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

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DECLARATION

I declare that this project report entitled "Effect of Humidity on The Mechanical Performance of Joints Bonded With Electrically Conductive Adhesive" is the result of my own work except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Mechanical Engineering with Honours.

Signature	: ....
Supervisor Name	: ....
Date	: ....

DEDICATION

To my beloved parents and my respected supervisor

ABSTRACT

The research describes about the effect of humidity on the mechanical properties of joints bonded with electrically conductive adhesive. Through the background of the study, the applications of adhesive bonding with electrically conductive adhesive were described together with the advantages and limitations of the adhesive joints. The aim of this research is to investigate the mechanical properties of adhesive joints under various humidity conditions and to examine the surface profiling of adhesive bonding taken under 3D Non-Contact Surface Profilometer. The research covers on the design and fabrication of adhesive joints bonded with electrically conductive adhesive. Apart from that, the methodology used in this research includes the design of jig, preparations of specimens and test joints, and also experimental set up to obtain the analysis of mechanical properties and characterization of surface profiling tested through various humidity conditions. The results shows that the humidity factor will lead to higher shear strength depends on the type of adhesive used together with the effect of surface roughness. In comparison between high and low humidity condition, higher lap shear strength were obtained at low humidity condition as compared to high humidity condition. Besides, from the analysis of surface profiling, it can be analyzed that humidity factor will result in different surface textures depends on the shear strength developed from the mechanical properties of adhesive itself. In this research, the shear strength obtained from the humidity test will depends on the height distributions of the surface profile. For future works, it is recommended to improve the effect of surface roughness by using different techniques instead of mechanical abrasion method in order to enhance the strength of the adhesive joints. Besides, in terms of formulated adhesive as prepared in this project, the future research is recommended to identify the composition ratio of the adhesive with different mix ratio to get variation of results in the mechanical performance of joints bonded with electrically conductive adhesive.

ABSTRAK

Penyelidikan ini menerangkan tentang kesan kelembapan pada sifat mekanik sendi yang terikat dengan pelekat konduktif elektrik. Melalui latar belakang kajian ini, aplikasi ikatan pelekat dengan pelekat konduktif elektrik digambarkan bersama dengan kelebihan dan batasan sendi pelekat. Tujuan penyelidikan ini adalah untuk mengkaji sifat-sifat mekanik sendi pelekat melalui pelbagai keadaan kelembapan dan untuk mengkaji profil permukaan pelekat ikatan yang diambil di bawah Profilometer permukaan tanpa sentuh 3D. Kajian ini merangkumi reka bentuk dan fabrikasi sendi pelekat yang terikat dengan pelekat konduktif elektrik. Selain itu, metodologi yang digunakan dalam penyelidikan ini termasuk reka bentuk jig, persediaan spesimen dan sendi ujian, dan juga eksperimen yang dijalankan untuk mendapatkan analisis sifat-sifat mekanik dan pencirian profil permukaan yang diuji melalui pelbagai keadaan kelembapan. Keputusan menunjukkan bahawa faktor kelembapan akan membawa kepada kekuatan ricih yang lebih tinggi bergantung pada jenis pelekat yang digunakan bersama-sama dengan kesan kekasaran permukaan. Sebagai perbandingan antara keadaan kelembapan yang tinggi dan rendah, kekuatan ricih pusingan yang lebih tinggi didapati pada keadaan kelembapan yang rendah berbanding keadaan kelembapan yang tinggi. Selain itu, dari analisis profil permukaan, dapat dianalisis bahawa faktor kelembapan akan menghasilkan tekstur permukaan yang berbeza bergantung pada kekuatan ricih yang dihasilkan dari sifat mekanik pelekat itu sendiri. Dalam kajian ini, kekuatan ricih yang diperoleh daripada ujian kelembapan bergantung kepada ketinggian profil profil permukaan. Untuk kerja-kerja masa hadapan, adalah disyorkan untuk meningkatkan kesan kekasaran permukaan dengan menggunakan teknik yang berbeza dan bukan kaedah lelasan mekanikal untuk meningkatkan kekuatan sendi pelekat. Selain itu, dari segi pelekat yang dirumuskan seperti yang disediakan dalam projek ini, penyelidikan masa depan adalah disyorkan untuk mengenal pasti nisbah komposisi pelekat dengan nisbah campuran yang berbeza untuk mendapatkan variasi keputusan dalam prestasi mekanikal sendi yang terikat dengan pelekat konduktif elektrik.

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LIST OF ABBREVIATIONS

ECA	Electrically Conductive Adhesive
ICA	Isotropic Conductive Adhesives
ACA	Anisotropic Conductive Adhesives
LCD	Liquid Crystal Display
3D	3 Dimensional
ISO	International Organization for Standardization
DC	Direct Current
VDC	Volts Direct Current
MPa	Mega Pascal
g	Gram
ml	Milliliter
mm	Millimeter
ASTM	American Society for Testing and Materials
Ra	Arithmetical Mean Roughness
Sn	Tin
Ag	Silver
RH	Relative Humidity
CATIA	Computer Aided Three-Dimensional Interactive Application
ABS	Acrylonitrile Butadiene Styrene
CAD	Computer-Aided Design
STL	Stereolithography
IPA	Isopropyl Alcohol
µm	Micrometer
N	Newton
mm^2	Square millimeter
Rz	Maximum Average Peak-To-Valley Height

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Generally, an adhesive can be defined as a non-metallic substances that have the ability to join materials in terms of surface bonding (adhesion) meanwhile in term of bonding, it can be defined as one of the material joining methods that is capable to joint between a surfaces to another surfaces in terms of identical or antithetical materials. Usually, by using a substance that is made of different materials, it will enable the two adherents to be joined by transporting the forces from one adherents to another adherents [1].

Nowadays, one of the great applications of adhesive bonding is mainly known as electrically conductive adhesive whereby it is actually being developed to be used in electronics applications. This electrically conductive adhesive can be considered as a glue that can hold the electronic components in place while passing the electrical current between them. In general, people used to do soldering as the conventional method to allow the electrical current to flow through the electronic components. Solder joints are usually the best choice in the electronics construction however if there are too much solder on a certain joint, it may cause to poor joints itself. Sometimes, it can have the possibility of failure that will lead to a short circuit if the solder spilled over on another track on printed circuit boards. Besides, in the traditional soldering techniques, different types of solders are used for distinct use. The most common solder that are widely used is generally made of a mixture of tin and lead. However, due to environmental and health issues, lead is no longer available to be used commercially in soldering process.

Therefore, electrically conductive adhesive is being introduced to the electronics constructions by using bonding method instead of soldering process. According to Heindl [2] , there are two types of electrically conductive adhesives which are isotropic conductive adhesives (ICA) and anisotropic conductive adhesives (ACA). Generally, isotropic conductive adhesive is an element that have the capability of conducting electric in all directions as desired whereby it is currently being used in the information technology applications such as chip connection. Meanwhile for anisotropic conductive adhesives, it can be summarized as a material that have an exclusive elements within the µm range whereby it only have the ability of conducting electric in a single direction as compared to previous type of adhesives. Anisotropic conductive adhesives are widely used to adhere various types of complex structures on circuit boards. For example, it is commonly used to connect any flexible components on printed circuit boards as well as to strengthen the liquid crystal display (LCD) connections.

Apart from that, the main advantages of using this electrical conductive adhesives instead of soldering is due to its flexibility and capability to resist vibrations is better than the solder itself. Besides, this electrical conductive adhesives are absolutely a lead-free material that comes in an ideal resolution to produce electrical contacts on any substrates. However, there are certain limitations to the application of the adhesives bonding itself. For example, a few important factors such as sensitivity to the environmental conditions, adhesives temperature, ambient temperature, and condition of materials must be considered during the adhesives bonding process [3]. In terms of ambient temperature, it is actually involves the temperature of the surrounding air that is usually influenced by the humidity range of the surrounding. Brennan [4] stated that relative humidity can be expressed as the amount of moisture contains in the air that are in conjunction to the temperature parameter. Normally, when the relative humidity increases, it is usually occurs due to the temperature drops while the water vapor remains the same since cool air only need a small amount of moisture to become saturated as compared to warm air. Therefore, it is important to maintain a relevance ambient temperature in order to produce a great adhesive bonding since the ambient temperature will automatically effects the humidity of the surrounding hence it give impacts on the lifespan of the bonds in the finished product.

1.2 Problem Statement

In the material designing and manufacturing process of adhesives bonding, there are several significant things that need to be considered in order to produce great product. In the previous research, it was found that reliability of anisotropic conductive adhesives (ACAs) interconnects is affected by degradation due to moisture absorption [5] . According to this study, ACAs is made of large amount of polymers, therefore water can degrade polymers in several ways that will eventually lead to mechanical degradation since moisture absorption that is affected by relative humidity can cause the interruption of conductivity within the joining of electrodes. This will also contributes to the formation of defects on the electrically adhesive bonding such as cracks and delamination.

1.3 Objectives

The objectives of this study are:

- To identify the characterization and mechanical properties of an adhesive bonding based on various humidity.
- To examine the surface profiling of adhesive bonding taken under 3D Non-Contact Surface Profilometer.

1.4 Scope of Study

The study covers the design and fabrication of specimen of single lap joint according to the ISO standard in order to join between two materials by using an adhesive bonding substrates. Besides, the characterization of mechanical properties were observed and mechanical testing was conducted under various humidity level at certain space. Apart from that, the analysis of surface profiles and characterization of mechanical strengths on the tested specimens also investigated in this research.

1.5 Organization

The report is divided into several chapters and all of these chapters will explain about the details information of the study. The organization of this report will follows the details as follows; chapter 1, the introduction covers the background of the study, problem statement, objectives of the study, scope of the study, and also general methodology of the study. Next, chapter 2 consists of literature review that will covers on the previous study or research that are related to this project. Then, chapter 3 is a details description on the methodology that are being used for further analysis. After that, the result and discussions of this project are then discussed in the chapter 4. Finally, chapter 5 will include the conclusion and recommendations for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Adhesives are greatly being used in joining or reconstruction of any parts in certain materials. Due to high durability of the adhesive, it has replaced the usage of rivet joints in bonding or repairing process because adhesive bonding have minor concentration stress and less potential of having leakage and deterioration. Besides, it will results in less shape change on the repaired structure [6]. Mainly, in an adhesive joint, any adhesive that is applied between two plates can be defined as adherent. In the bonding process, adhesives are being used widely to grip and strengthen the bond between two bodies when the adhesive elements infiltrate into the adherent component. Besides, in order to form a durable bond, long polymeric chain will diffuse into the adherent body from the adhesive element itself. Then, the bonding between two bodies will occurs due to the electrostatic force that are generated along the bonding process. Normally, there are a few types of adhesive joints that are being used in this cases such as single lap joint, double lap joint, scarf joint and others.

As stated by Lempke [7] , single lap joints have been identified as one of the best methods to join between two materials through the application of overlying bond. This method are widely-used due to its respective strength and also the way it is being assembled which is much simpler than the traditional bonding techniques. Besides, the ability of adhesive to adhere between two contradictory materials has developed the behavior of single lap joint itself.

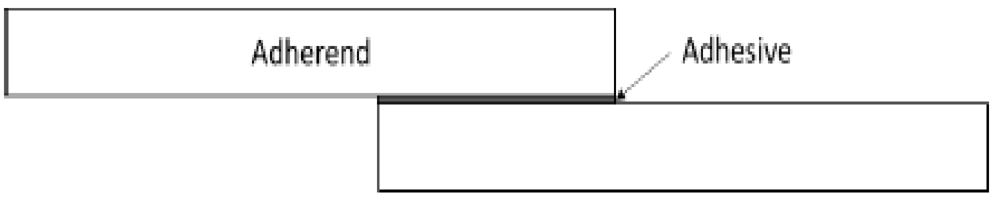

Figure 2.1: Single lap (unsupported) joint [7]

A full single lap joints as illustrated in Figure 2.1, can be defined as a bonding of adherents through an overlapping process with the help of adhesive, whereby there will be no substances is removed at the bond. In other words, no adherent material is being modified along the full overlap of the joint. According to Yan [8], a great fatigue resistance can be obtained by a smooth joint without any stress concentration. Besides, to absorb impact strength as well as to reduce any external disturbance such as noise and vibration, it is very important in to produce a good joint by using the adhesive bonding applications. To investigate the stress distribution and strength of single lap joints, there are several parameters that need to be considered when designing the lap joints [7]. The parameters include type of adhesive and its properties, substrate materials, surface preparations, overlap length, adhesive thickness and environment on the adhesive joints strength, and so on.

2.2 Application of Electrically Conductive Adhesive in Single Lap Joints

In previous century, soldering methods have been used widely in the electronic manufacturing as a standard interconnection technologies. However, this processes are slowly being dismantle through the worldwide because the usage of tin or lead during the soldering processes have been identified as an environmentally harmful material by the European Union, thus it is very important make sure that any solder process need to be lead-free by that respective year [7]. Therefore, a study on alternative method to replace the conventional soldering techniques has been conducted that eventually leads to the investigation on electrically conductive adhesives (ECAs) which have developed and became as one of the important applications of adhesive bonding. In this case, the ECAs are generally made from composites of insulating polymer matrix and conductive fillers. These two main criterions are very important in designing the ECAs because the characteristics of polymer matrix itself would enable the adhesive to bond and resist the mechanical stresses. Meanwhile, the electrical conductivity of the adhesive would depends particularly on the fillers [5].

Generally, the application of single lap joints are the most used type of joints in the industry because they are much simpler to be fabricated. Therefore, the most efficient type of loading for the adhesive is shear since adhesive is normally loaded in shear [9]. In order to minimize the stress concentrations and increase the joint strength, it was identified that mixing of adhesive joints using a strong adhesive in the middle of overlap will contribute to a more uniform distribution of stresses and enhance the joint strength. Epoxy-based ICAs would improve the adhesion strength as compared to polyimide and silicone-based ICAs [10]. Thus, mixing technique can be applied by mixing the ECA with epoxy adhesive to increase the lap-joints strength. There are numerous type of adhesives that can be used in the application of single lap joints such as Araldite® Rapid (Huntsman, Basel, Switzerland). The properties of this adhesive is shown in the Table 2.1 below.

Table 2.1: Properties of Araldite® Rapid [11]

Property	**Araldite® Rapid Resin**	**Araldite® Rapid Hardener**	**Araldite® Rapid mixed**
Color visual	Opaque	Pale Yellow	Pale Yellow
Specific gravity	1.16 – 1.18	1.15-1.18	Ca 1.18
Viscosity at 25°C (Pas)	30 – 75	20 – 40	Typically 25 – 50
Pot Life (100 g at 25°C)	-	-	5 – 8 minutes

Meanwhile, for the ECA composition, Bare Conductive Electric Paint can be considered as another type of electrically conductive adhesive which is a non-toxic material with water based and electrically conductive properties [12]. Besides of acts much like other paints, it can also be used as adhesive because it adheres to a wide variety of substrates. Bare Paint is a unique material due to its flexibility which is affected by two factors, the layer thickness and type of substrates used. In terms of electrical conductivity, Bare Paint is recommended for low voltage usage with DC power sources not more than 12VDC to avoid any failure in further application. In addition, this material is fast drying at room temperature as referred to typical properties of Bare Paint in the Table 2.2.

Table 2.2: Properties of Bare Paint [12]

Color	Black
Viscosity	Highly viscous and shear sensitive
Density	1.16 g/ml
Surface Resistivity	55 Ω/Sq @ 50 microns
Vehicle	Water-based
Shelf Life Unopened	6 Months
Drying Temperature	Bare Paint should be allowed to dry at room temperature. Drying time can be reduced by placing Bare Paint under a warm lamp or other low intensity heat source.

In the preparation of mixing the adhesive materials itself, there are certain processes that are required in the application of adhesive. For example, the pre-treatment process should be done in order to obtain the best result of the adhesive strength because the strength and durability of a bonded joints will depend on the appropriate treatment of the surfaces to be bonded. A good degreasing agent such as acetone or iso-propanol should be used to clean the joint surfaces in order to remove all the traces of oil, grease or any dirt [11]. Besides, the mix ratio of adhesive should be done as shown in the Table 2.3. The mix ratio should be done in the composition of 1:1 in order to achieve the best result of adhesive strength.

