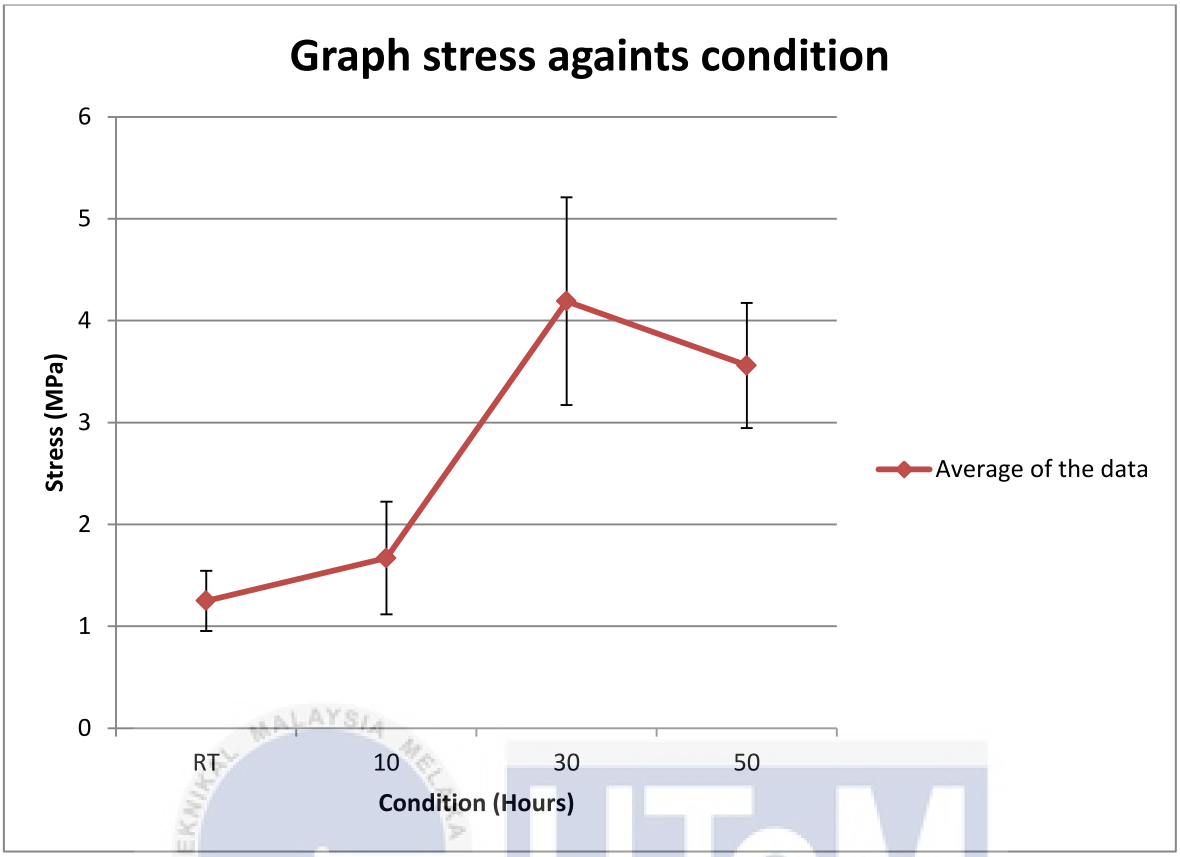


Figure 4.26: Average data of lap shear strength for RT, 10, 30 and 50 hours of specimen at 85 ˚C

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

An electrically conductive adhesive is an advance technology used in electronic industry. Electronic parts are known due to sensitivity to the temperature. Therefore, an ECA is a problem solving to the electronic industry because the temperature of ECA is a much lower than soldering process. This purpose of this paper is to study the effect of the temperature on the mechanical performance of joints bonded with electrically conductive adhesive. As a conclusion, the lap of shear strength for single lap joints tested at low temperature application of 6 ˚C for 10 hours decreased approximately 16% than RT. Furthermore, approximately 41.6% of lap shear strength was decreased at 30 hours application while approximately 73.6% at 50 hours application. Besides that, at high temperature application of 85 ˚C for 10 hours, approximately 16.8 % was increased than at RT. Moreover, approximately 235.2 % of lap shear strength was increased at 30 hours application while approximately 184.8 % for 50 hours application. At low temperature, the surface of the ECA becomes more ductile due to the number and frequency of lower peak. At high temperature, the surface of ECA becomes more brittle due to the number and frequency of higher peak.