In addition, in adhesive joint design, another factors such as requirement of heated curing versus nature room temperature curing may also be considered to evaluate the lap shear strength [8]. Thus, the curing process of adhesive is also discussed in this section whereby there are certain requirements needed to obtain the minimum shear strength such as time and temperature parameter. As illustrated in Table 2.4, the expected cure time to reach lap shear strength above 1 MPa is about 30 minutes within the temperature of 23 °C. Besides, the expected cure time to reach lap shear strength above 10 MPa is about 4 hours within the same temperature.

Table 2.3: Mix ratio of adhesive [11]

Mix ratio	Parts by weight	Parts by volume
Araldite® Rapid Resin Araldite® Rapid Hardener	100 100	100 100

Table 2.4: Times to minimum shear strength [11]

Temperature	°C	23
Cure time to reach LSS > 1MPa	minutes	30
Cure time to reach LSS > 10MPa	hours	4

*LSS = Lap shear strength

Besides, during the application of adhesive, the thickness of adhesive applied should also be considered because it will affect the lap shear strength to the joint. Normally, a layer of adhesive 0.05 to 0.10 mm will normally produce the excellent strength to the bonded joint. Apart from that, to acquire a durable bond, it is very important to develop a proper adhesive joint design. To be precise, the joint components should be assembled and secured in a fix position as soon as the adhesive has been applied. Therefore, the adhesive joint design must be properly created by referring to the design of single lap joints itself. The design of single lap joints was referred as test specimens which was designed based on ASTM D 1002 that described the standard test method for apparent shear strength of single-lap-joint adhesively bonded metal specimens by tension loading (metal-to-metal). According to the standard test method, the test specimens shall be conform to the form and dimensions as shown in Figure 2.2. The recommended thickness of the sheets is 1.62 ± 0.125 mm. The recommended length of overlap for most metals of 1.62 mm in thickness is 12.7 ± 0.25 mm. Nevertheless, the permissible length of overlap in the specimen will vary with the thickness and type of metal, and on the general level of strength of the adhesive being investigated.

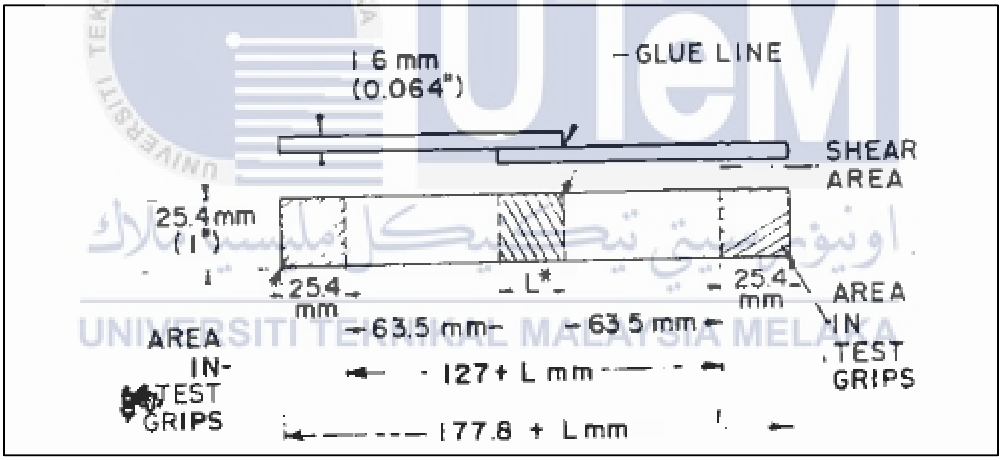

Figure 2.2: Form and dimensions of test specimen

2.3 Effect of Surface Roughness on Mechanical Properties of Adhesive Joint

In evaluating the mechanical performance of adhesive bonded joints, it is important to acknowledge the parameters that affecting the joints itself such as the effect of surface roughness on the adhesive bond strength [13]. Besides, Budhe et. al [14] identified that the design stage of adhesive joints should include the surface roughness factor as the adhered material parameter. The durability of adhesive bonding joints may be influenced by the adherent surface roughness since the surface treatment will produce positive impact on the bond strength itself. Apart from that, Zhang et. al [15] investigated that the adhesive properties of aluminium alloys can be affected by the surface pre-treatment whereby the durability of adhesive bonding joints and the maximum lap shear strength can be enhanced with the application of surface treatment and roughness modification methods. As emphasized by Budhe et al. [14], the distinct value of surface roughness will produce different value of bonding strength. The maximum bond strength of aluminum adherent joints can be achieved through the optimum surface roughness value; depends on the variation of methods of surface treatment itself.

Meanwhile, the effect of surface roughness on the fatigue behavior of single lap joints was studied by Boutar et al. [16] and it discovered that maximum fatigue life can be obtained by the combination of surface roughness and adhesive thickness which also influenced the durability of the joint itself. Besides, the highest lifetime of bonded aluminum assembly can be achieved with the optimum surface roughness $Ra \approx 0.6$ µm and adhesive thickness $e = 1$ mm. Apart from that, Yan [8] investigated the relation of surface roughness with the bonding strength of metal-metal single-lap joints which discovered that rougher surface will contribute in higher interface strength whereby the surface roughness parameter will affect the bonding strength through the effective surface (interface) area within the bonded joints.

2.4 Effect of Humidity on Mechanical Properties of Adhesive Joint

In general, the mechanical properties of adhesive joints have been studied thoroughly. Cui et al. [17] stated that the humid and thermal surroundings are one of the factors that effects the reliability of ECAs. Normally, any failure of electronic devices such as delamination are mostly caused by the ratio of electrical resistance which is directly proportional to the bonding strength. In other words, the water gain of polymer matrixes may cause the electrochemical corrosion at the contact interface, as well as the stress concentration due to the surroundings changes may become the contributing factors to the mechanical properties of this adhesive. To investigate the mechanical properties of this ECAs bonded joint, the shear strength (σ, MPa) of the adhesive samples can be obtained by using the formula:

$$\sigma = \frac{F}{BD} \tag{2.1}$$

Where $\sigma =$ Mpa is the shear strength, F (N) is the maximum load, and B (mm) and D (mm) are the length and width of fracture region subsequently.

The reliability of conductive adhesive interconnection joints can be effected by moisture absorption. As emphasized by Li et al. [10], in polymer composites, the moisture effect would have negative impact on mechanical and electrical properties of epoxy. The effect of moisture absorption on conductive adhesive joints can be characterized in terms of mechanical strength whereby it may cause degrade bulk in mechanical performance of the joints. Besides, it would reduce interfacial adhesion strength due to swelling stress in joints of adhesive. Therefore, to produce high reliability of the adhesive performance, low moisture absorption condition should be in compliance with the conductive adhesives application. Besides, in ACA joints, the moisture absorption can influence the polymer degradation because water are able to degrade polymers through the depression of the glass transition temperature T_g, cause the increase of swelling stresses and also producing voids as a result of damage or failure. Moisture absorption may also lead to the interruption of conductivity between the connections of electrodes. Liu et al. [5] identified that in two different condition; which are 85℃/85% RH and 22℃/97% RH will result in moisture degradation due to the hydrolysis of the ester linkages.

Besides, the chemical and physical characteristics of the adhesive such as the interface between adherent and substrate might get affected by the water. When exposed to high humidity, liquid water and/or high temperatures, the joint strength in adhesively bonded joints may get destructed. Apart from that, the mechanical properties and may have alteration due to the deterioration in the joint durability which caused by the water uptake [18]. In addition, the mechanical properties of adhesive can be affected by the environmental conditions whereby the interaction of temperature and moisture could produce greater degradation on the adhesive joint. The deterioration process may increase in a less duration due to rapid diffusion process of moisture into the adhesive layer which is stimulated by the higher temperature [19] [20].

Furthermore, Kim et al. [21] studied that at high humidity, there will be a possibility of poor compatibility between the adherents such as elements with Sn and Ag-epoxy ICAs due to the environmental joint reliability. During the high humidity condition, it will results in increase of electrical resistance with lower joint reliability and strength due to the interfacial deterioration of Ag-epoxy ICA joints. For example, in the 85℃/85% relative humidity (RH) test, there are some change in the microstructural interface of Sn/Ag-epoxy ICA whereby it may be related to the variation of electrical resistance. Apart from that, during a high-humidity environments, the ICAs joints with different types of metallization would cause the bonding surfaces to have distinct reliability performances. Therefore, it will results to the increment of electrical resistance of the joint after the humidity analysis [5].

Apart from that, Jurf et. al [20] identified that the effect of moisture should be considered in the properties of bonded component because the presence of moisture together with the effect of temperature would result in lower viscoelastic shear characteristics between the two adhesives. Besides, when the polymer-based ACA joints are subjected to high relative humidity condition at higher temperature, it will cause the swelling of polymeric materials due to moisture absorption which greatly affect the reliability for the ACA joints [21].

In addition, Zhong [22] investigated the influencing factors on anisotropic conductive adhesives joining and found that the environmental factors would effects on the reliability of ACA joints. When the polymer-based ACA joints is subjected to high relative humidity condition, the elements are actually being exposed to moisture absorption with high temperature, whereby it may contribute to the main reliability matters in the ACA joints. If the joints absorbed moisture, it will give effects on the physical attributes of the adhesive thus affecting the performance of the adhesive's component itself. Apart from that, if the component is absorbing moisture, it will cause the swelling of polymeric materials and this phenomenon could produce failures in ACA joints.

Meanwhile, the degradation behaviors of adhesion strength for weld-bonding under high temperature and humidity environments was studied by Tomita et al. [23] to observe the surface fracture by using a lap shear test. During this research, a structural adhesive for weld-bonding with the 0.2 mm thickness of adhesive was prepared as shown in Figure 2.3, and the lap joint specimens were tested under 40°C in 95% RH and 80°C in 95% RH. As a result, it was found that the fracture mode of the adhesive was cohesive fracture when subjected to 40°C in 95% RH condition. Meanwhile for the 80°C in 95% RH condition, the main fracture mode of adhesive changed from cohesive fracture to interfacial fracture. Therefore, it can be concluded that the degradation of the adhesive strength was affected by the hydrolysis of adhesive that lead to deterioration on the adhesive itself.

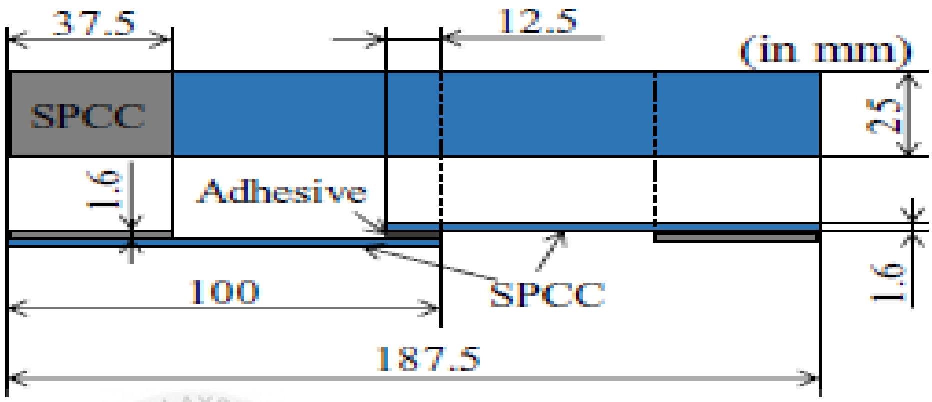

Figure 2.3: Shape and dimension of lap joint specimen [23]

As a conclusion, as the environmental factor, humidity would give effect to the mechanical properties of adhesive bond especially in terms of durability of the joint itself. From previous studies, it was found that the reliability, strength and structural joint of adhesive bond will change due to the absorption of moisture with respect to the humidity factor.

CHAPTER 3

METHODOLOGY

In this chapter, the methodology used for this study will be explained according to the general methodology as emphasized in previous chapter. The methodology starts with designing a jig in order to bond the adhesive joints. During the process of designing jig, material used in this research will be briefly described together with the procedures of this stage. After that, it will be followed by the fabrication process of adhesive joints whereby the design of substrates will be created with a proper dimension according to the related standards for adhesive joints. Besides, the preparation of electrically conductive adhesive and the preparation of test joint were also described briefly in this section. Then, humidity testing and mechanical testing will be set up to observe the mechanical properties of adhesive joint. It will be followed by analysis of data which consisted of tensile lap shear result and also surface profiling that are being collected throughout the experiment stages.

3.1 Designing of Jig

In the designing of jig, it started with the research of adhesive standards to make sure the jig was designed according to the related standard such as ASTM D1002 which described the persistence of the possible shear strengths of adhesives for bonding metals when tested on a standard single-lap-joint specimen and under specified situations of preparation and test. Then, the drawing of jig was designed using CATIA software. For joining substrate, acrylonitrile butadiene styrene (ABS) was used as the material to fabricate the jig itself. The dimension of the jig as shown in Figure 3.1 is 200.5mm x 25.4mm x 15.9mm (length x width x height).

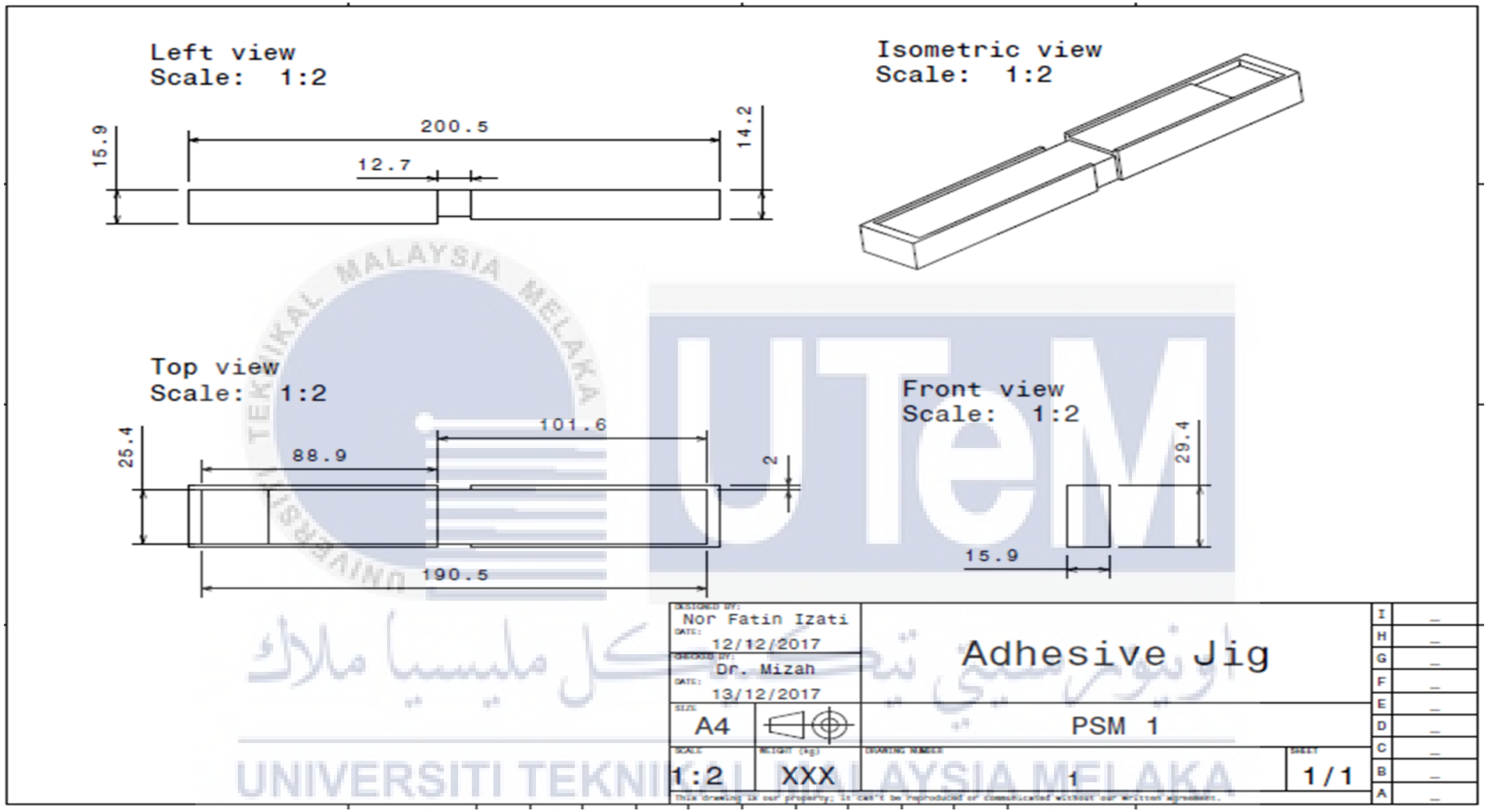

Figure 3.1: Drawing of jig with complete dimensions

3.2 Fabrication of Jig

The fabrication of jig was carried out using the CubePro 3D Printer Machine as shown in Figure 3.3. Before the printing process started, the selected drawing from CAD file must be converted into STL file for slicing process so that the selected parts would be able to be printed out using the 3D printer. During this fabrication process, ABS material as shown in Figure 3.2 was selected as the material for the jig due to its strong resistance to corrosion and physical impacts. Besides, this material is very easy to operate and has a low melting temperature thus making it particularly simple to be used in 3D printing. Apart from that, in terms of mechanical properties, ABS is absolutely strong and stiff plastic that are more reliable when subjected to external impacts as compared to other materials.

While operating the 3D printer, there are several procedures that need to be followed. For example, the printing bed must be clean from any impurity. Then, glue must be applied on the surface of bed to ensure that the first layer of printed part will stick onto the bed's surface. As illustrated in Figure 3.4, this glue also helps in the parts removal process as it will make the printed parts became easier to remove from the printing bed. During the removal process, the best way is to pour or sprinkle water onto printing bed so that the glue is less sticky and the printed parts will be easier to remove using the scraper as portrayed in Figure 3.5.

Figure 3.2: ABS material

Figure 3.3: CubePro 3D Printer Machine

Figure 3.4: Glue

Figure 3.5: Scraper

3.3 Preparation of Specimens

In this stage, the specimen used in this experiment was designed according to ASTM D1002 which stated the dimension recommended for the test specimen should be in range of 1.62 $\pm$ 0.125 mm for thickness of the sheets, recommended length of overlap for most metals is 12.7 $\pm$ 0.25 mm and 1.62 mm in thickness. However, the allowable length of overlap in the specimen will change respectively with the thickness and type of metal. In this research, the dimension of the specimen as illustrated in Figure 3.6 is 101.6mm (L) x 25.4mm (W) x 1.6mm (H). Meanwhile, for overlap specimen, the dimension is shown in Figure 3.7. Type of metal used for this research is aluminum for overall test specimens. During the preparation of specimens, sets of grips were also fabricated to be used in lap shear testing. For the grips part, the dimension of the grips will be determined by the size of the substrates which is 25.4mm (L) x 25.4mm (W) x 1.6mm (H).

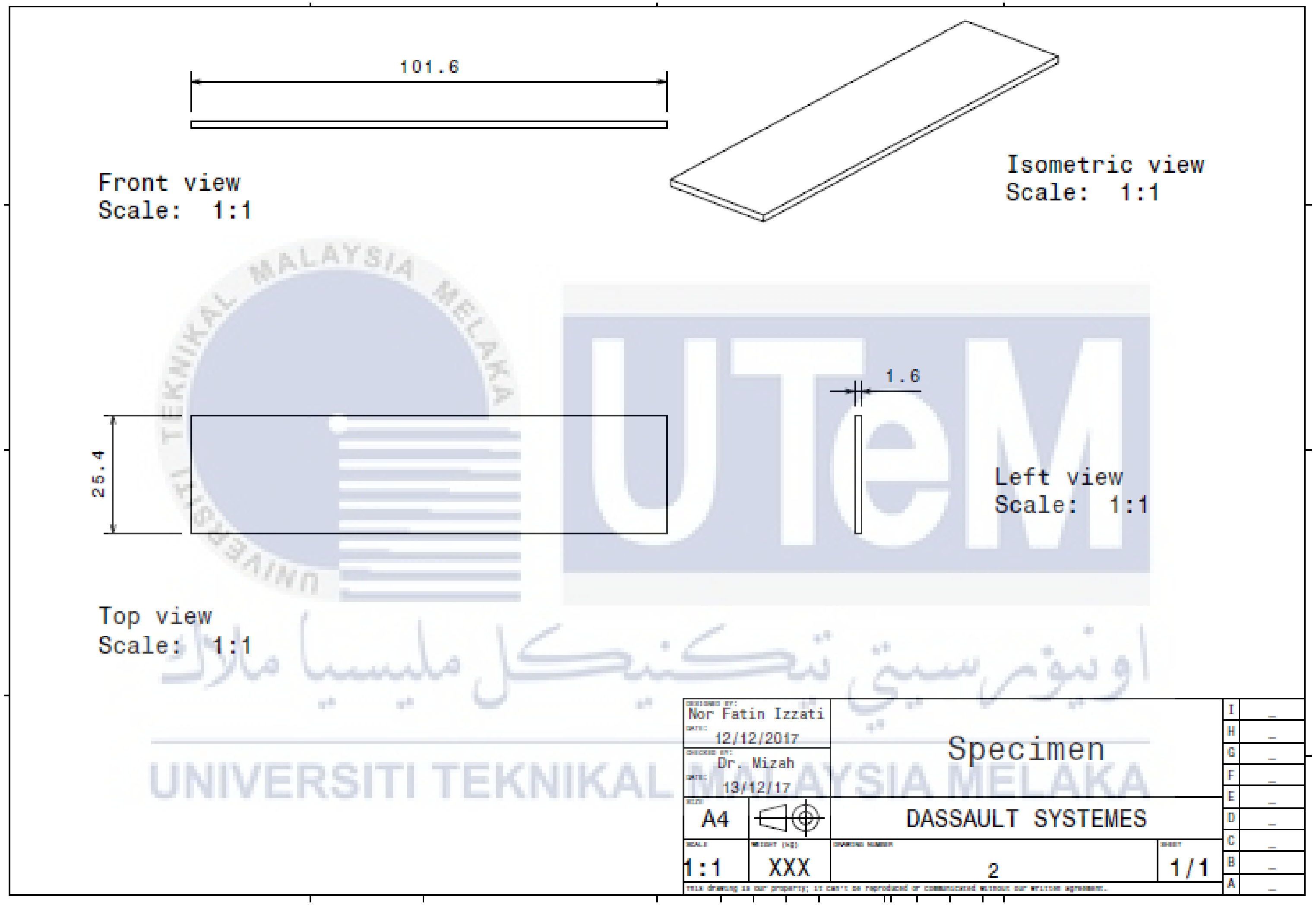

Figure 3.6: Drawing of specimen without overlap

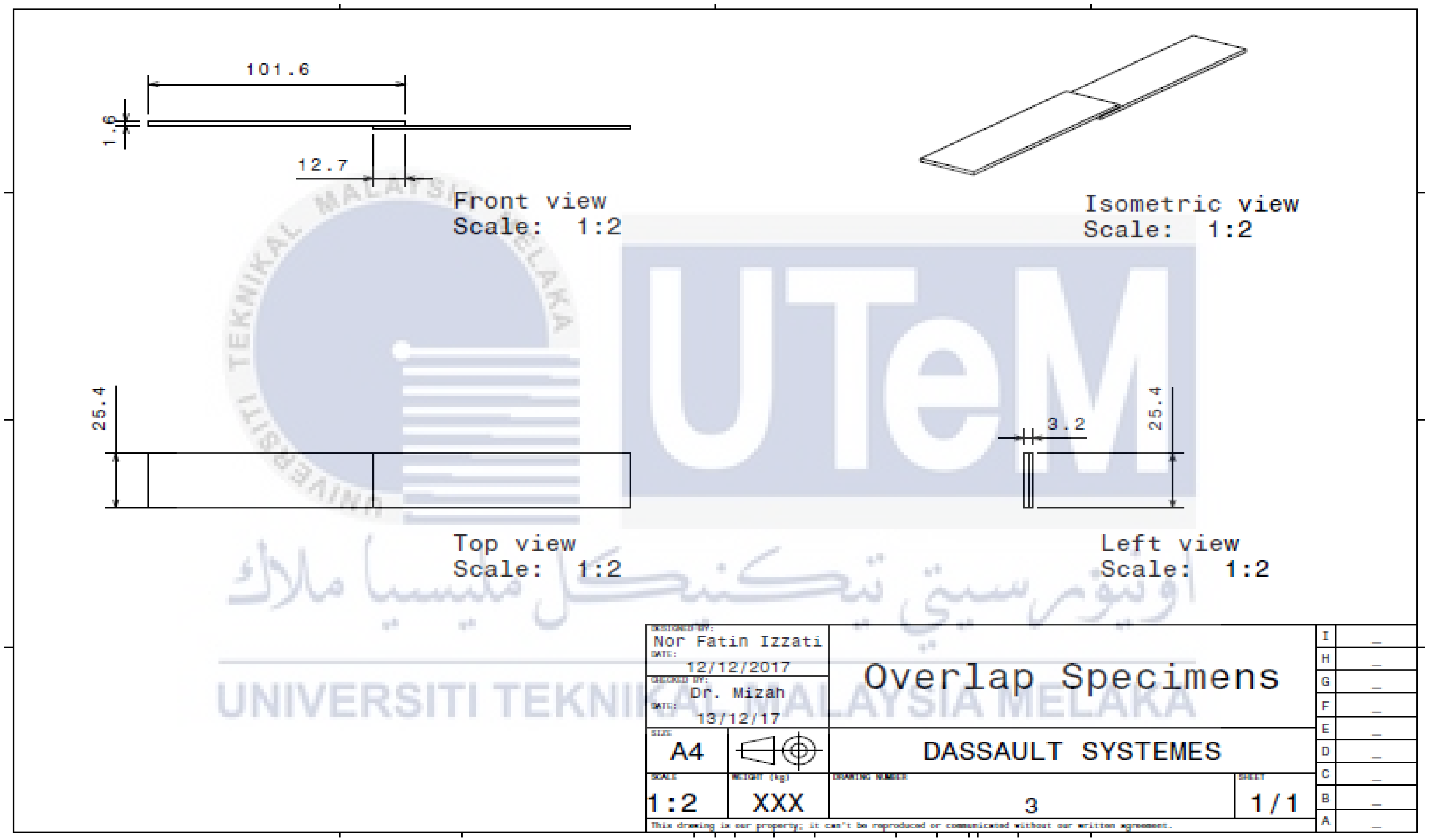

Figure 3.7: Drawing of specimens with overlap

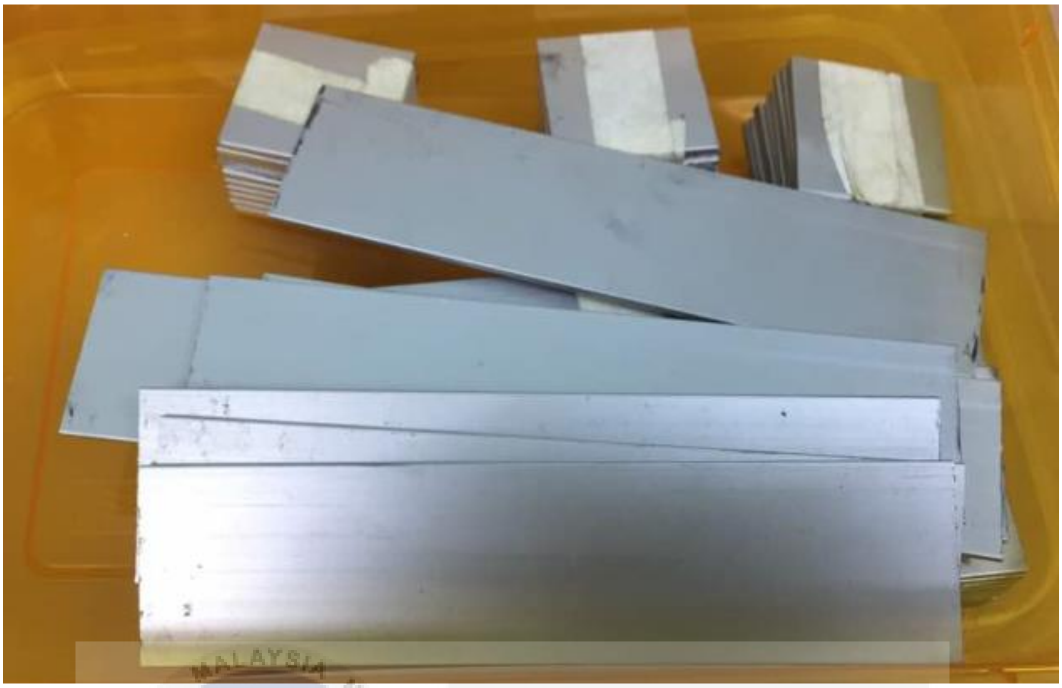

Figure 3.8: Sample of test specimens and grips

3.4 Preparation of Electrically Conductive Adhesive

The substrates will be bonded on the jig by using the electrically conductive adhesive which is mixed with the epoxy to produce a formulated adhesive. Type of adhesive being used in the bond stages is Bare Conductive Electric Paint and Araldite® Rapid, which is available in the current market. Bare Paint can be considered as a type of adhesive which is a non-toxic, water based, and electrically conductive adhesive. As shown in Figure 3.9, Bare Conductive Electric Paint is a good adherent because it adheres to a wide variety of substrates and is easily removed with water. Meanwhile, for the Araldite® Rapid adhesive as shown in Figure 3.10, it consisted of two parts which are Araldite® Rapid Resin and Araldite® Rapid Hardener. Both parts of this epoxy should be mixed accordingly in order to get maximum adhesive strength. Besides, to produce the formulated adhesive, each composition of Bare Paint and Araldite® Rapid should be mixed together with the mix ratio of 1:1:1 to achieve the best result of adhesive durability.

In the preparation of the formulated adhesive, it started with the weighing process of each adhesive with approximately similar mass. Besides, to measure the weight of each adhesive, there are a few equipment needed such as weighing scale, filter paper, laboratory spatula and glass beaker; as portrayed in Figure 3.11 – Figure 3.14. The step-by-step preparations of formulated adhesive was illustrated in the Figure 3.15. The first step to be done is to place every material on the filter paper by using the laboratory spatula. After that, each of the material should be weighed on the weighing scale with similar mass (approximately), according to the mix ratio of 1:1:1. Then, all of the weighed material should be mixed evenly in the glass beaker by using the spatula.

Figure 3.9: Bare Conductive Electric Paint

Figure 3.10: Araldite® Rapid

Figure 3.11: Filter paper

Figure 3.12: 100ml glass beaker

Figure 3.13: Weighing scale

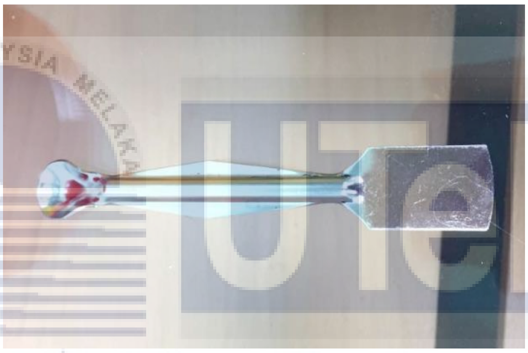

Figure 3.14: Laboratory spatula

Figure 3.15: Preparation of Electrically Conductive Adhesive

3.5 Preparation of Test Joints

In this case, the formulated adhesive will be applied on each surface of the substrates to be bonded, and it will be hold until complete curing. Besides, single lap joint method was used in this research to bond the substrates. The overlap section of the adhesive should be in 12.7 mm in length and 0.1 mm in thickness which will be controlled by the jig itself. The step-by-step preparation of test joints was illustrated in the Figure 3.16.

First step to be done is to clean the surface of substrates from any impurity by using the Isopropyl Alcohol (IPA) as the cleaning agent. Then, the substrates should be placed on the jig and marked the area to bond the adhesive. To prevent any excessive adhesive from spreading to other areas, adhesive tape should be placed in order to control the overlap section of bonded area. After that, the formulated adhesive should be applied on the marked area, which is the overlap section by using a spatula and razor blade in order to spread the adhesive evenly along the bonded area. Then, another substrates should be placed onto the bonded section to produce a complete specimens and it must undergo a curing process within 24 hours at room temperature to allow the adhesive to dry.