5.2 RECOMMENDATION

Electrically conductive adhesive is one of the advance technologies to replace soldering process. In order to increase the lifespan of the electronic parts, electrically conductive adhesive is recommended due to ability to withstand the vibration. Furthermore, electrically conductive adhesive can expand their usage to other industries such as automotive industry and aerospace industry. However, a lot of work must be made to study their characteristic for variation of temperature. At high temperature, the reaction of the adhesive to the high temperature must be study carefully in order to ensure there is no degradation in strength of the adhesive. At low temperature, the presence of the moisture content must be prevent to them from degrade the strength of the adhesive. In addition, the curing temperature to the entire specimen must be same to avoid any fault happened. The density of the araldite (resin + hardener) and electrically conductive ink must been considered during the process of preparation of electrically conductive adhesive. Besides that, the duration during mixing process of electrically conductive adhesive must be taken carefully because electrically conductive adhesive is sensitive to the air exposure. It is recommended to mix the portion of electrically conductive adhesive for one specimen only.

REFERENCES

[1] "Electrically Conductive Adhesive." [Online]. Available: http://www.permabond.com/2016/07/26/electrically-conductive-adhesives/. [Accessed: 10-Dec-2017].

[2] "Electrically Conductive Adhesive." [Online]. Available: https://www.panacol.com/adhesives-glue/electrically-conductive-glue/. [Accessed: 10-Dec-2017].

[3] M. D. Banea, L. F. M. da Silva, and R. D. S. G. Campilho, "Effect of temperature on the shear strength of aluminium single lap bonded joints for high temperature applications," *J. Adhes. Sci. Technol.*, vol. 28, no. 14–15, pp. 1367–1381, 2014.

[4] M. D. Banea, L. F. M. da Silva, R. D. S. G. Campilho, and A. M. P. de Jesus, "Characterization of Aluminium Single-Lap Joints for High Temperature Applications," *Mater. Sci. Forum*, vol. 730–732, no. November 2012, pp. 721–726, 2012.

[5] M. D. Banea and F. De Engenharia, "Static and Fatigue Behaviour of Rtv Silicone Adhesives for High Temperature Aerospace," no. July, pp. 1–2, 2009.

[6] M. D. Banea and L. F. M. da Silva, "Mechanical characterization of flexible adhesives," *J. Adhes.*, vol. 85, no. 4–5, pp. 261–285, 2009.

[7] C. E. Ojeda, E. J. Oakes, J. R. Hill, D. Aldi, and G. a. Forsberg, "Temperature Effect on Adhesive Bond Strengths and Modulus for Commonly Used Spacecraft Stuctural Adhesives," no. August, 2011.

[8] S. N. A. Razak *et al.*, "Scientific Article 1 : Effect of Temperature on the Strength Properties of Adhesively Single - Lap Bonded Joint for Composite Laminates," vol. 2014, no. March 2014, pp. 2014–2017, 2016.

[9] M. D. Banea, L. F. M. Da Silva, and R. D. S. G. Campilho, "Effect of Temperature on Tensile Strength and Mode I Fracture Toughness of a High Temperature Epoxy Adhesive," *J. Adhes. Sci. Technol.*, vol. 26, no. 7, pp. 939–953, 2012.

[10] R. A. Islam and Y. C. Chan, "Effect of microwave preheating on the bonding performance of flip chip on flex joint," *Microelectron. Reliab.*, vol. 44, no. 5, pp. 815–821, 2004.

[11] R. Zheng, J. ping Lin, P. C. Wang, and Y. R. Wu, "Effect of hot-humid exposure on static strength of adhesive-bonded aluminum alloys," *Def. Technol.*, vol. 11, no. 3, pp. 220–228, 2015.

[12] S. Li, T. Zhu, Y. Lu, and X. Li, "Effect of Temperature Variation on Bond Characteristics between CFRP and Steel Plate," *Int. J. Polym. Sci.*, vol. 2016, 2016.

[13] S. Lahokallio, M. Hoikkanen, J. Vuorinen, and L. Frisk, “High-temperature storage testing of ACF attached sensor structures,” *Materials (Basel).*, vol. 8, no. 12, pp. 8641–8660, 2015.

[14] D. D. L. Chung, “NOTE EFFECT OF HEATING ON THE STRUCTURE OF AN ADHESIVE JOINT , AS INDICATED BY ELECTRICAL,” no. October 2002, pp. 549–557, 2003.

[15] I. Scientific and C. Vsu, “XIII МЕЖДУНАРОДНА НАУЧНА КОНФЕРЕНЦИЯ ВСУ’2013 13th INTERNATIONAL SCIENTIFIC CONFERENCE VSU’2013,” pp. 7–12, 2013.