Besides, after the curing process at room temperature as portrayed in Figure 3.17, the bonded specimens should undergo another additional process of curing in the oven as illustrated in Figure 3.18 in order to make sure that the bonded joints is completely dry. The condition of the additional curing process was set to temperature of 100℃ within 30 minutes as shown in Figure 3.19. After the additional curing process was completed, the specimens should be cooled at room temperature for 24 hours as referred to Figure 3.20 before it can be proceed for further testing.

Figure 3.16: Preparation of test joints

Figure 3.17: Sample of specimen after bonding and curing process at room temperature

Figure 3.18: Specimens were placed on the oven tray for additional curing process

Figure 3.19: Specimens were heated in the oven with temperature of 100°C within 30 minutes

Figure 3.20: Specimens were cooled at room temperature for 24 hours

3.6 Experimental Set Up (Humidity Test)

In this section, the bonded specimens were tested under two different humidity conditions which are 85℃/85RH and 85℃/40RH. Each condition was measured in three different durations which are 1 day, 3 days, and 5 days. Besides, during the first humidity test (85℃/85RH), 9 specimens were placed in the humidity chamber at the same time as illustrated in Figure 3.21. After that, 3 specimens will be taken out from the humidity chamber after 1 day of testing, and the rest specimens will be taken out from the humidity chamber after 3 days of testing and continuously. The experimental methods were repeated for the second humidity test (85℃/40RH).

Figure 3.21: Specimens were placed in the humidity chamber

3.7 Experimental Set Up (Tensile Lap Shear Test)

To measure the effect of static or dynamic load pattern the bonding strength of the adhesive, lap shear joint adhesive tensile test and shall be conducted in this experiment [8]. By using the specimen configurations of single lap joint as shown in previous section, the experimental process of the tensile test was set up as shown in Figure 3.23. Besides, to provide a simple shear load, a set of grips were designed on both ends of the specimen as shown in Figure 3.22. The grips were attached at the specimens by using Araldite® Rapid. The grips will ensure the bending stress caused by the unbalanced alignment between the substrates and the clamping heads to be minimized during the mechanical testing.

The first step in the test procedure is to measure the amount of shear area, which was calculated using the following formula:

$$\text{Area} = \text{Length (L)} \times \text{Width (W)} \tag{3.1}$$

$$= 12.7\ \text{mm} \times 25.4\ \text{mm}$$

$$= 322.58\ \text{mm}$$

Then, each end of the specimen was loaded in the tensile grips as shown in Figure 3.24. During this stage, the grip inserts should be aligned so that the grip assembly is aligned with the adhesive bond. After that, a force at a controlled rate (1.30mm/min) was applied to the specimen and it was break up at the end of the tensile lap shear test as illustrated in Figure 3.25. Next, the maximum force (N), amount of elongation (mm), and lap shear strength (MPa) were recorded for future analysis.

Figure 3.22: Specimen with a set of grips

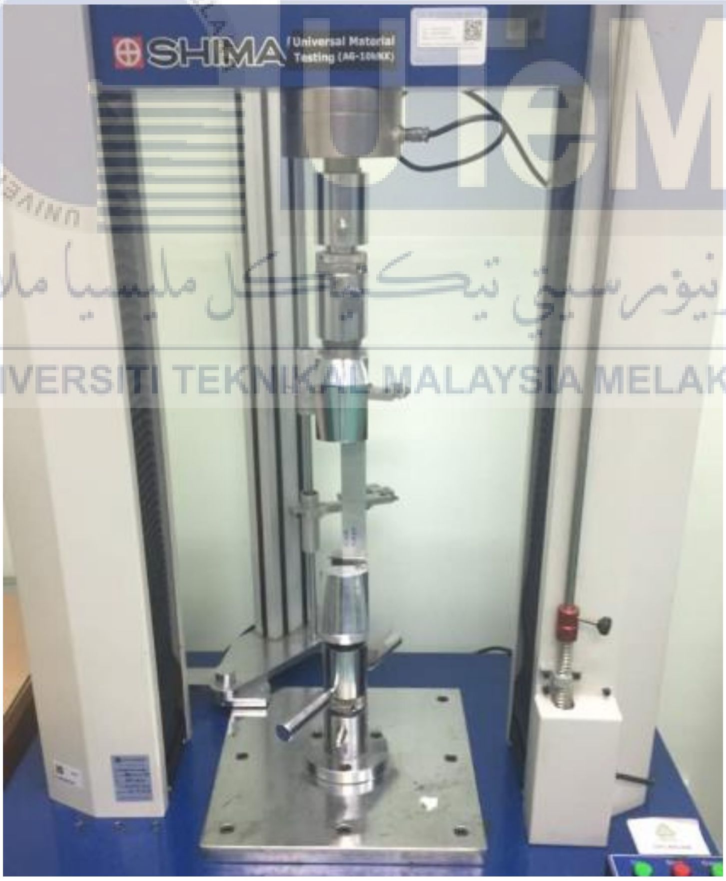

Figure 3.23: Universal testing machine

Figure 3.24: Specimen with tensile grips

Figure 3.25: Specimen was break up after tensile test

3.8 Result Analysis under 3D Non-Contact Surface Profilometer

To determine the surfaces profiling of adhesives, micrographic analysis was conducted after the completion of tensile test by using the 3D Non-contact Surface Profilometer as portrayed in Figure 3.26 in order to examine the surface's suitability for its intended purpose. Surface profiling or generally known as 3D surface profiling is usually used to measure the three dimensional topography of precision surfaces. Besides, it can also determine many other types of measurements such as surface shape, surface profile roughness (Ra) and others.

However, in this research, it will focuses on surface profile roughness (Ra) and also surface profiling (topography) only. The analysis of surface profile roughness (Ra) was conducted on the overlap area of the specimens; which is the particular area of adhesively bonded joints. Then, the roughness measurements and 3D measurement functions was obtained by using the WinROOF 2015 Image Analysis / Measurement Software.

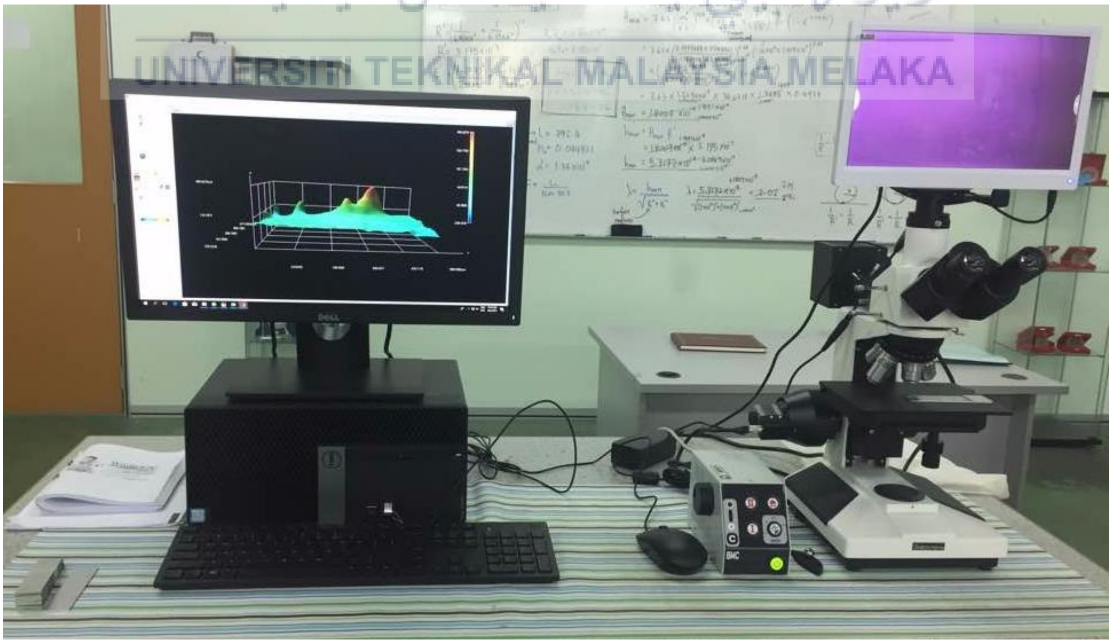

Figure 3.26: Surface profiling under 3D non-contact surface profilometer

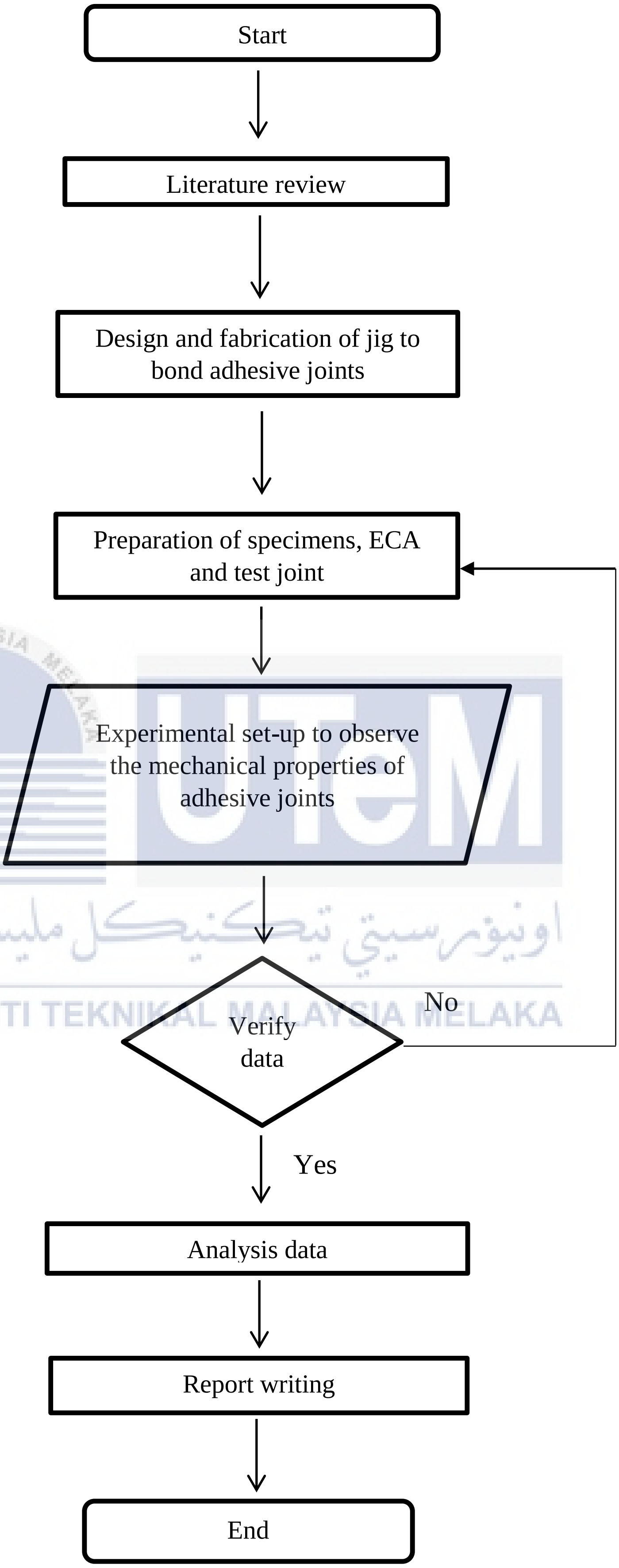

Figure 3.27: Flow chart of the general methodology

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, preliminary results will be explained in terms analysis of jig which includes the design of jig, failures that occurs during the fabrication of jig, and also the alternative method to countermeasure the failures. Besides, the analysis of lap shear joint adhesive tensile test and surface profiling analysis were also described in this section.

4.1 Analysis of Jig

In producing the real jig to bond the adhesive joints, there are several designs that have been created in order to get the best configuration of the jig itself. During the first attempt of fabricating the jig, there is some failures occurred in the first prototype as shown in Figure 4.1. At the end of the jig, the grips part is not properly printed out due to absence of support during the printing process. Apart from that, the dimension of the jig was not configured out properly thus the overlap section are considered to be failed through this design. To encounter the grips problem, a supporting part should be done in order to make sure every layer of part can be printed out smoothly. Besides, the overall jig has been redesigned according to the standard dimensions of adhesive jig so that the thickness of overlap joint can be controlled and measured by the jig.

Meanwhile, during the second attempt of fabricating the jig, there are another failures occurred on the printed sets of jig prototype. For the second prototypes, it can be identified that the failures occurred due to the improper surface finish, and also the presence of gap in the middle of the jig as shown in Figure 4.2. These problems occurred due to the technical problems during the set-up of 3D printer machine and also caused by improper support created by the 3D printer itself. Apart from that, another deteriorations also appeared during this stage whereby there are bending issue with the jig prototype as shown in Figure 4.3; and lower durability of material which leads to fracture of jig as illustrated in Figure 4.4. Thus, to avoid these deficiencies, the first step that need to be taken is to improve the design of jig by increased the height of jig so that no bending issue arise after the fabrication process. Besides, to avoid the fracture of jig, the material for jig was changed from low-quality ABS to high-quality ABS so that it will have better surface finish and higher durability to impact strength. In additional, to avoid the gap in the middle of the jig, the 3D printer machine must be set-up properly and it is very important to make sure that the commands to operate 3D printer was selected correctly to produce a good quality of prototypes by the 3D printing process.

After several attempts of fabricating the jig, the third attempt can be considered as a success because there is no failure appeared through this jig. The third prototype as shown in Figure 4.5 have been improved in terms of height of the jig and better surface finish. With the increased of height for jig, it has improved the removal process of jig from the printing bed thus reduced the possibility of bending problem.

Figure 4.1: First prototype of jig

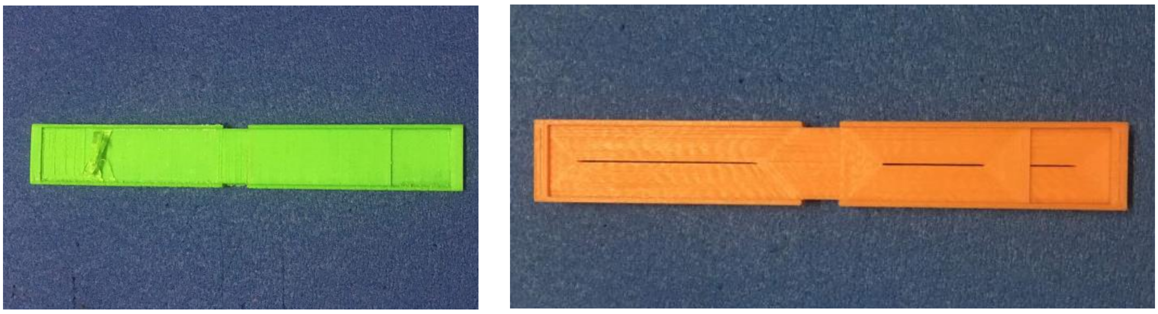

Figure 4.2: Second prototypes of jig with improper surface finish and presence of gap

Figure 4.3: Bending issue in jig

Figure 4.4: Fracture of jig

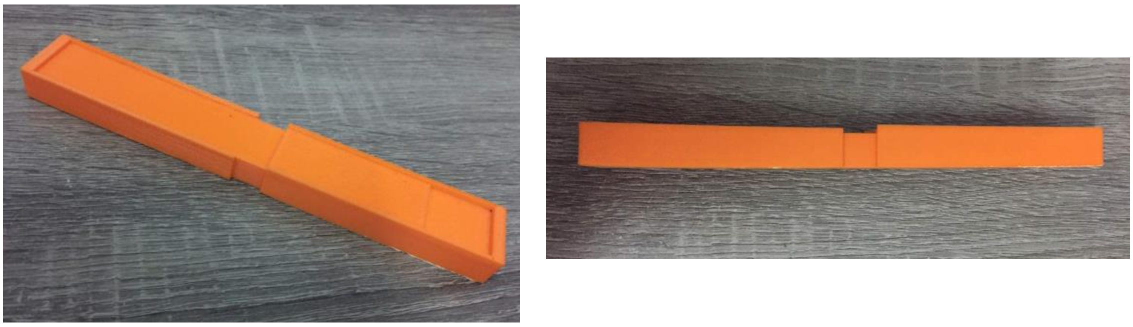

Figure 4.5: Final design of jig

4.2 Analysis of Lap Shear Joint Adhesive Tensile Test and Surface Profiling at Room Temperature (Without Surface Treatment)

To identify the mechanical properties of the adhesive joints, tensile lap shear test was conducted by using the universal testing machine. Three specimens were used in the test in order to determine the average value of maximum force required to break the specimens. In this case, the specimens were bonded using the formulated adhesive as mentioned in the previous methodology. Besides, there is no surface treatment was conducted on each specimens and it did not undergone any additional curing process, whereby the specimens only cured at room temperature within 24 hours period instead of additional curing method in the oven.

As referred to Table 4.1, the average value of surface roughness (Ra) before undergone any surface treatment was obtained within the range of 0.4 µm to 0.6 µm. Therefore, it leads to lower average lap shear strength which was about 0.61 MPa as shown in Table 4.2. Meanwhile, in this case, it can be identified that the maximum force required to break the specimen was 220.36 N with 0.76 mm maximum elongation as illustrated by Specimen 2 in Figure 4.7.

Generally, Ra is used as a global evaluation of the roughness amplitude on a profile. In terms of 3D surface measurement, it is usually demonstrated in four general parameters such as amplitude, spatial, hybrid and functional. However, in this research, it only focuses on the amplitude parameters because it is the most important parameters to characterize surface topography [24]. Surface amplitude can be measured based on the overall heights that included the root-mean-square of height distribution. Apart from that, it also included the skewness measurement which described the degree of asymmetry of a surface height distribution, the kurtosis analysis which represent the degree of peakedness of a surface height distribution, as well as the average value of the highest and lowest points in the 3D surface analysis.

Based on the surface topography in Figure 4.6, it showed that the surface 3D profile without surface treatment on Sample 2 would result in higher surface's height distribution which is about 24.2352 µm. Besides, the surface topography without surface treatment resulted in surface waviness or irregularities pattern whereby the height distribution seems to be inconsistent due to the surface treatment factor.

Table 4.1: 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)
Sample 1	0.9010	0.6825	0.5928	0.3837	0.6673	0.6455
Sample 2	0.7183	0.7279	0.4748	0.5341	0.7157	0.6342
Sample 3	0.4875	0.2299	0.5587	0.5155	0.4977	0.4579

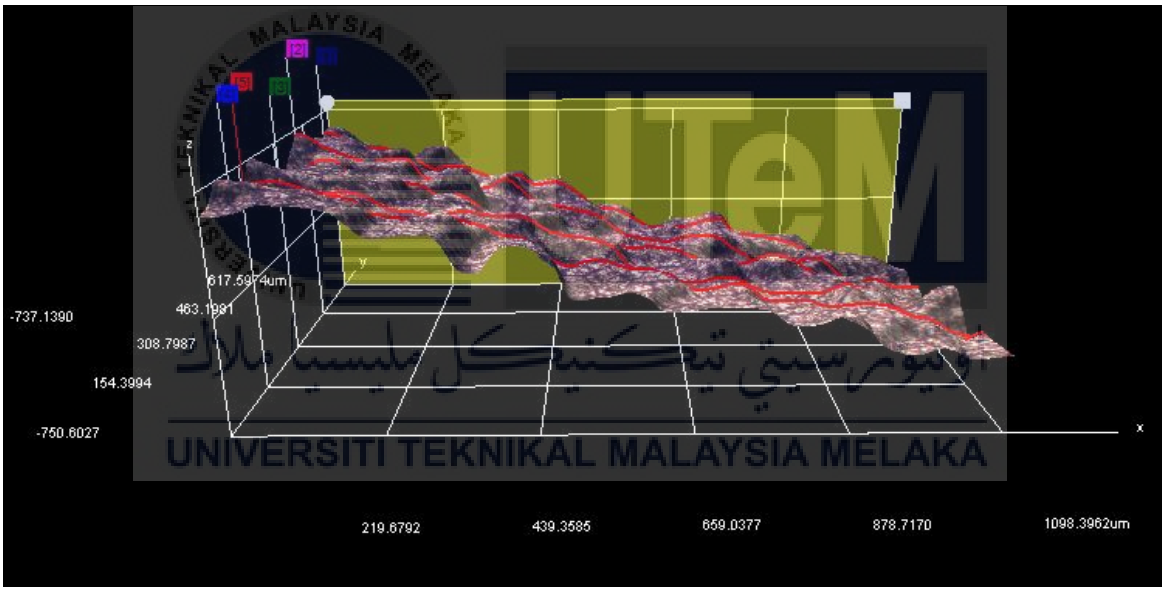

Figure 4.6: Surface 3D profile without surface treatment

Table 4.2: Result of tensile lap shear test at room temperature (without surface treatment)

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

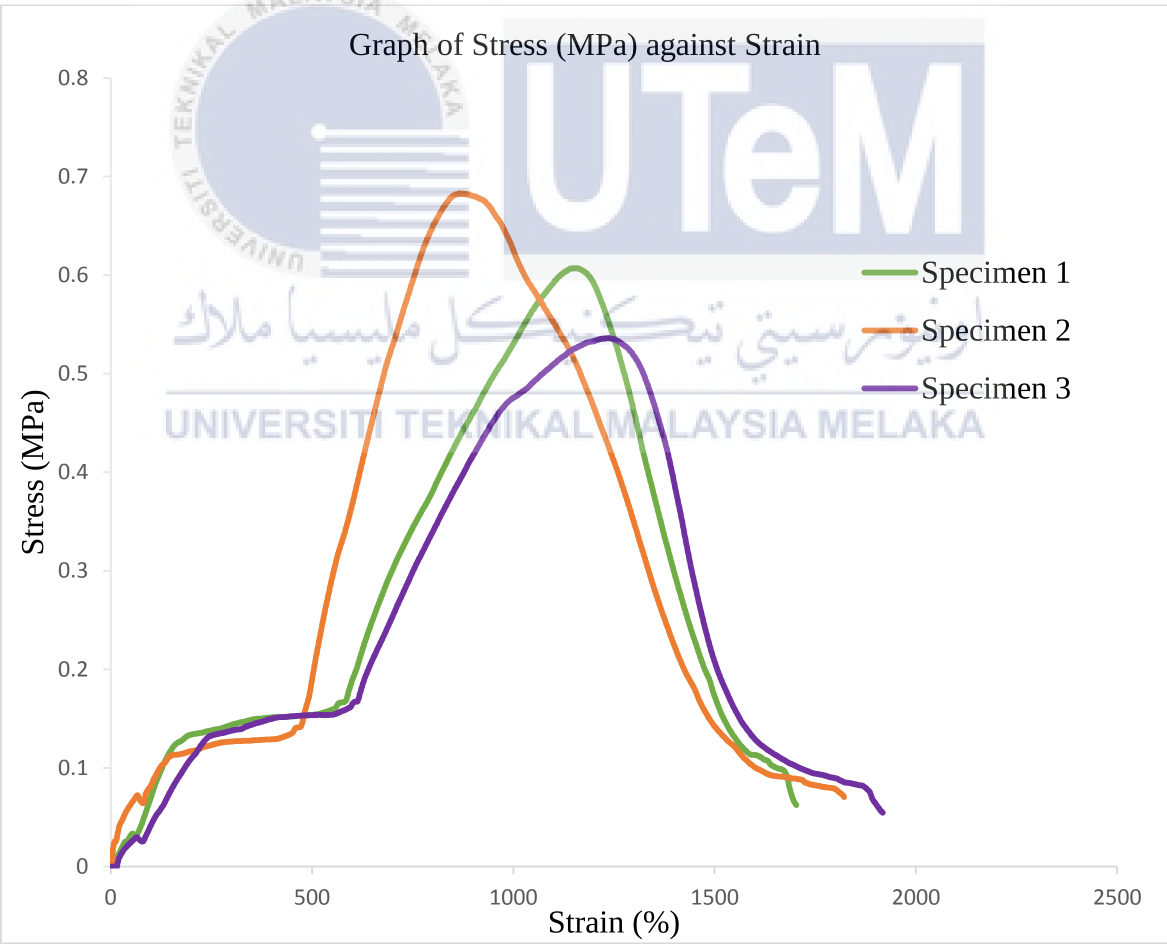

Figure 4.7: Graph of stress against strain of joints bonded at room temperature (without surface treatment)

4.3 Analysis of Lap Shear Joint Adhesive Tensile Test and Surface Profiling at Room Temperature (With Surface Treatment)

In previous section, it can be identified that the average lap shear strength obtained without any surface treatment is limited to a value around 1.0 MPa. Therefore, an alternative method was conducted in order to increase the lap shear strength whereby mechanical abrasion using sand paper for aluminium sample was used in this method [14].

Three specimens were used in the test to determine the average value of maximum force required to break the specimens. In this case, all specimens were treated at the bonded area which is the overlap section with mechanical abrasion technique by using P80 sand paper to produce the surface roughness on the aluminium plate. Besides, the specimens were bonded using the formulated adhesive and cured at room temperature together with the additional curing process in the oven as mentioned in the previous methodology.

By referring to Table 4.3, the average value of surface roughness (Ra) after surface treatment was obtained within the range of 0.8 μm to 0.9 μm. Therefore, it leads to higher average lap shear strength which was about 1.25 MPa as shown in Table 4.4. Meanwhile, in this case, it can be identified that the maximum force required to break the specimen was 513.57 N with 0.96 mm maximum elongation as illustrated by Specimen 1 in Figure 4.9.

Apart from that, based on the surface topography in Figure 4.8, it illustrated that the surface 3D profile with surface treatment before adhesively bonded process would result in lower surface's height distribution which is about 7.4008 μm for Sample 2. Besides, the surface topography with surface treatment produced better surface texture with lower amplitudes. In terms of height distribution, the results of mechanical abrasion led to more consistent and controlled value of height distribution itself.

In addition, after completed the lap shear tensile test, the specimens were analyzed under the 3D Non-Contact Surface Profilometer once again in order to investigate the surface topography of the specimens after bonded and cured at room temperature. Based on Figure 4.10, it can be identified that the maximum average peak-to-valley height (Rz) is about 600.1715 µm with irregularities pattern of the surface texture. The height distributions was in compliance with the shear strength obtained from the previous lap shear tensile test.

Thus, it can be concluded that the lap shear strength and surface topography of adhesive joints can be improved by surface treatment method. This analysis was considered as a benchmark evaluation of the overall analysis in the next section.

Table 4.3: Surface roughness (Ra) value with surface treatment

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

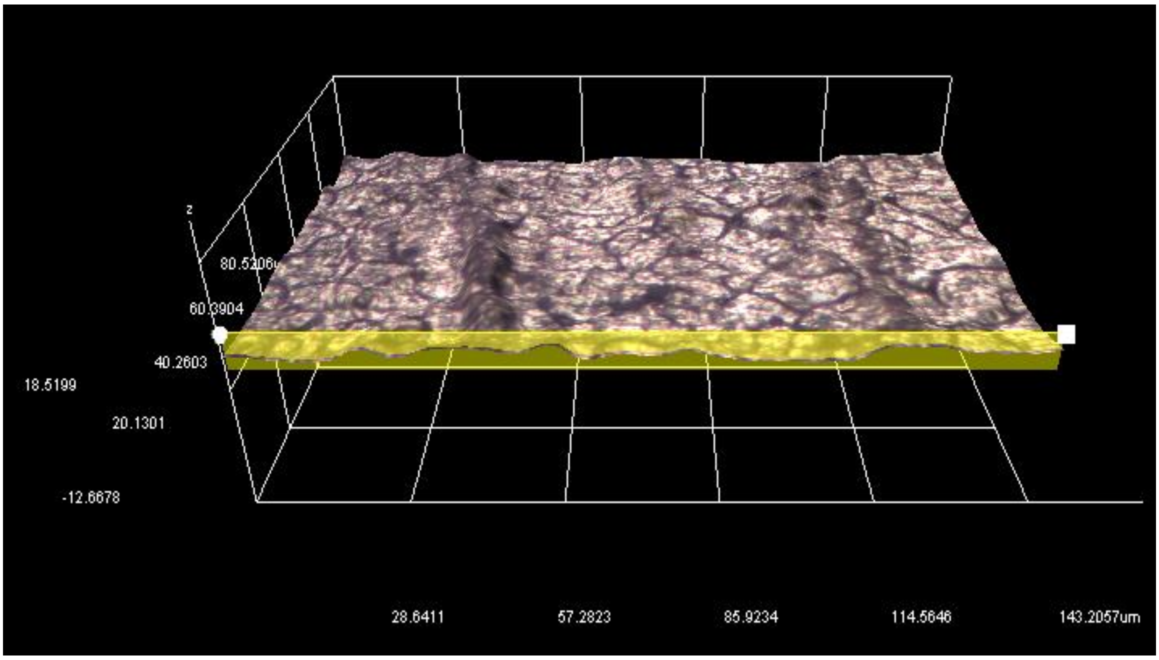

Figure 4.8: Surface 3D profile with surface treatment before adhesively bonded process

Table 4.4: Result of tensile lap shear test at room temperature

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	513.57	0.96	1.59	1.25
2	322.58	344.61	1.07	1.07	
3	322.58	352.45	0.84	1.09	

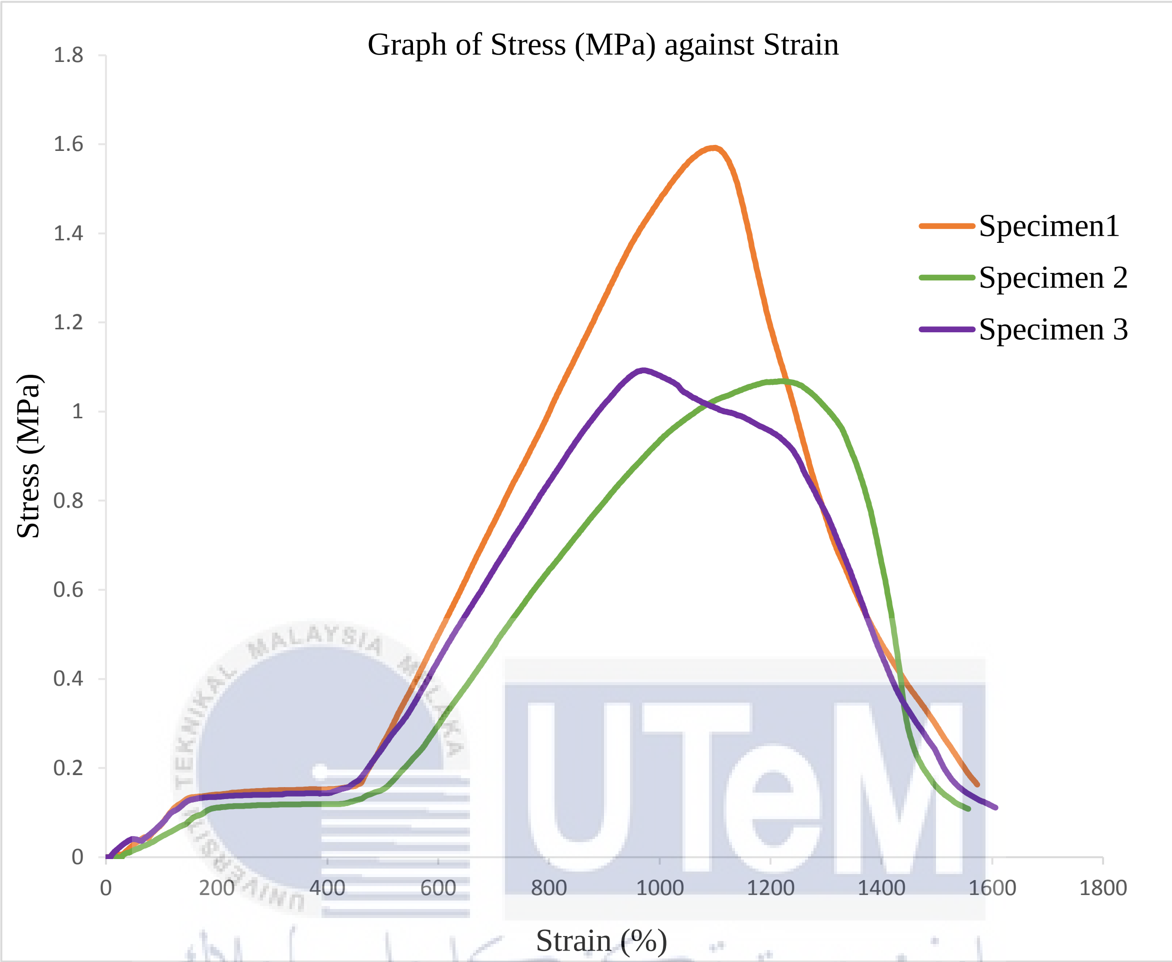

Figure 4.9: Graph of stress against strain of joints bonded at room temperature (with surface treatment)