[16] E. Henriques and L. Reis, “Bonded joints of dissimilar adherends at very low temperatures - An adhesive selection approach,” no. August 2016, 2017.

[17] K. R. Osanai, “TEMPERATURE EFFECT ON THE STRENGTH OF ADHESIVELY BONDED SINGLE LAP JOINTS,” vol. 11, no. 1, pp. 3–6, 2012.

[18] M. D. Banea and L. F. M. da Silva, “The effect of temperature on the mechanical properties of adhesives for the automotive industry,” *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, vol. 224, no. 2, pp. 51–62, 2010.

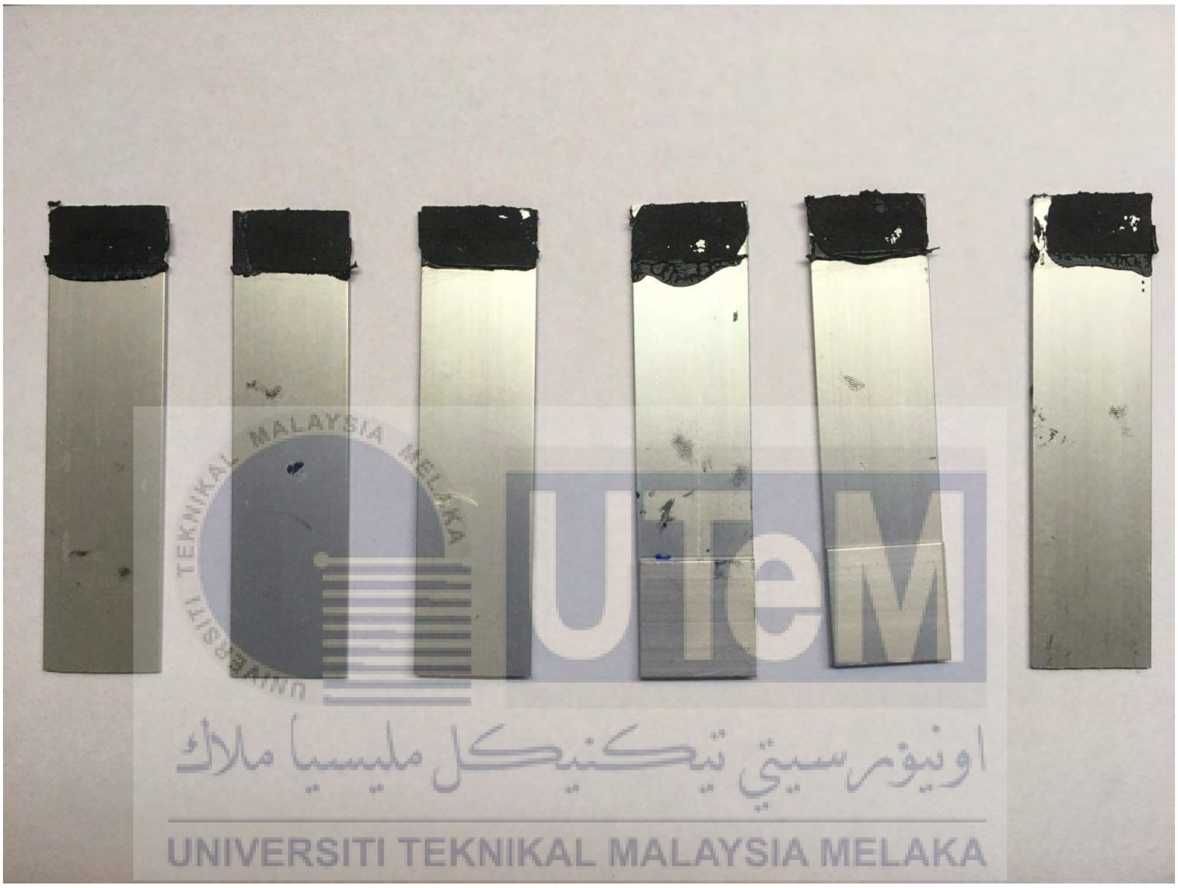
[19] M. Usman, J. A. Pascoe, R. C. Alderliesten, and R. Benedictus, “The effect of temperature on fatigue crack growth in FM94 epoxy adhesive bonds investigated by means of energy dissipation,” *Eng. Fract. Mech.*, 2017.

[20] J. LeBono, L. Barton, and M. Birkett, “Low temperature tensile lap-shear testing of adhesively bonded polyethylene pipe,” *Int. J. Adhes. Adhes.*, vol. 74, no. November 2016, pp. 57–63, 2017.