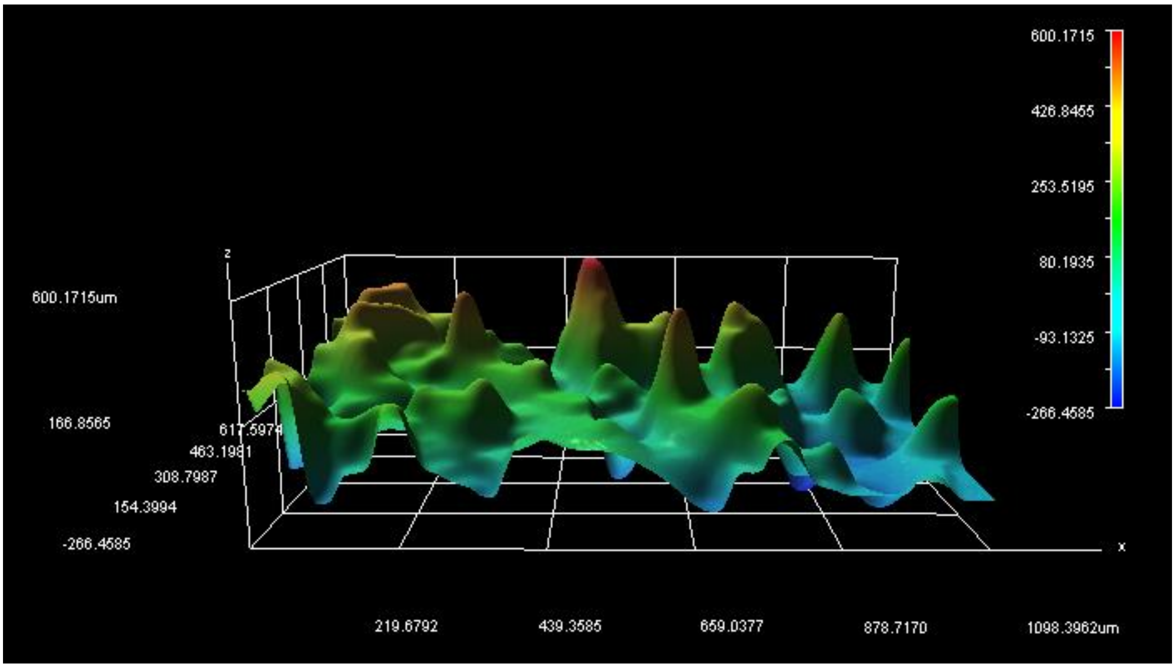

Figure 4.10: Surface topography after lap shear tensile test at room temperature

4.4 Analysis of Lap Shear Joint Adhesive Tensile Test and Surface Profiling at 85℃/85% Relative Humidity (RH)

During the humidity test, the first condition used in the test was 85℃/85RH by using 9 specimens within three different period which is 1 day, 3 days, and 5 days consecutively. Each condition of this humidity test will contribute in different result based on the analysis of lap shear tensile test and surface profiling under 3D Non-Contact Surface Profilometer.

4.4.1 Humidity Test at 85℃/85RH for 1 Day

For humidity test at 85℃/85RH for 1 day, it can be recognized that each of the specimen resulted in different strength whereby the average value of lap shear strength obtained was 1.50 MPa as depicted in Table 4.5. Based on the previous result of tensile lap shear test at room temperature, the average value of lap shear strength was 1.25 MPa.

During high temperature and high humidity condition, the reliability and strength of the adhesive supposed to have deterioration and change in microstructural interface that led to lower reliability performances [22]. In terms of the effect of environmental moisture, the mechanical behavior and the interface properties of the adhesive will be affected by the moisture absorption of the polymeric adhesives [25]. Besides, moisture absorption in adhesive joints would affect the physical attributes and reliability of the adhesive itself [26].

However, in this case, the shear strength of the adhesive at humidity test seems to be higher than the shear strength from benchmark test at room temperature. Based on Figure 4.11, the humidity test at 85℃/85RH for 1 day portrayed that the highest lap shear strength of 2.13 MPa was achieved by Specimen 1. This result may be varied due to the effect of surface treatment as well as the properties of the adhesive itself. The bonding strength was affected by the surface roughness through the effect on effective surface (interface) area whereby rougher surface resulted in higher interface surface [8]. Besides, the joint strength can be improved by mixing the adhesive using a strong adhesive with ductile adhesive at the overlap area in order to reduce stress concentration [9].

Apart from that, after completed the lap shear tensile test, the specimens were analyzed under the 3D Non-Contact Surface Profilometer to investigate the surface topography of the specimens after tested under the humidity test at 85℃/85RH for 1 day. Based on Figure 4.12, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 694.9432 µm with some distortion pattern of the surface texture. However, the surface texture can be assumed to be more stable in terms of amplitude parameter although the height distributions obtained was much higher than the previous result in the benchmark evaluation. This can be observed from the surface profile of the specimen whereby the profile seems to be more organized in a controlled curvature.

Therefore, the result of higher shear strength was justified through the surface treatment method and the mixed adhesive technique that enhance the durability of the adhesive. Besides, the humidity effect also improved the surface profile of the adhesively bonded joints itself.

Table 4.5: Result of tensile lap shear test for humidity test at 85℃/85RH (1 day)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	688.43	1.59	2.13	
2	322.58	288.51	1.02	0.89	1.50
3	322.58	480.13	1.10	1.49	

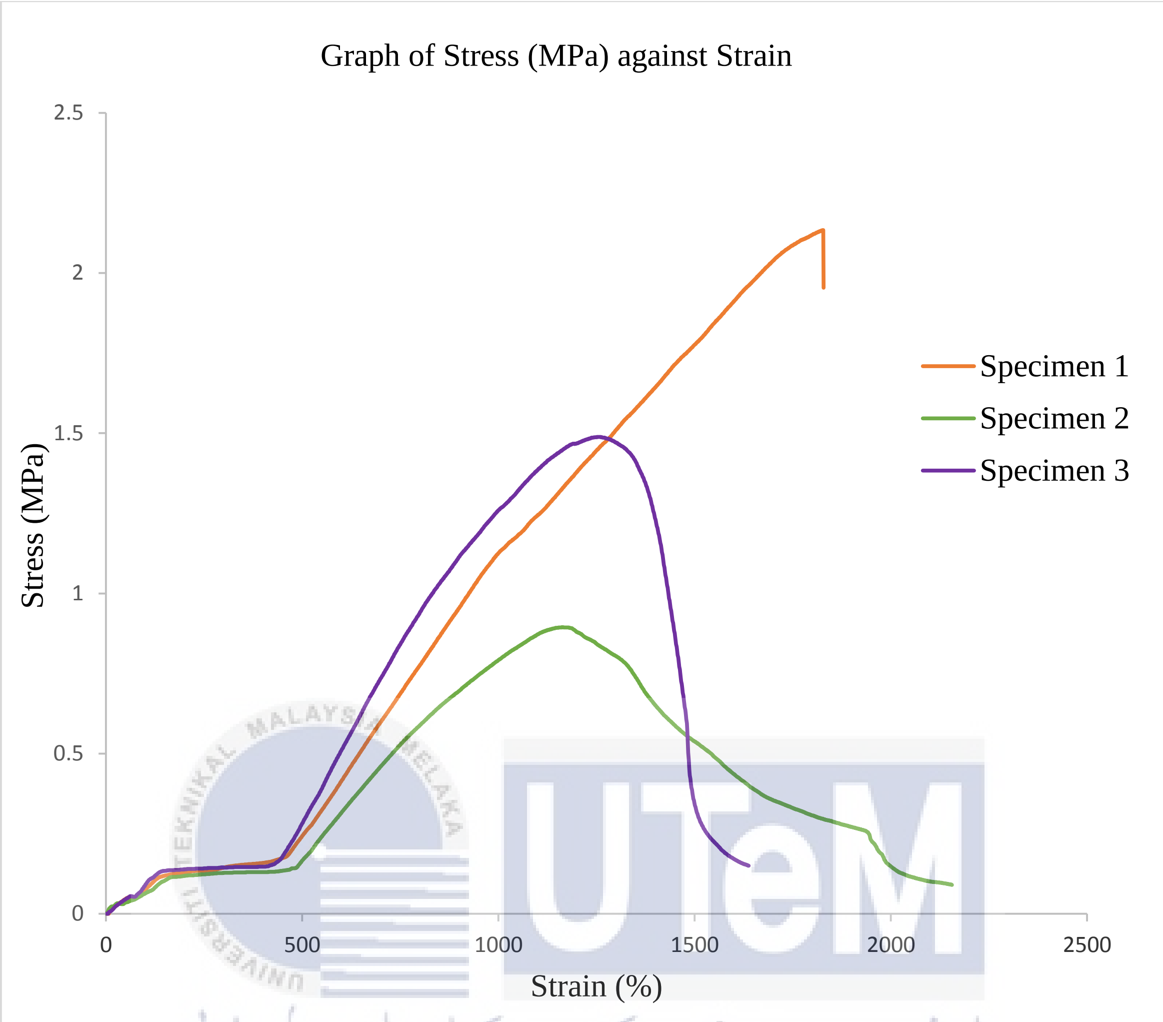

Figure 4.11: Graph of stress against strain of joints bonded for humidity test at 85℃/85RH (1 day)

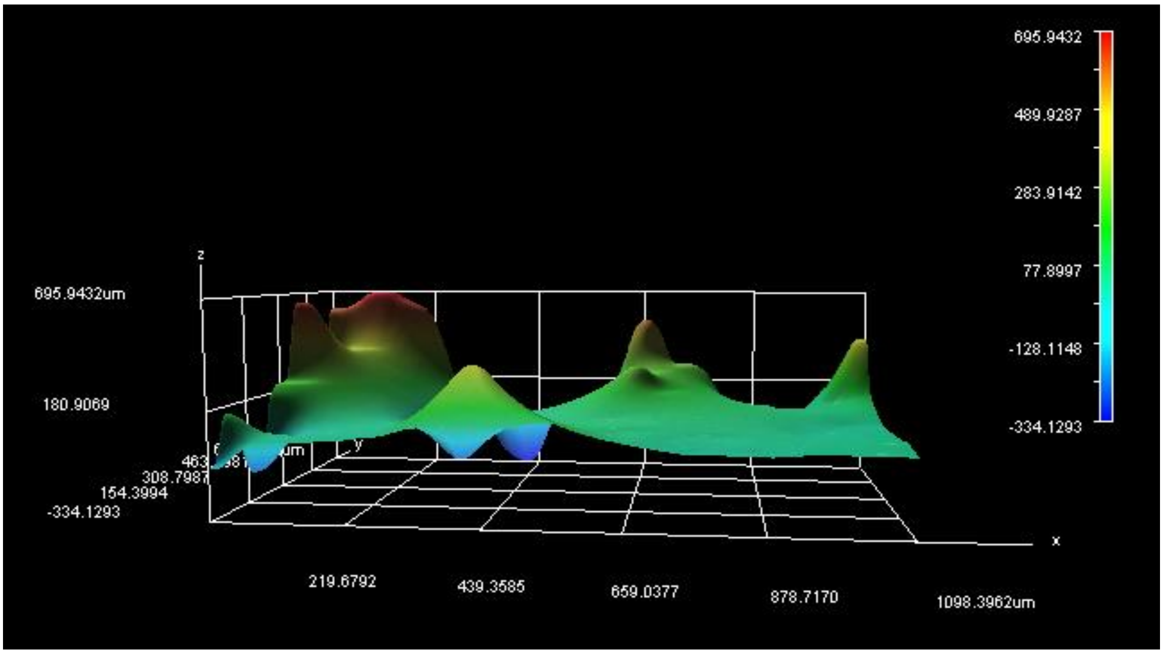

Figure 4.12: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/85RH (1 day)

4.4.2 Humidity Test at 85℃/85RH for 3 Days

For humidity test at 85°C/85RH for 3 days, it can be identified that average value of lap shear strength achieved was 2.65 MPa as displayed in Table 4.6. In this case, the shear strength of the adhesive for humidity test at 3 days seems to be higher than the shear strength of the adhesive for humidity test at 1 days. Based on Figure 4.13, the humidity test at 85°C/85RH for 3 days illustrated that the highest lap shear strength of 3.79 MPa was achieved by Specimen 1. This can be related with the previous result whereby the durability performance of the adhesive were greatly influenced by additional factors as mentioned in the previous section.

Apart from that, the surface topography of the specimens after tested under the humidity test at 85°C/85RH for 3 days were also investigated after completed the lap shear tensile test. Based on Figure 4.14, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 1305.5936 μm with inconsistency pattern of the surface texture. The height distributions obtained was greater than the previous height distributions for 1 day analysis.

Therefore, it can be justified that the increase of period for humidity test will also increase the amount of moisture absorption that leads to the greater height distributions in the surface topography. Besides, the effect of surface roughness also contributed in the surface topography whereby a rough surface provide bigger surface area for interface reaction thus proposed more mechanical interlocking [8].

Table 4.6: Result of tensile lap shear test for humidity test at 85°C/85RH (3 days)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	1223.58	1.50	3.79	2.65
2	322.58	548.09	1.05	1.69	
3	322.58	798.26	1.40	2.47	

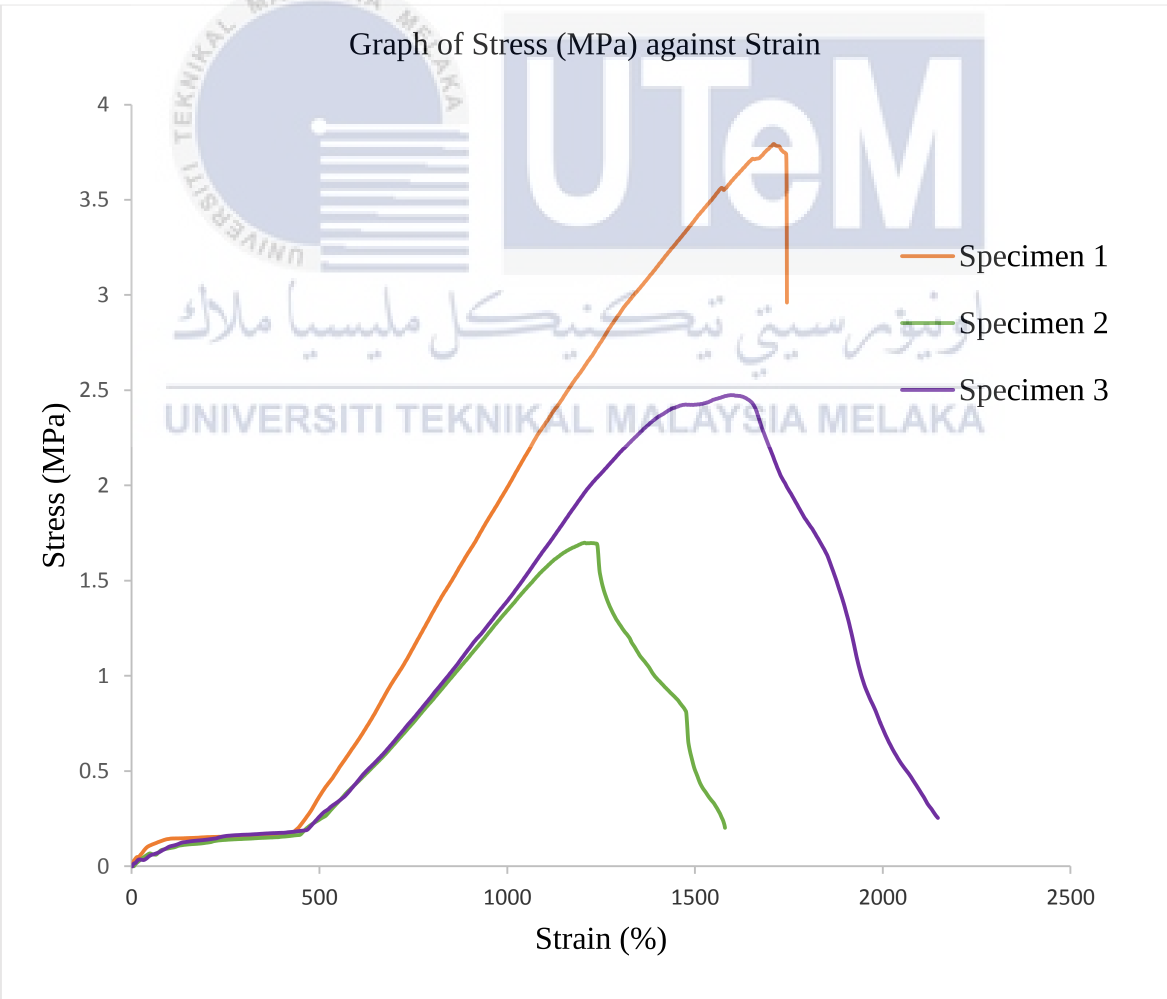

Figure 4.13: Graph of stress against strain of joints bonded for humidity test at 85°C/85RH (3 days)

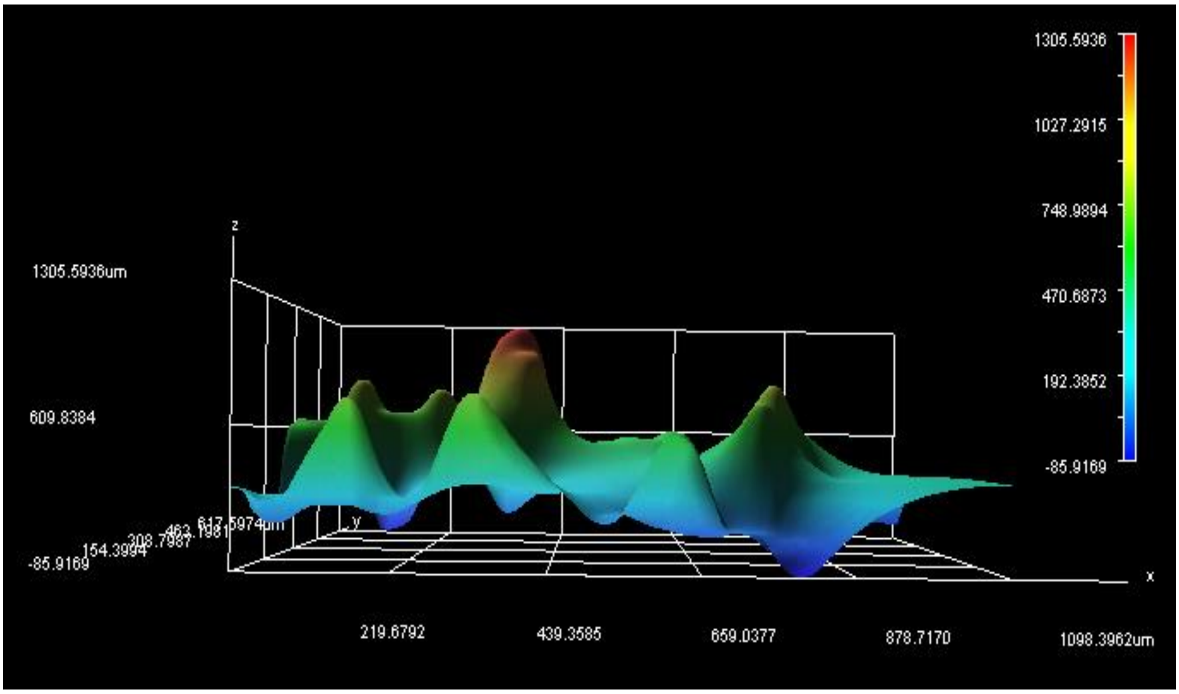

Figure 4.14: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/85RH (3 days)

4.4.3 Humidity Test at 85℃/85RH for 5 Days

For humidity test at 85°C/85RH for 5 days, it showed that average value of lap shear strength achieved was 1.77 MPa as displayed in Table 4.7. Generally, the shear strength of the adhesive for humidity test at 5 days was lower than the shear strength of the adhesive for humidity test at 3 days. Based on Figure 4.15, the humidity test at 85°C/85RH for 5 days depicted that the highest lap shear strength of 2.67 MPa was achieved by Specimen 3.

The results of the lap shear strength showed an inconsistency value within 3 distinct period of testing due to environmental effect occurred on previous specimens for 3 days of humidity test. However, the average value obtained from each condition did not give much effect on the performance of the adhesive's durability.

Besides, the surface topography of the specimens after tested under the humidity test at 85°C/85RH for 5 days were also observed after completed the lap shear tensile test. Based on Figure 4.16, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 913.1960 μm with inconsistency arrangement of the surface curvature. The height distributions obtained was lower than the previous height distributions for 3 days analysis due to the environmental effect as mentioned in the earlier section.

Table 4.7: Result of tensile lap shear test for humidity test at 85°C/85RH (5 days)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	327.44	1.52	1.02	1.77
2	322.58	527.21	1.09	1.63	
3	322.58	859.85	1.93	2.67	

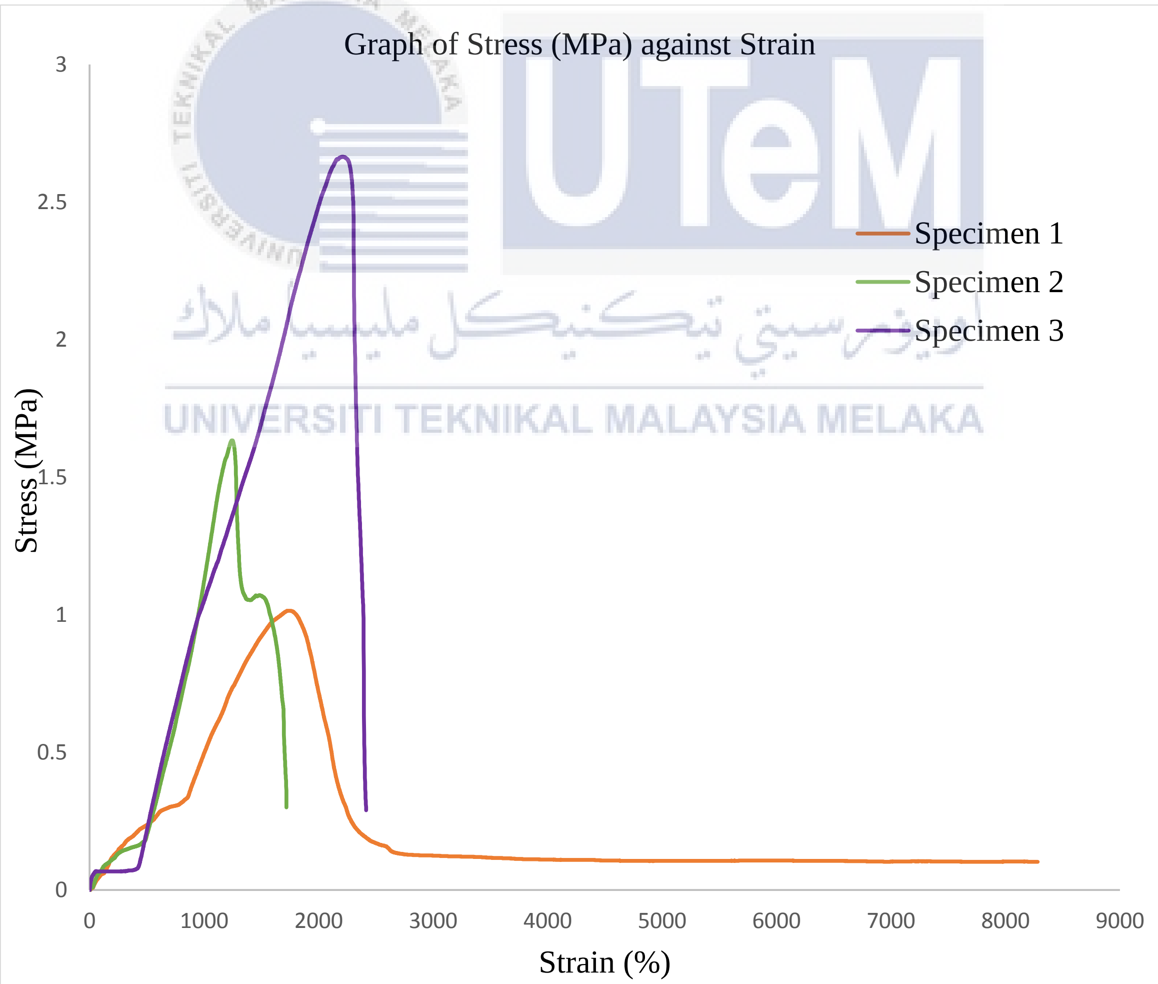

Figure 4.15: Graph of stress against strain of joints bonded for humidity test at 85°C/85RH (5 days)

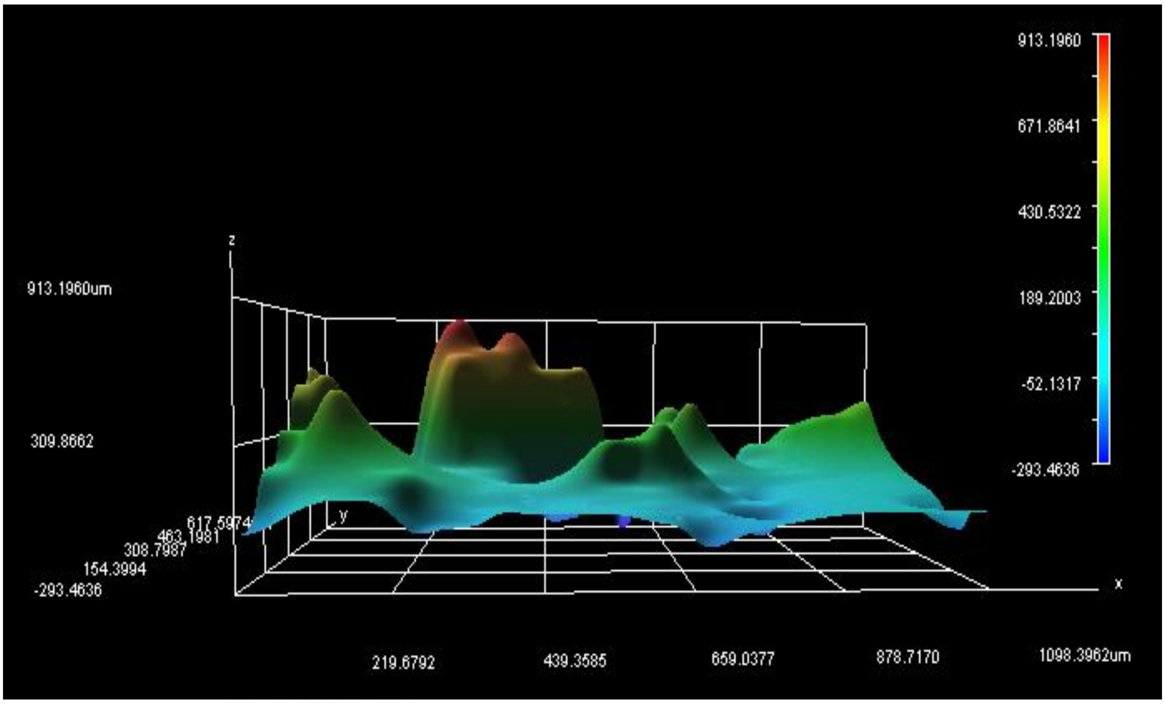

Figure 4.16: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/85RH (5 days)

4.4.4 Summary of the Humidity Test at 85℃/85RH

To summarized, the average lap shear strength will increase during high temperature and high humidity condition. Although the moisture absorption by the humidity effect should cause deterioration on the bonded joints of the adhesive, but the results of this experiment as shown in Figure 4.17 led to a higher strength in terms of the adhesive's performance itself as compared to the benchmark evaluation due to the surface roughness effect. The graph of average stress against days showed a linear trend line whereby the average stress is increased from the first day until the third day with respect to higher lap shear strength produced during high temperature and high humidity condition. However, the trend line decreased at a steady average stress during the third day to fifth day due to the environmental effect on the humidity test. Thus, the changes of lap shear strength as the time duration of exposure to high humidity increased are not significant.

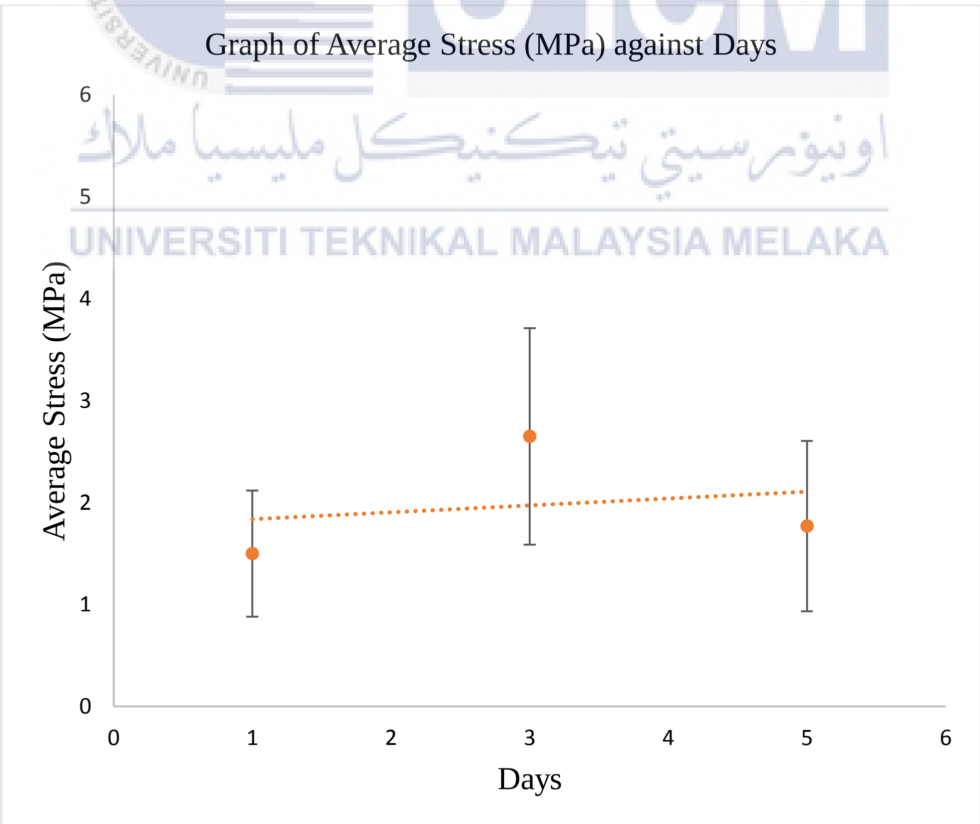

Figure 4.17: Graph of average stress against days for overall humidity test at 85°C/85RH

4.5 Analysis of Lap Shear Joint Adhesive Tensile Test and Surface Profiling at 85℃/40% Relative Humidity (RH)

During the second humidity test, the condition used in the test was 85℃/40RH by using 9 specimens within three different period which is 1 day, 3 days, and 5 days consecutively. Each condition of this humidity test will present different result based on the analysis of lap shear tensile test and surface profiling under 3D Non-Contact Surface Profilometer.

4.5.1 Humidity Test at 85℃/40RH for 1 Day

For humidity test at 85℃/40RH for 1 day, it can be recognized that each of the specimen resulted in different strength whereby the average value of lap shear strength obtained was 2.84 MPa as displayed in Table 4.8. During high temperature and low humidity condition, the shear strength of the adhesive was higher than the shear strength as compared to the humidity test at 85℃/85RH. Based on Figure 4.18, the humidity test at 85℃/40RH for 1 day showed that the highest lap shear strength of 3.05 MPa was achieved by Specimen 3. The result obtained was influenced by the lower moisture absorption due to the lower humidity condition.