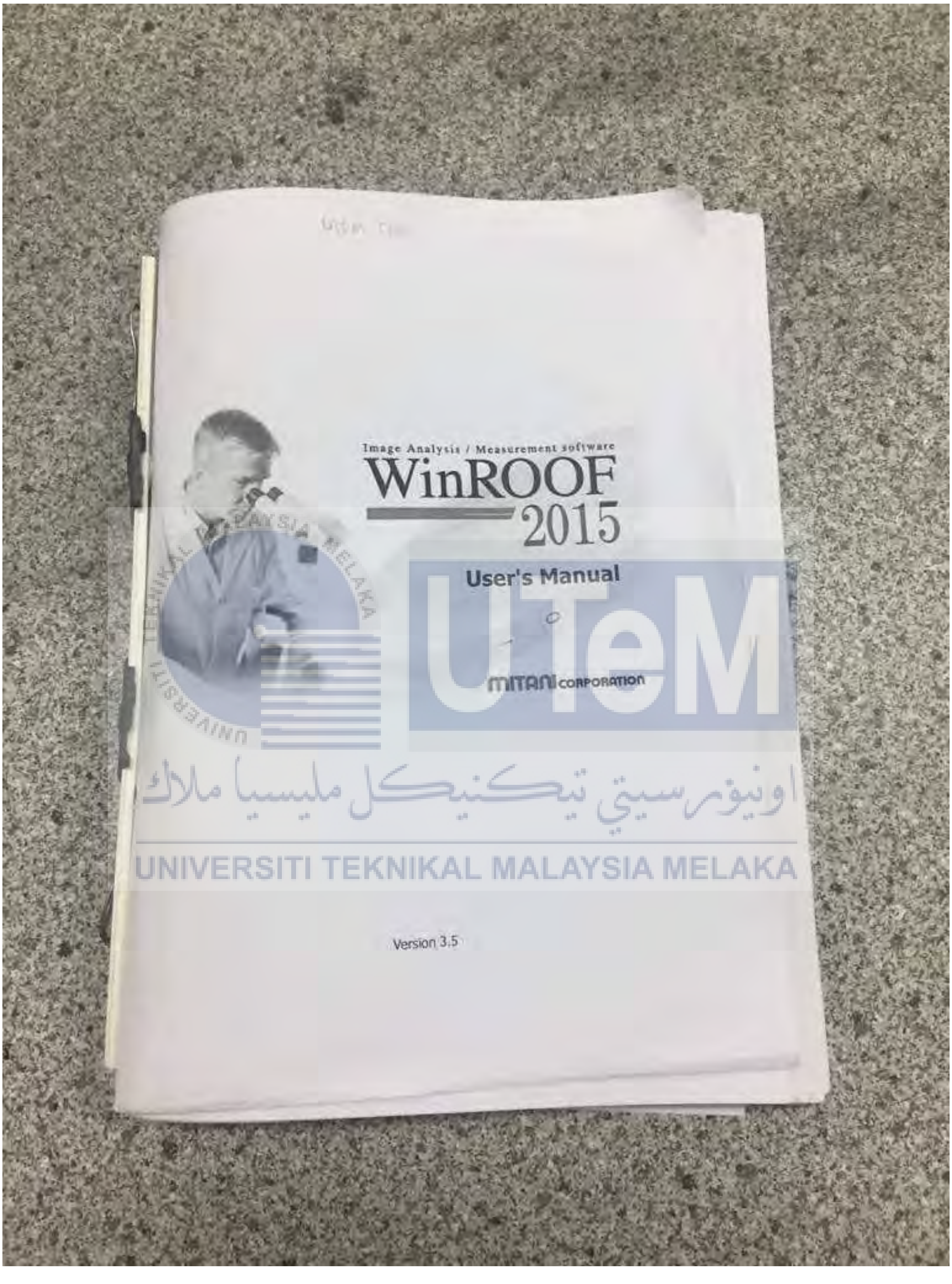
[21] R. Avendaño, R. J. C. Carbas, E. A. S. Marques, L. F. M. da Silva, and A. A. Fernandes, “Effect of temperature and strain rate on single lap joints with dissimilar lightweight adherends bonded with an acrylic adhesive,” *Compos. Struct.*, vol. 152, pp. 34–44, 2016.

[22] L. F. M. da Silva and R. D. Adams, “Adhesive joints at high and low temperatures using similar and dissimilar adherends and dual adhesives,” *Int. J. Adhes. Adhes.*, vol. 27, no. 3, pp. 216–226, 2007.

APPENDIX A



Sample of specimens fractured after tensile test



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