Apart from that, after completed the lap shear tensile test, the specimens were analyzed under the 3D Non-Contact Surface Profilometer to investigate the surface topography of the specimens after tested under the humidity test at 85℃/40RH for 1 day. Based on Figure 4.19, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 406.7587 µm with better surface texture whereby the profile seems to be more organized in a controlled curvature. In this case, the surface texture can be assumed to be more stable in terms of amplitude parameter although the height distributions obtained was much lower than the previous result at 85°C/85RH humidity test. This can be justified that lower humidity would result in lower height distribution of the amplitude parameter.

Table 4.8: Result of tensile lap shear test for humidity test at 85°C/40RH (1 day)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	907.41	1.56	2.81	2.84
2	322.58	861.81	1.56	2.67	
3	322.58	985.18	1.69	3.05	

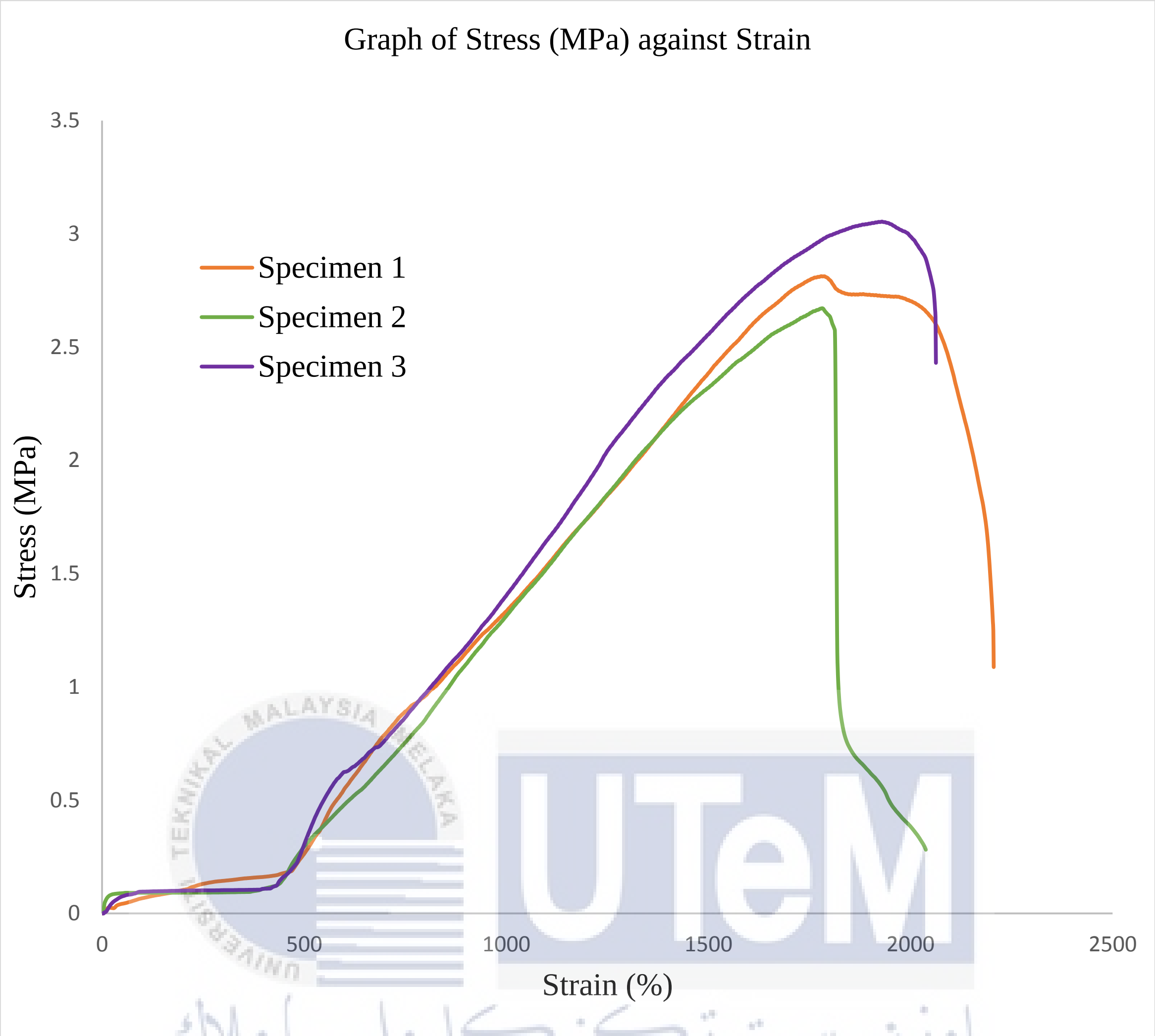

Figure 4.18: Graph of stress against strain of joints bonded for humidity test at 85℃/40RH (1 day)

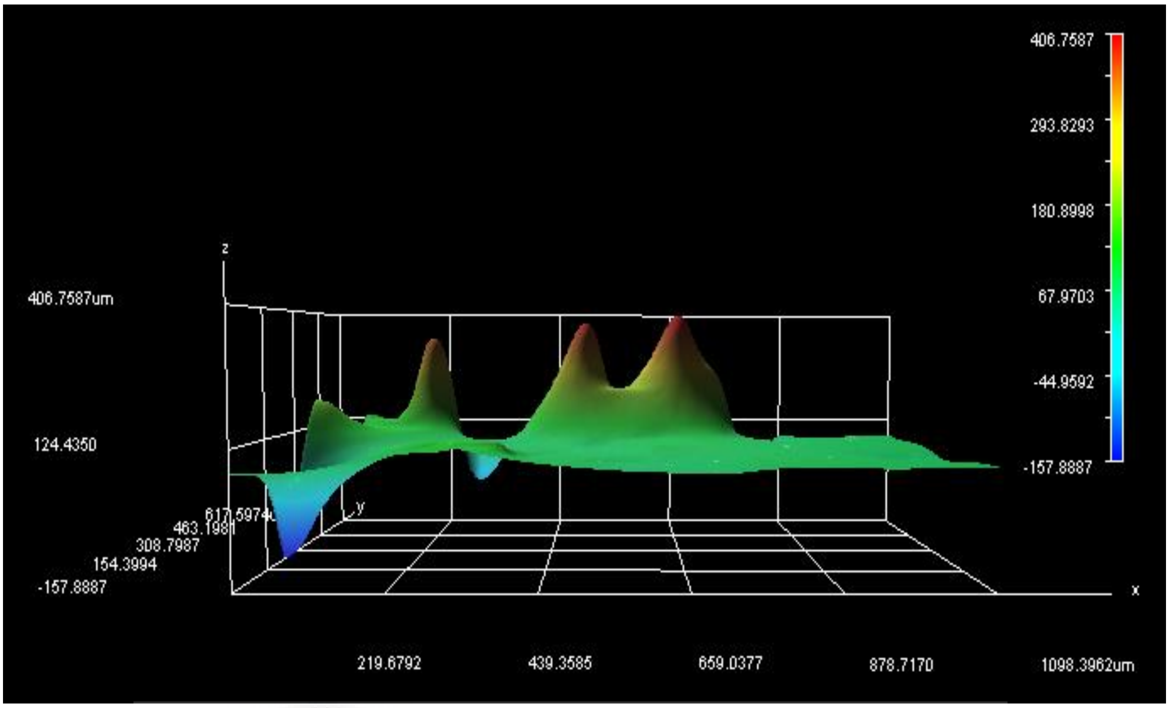

Figure 4.19: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/40RH (1 day)

4.5.2 Humidity Test at 85℃/40RH for 3 Days

For humidity test at 85℃/40RH for 3 days, it can be identified that average value of lap shear strength achieved was 3.55 MPa as displayed in Table 4.9. In this case, the shear strength of the adhesive for humidity test at 3 days much higher than the shear strength of the adhesive for humidity test at 1 day. Based on Figure 4.20, the humidity test at 85℃/40RH for 3 days illustrated that the highest lap shear strength of 3.66 MPa was achieved by Specimen 1.

This can be related with the previous result whereby the mechanical properties of joints bonded with adhesive can be influenced by environmental conditions. Besides, higher temperature will result in an elevated deterioration of the adhesive layer [20]. However, in this experiment, higher temperature with lower humidity caused an increment of shear strength due to less moisture was absorbed in low humidity condition.

In addition, the surface topography of the specimens after tested under the humidity test at 85℃/40RH for 3 days were also investigated after completed the lap shear tensile test. Based on Figure 4.21, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 465.8275 µm with a minor inconsistency in the design of that surface texture. The height distributions obtained was greater than the previous height distributions for 1 day analysis within the same humidity condition. In terms of height distribution, the effect of low humidity led to more consistent and controlled value of height distribution itself. Thus, it can be concluded that the shear strength of the specimens would be increased with lower humidity condition as well as improved the stability of the surface profile itself.

Table 4.9: Result of tensile lap shear test for humidity test at 85°C/40RH (3 days)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	1182.09	1.55	3.66	3.55
2	322.58	1102.17	1.83	3.42	
3	322.58	1150.81	1.76	3.57	

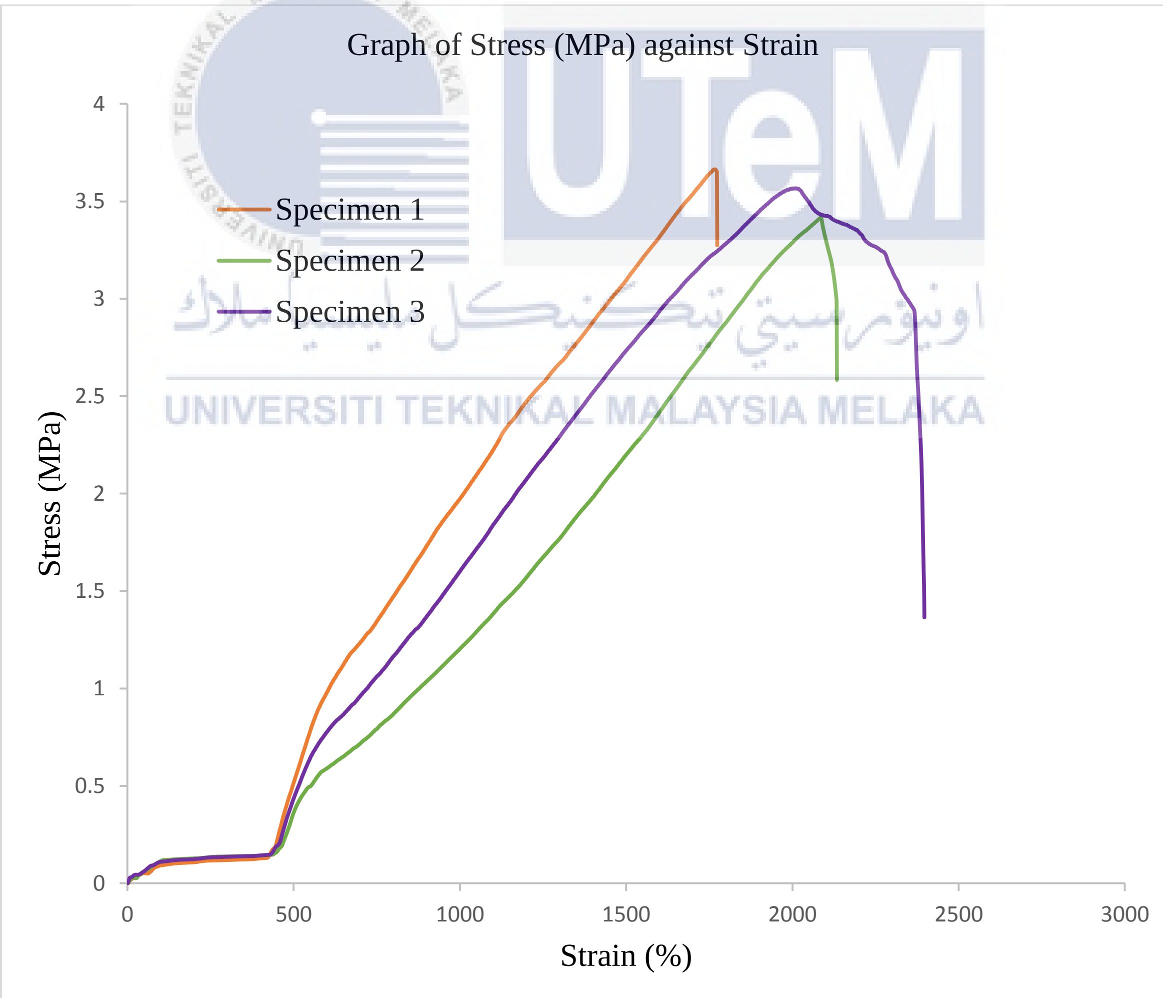

Figure 4.20: Graph of stress against strain of joints bonded for humidity test at 85°C/40RH (3 days)

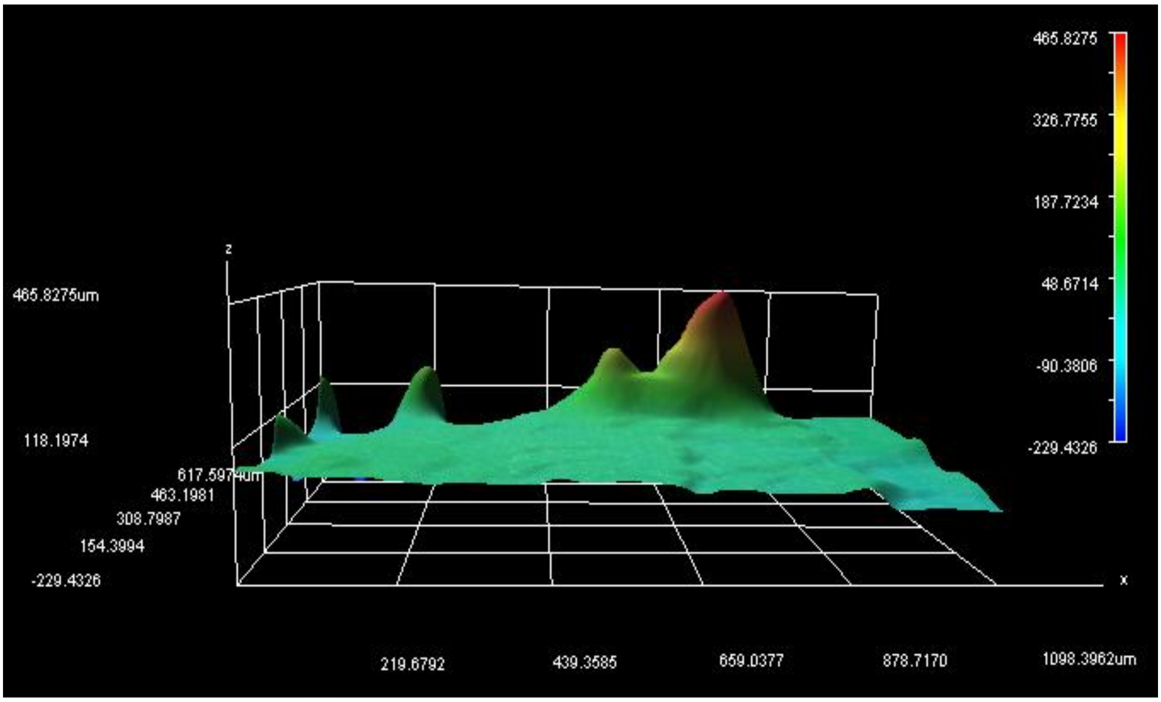

Figure 4.21: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/40RH (3 days)

4.5.3 Humidity Test at 85℃/40RH for 5 Days

For humidity test at 85°C/85RH for 5 days, it showed that average value of lap shear strength achieved was 4.80 MPa as displayed in Table 4.10. In general, the shear strength of the adhesive for humidity test at 5 days was higher than the shear strength of the adhesive for humidity test at 3 days. Based on Figure 4.22, the humidity test at 85℃/40RH for 5 days illustrated that the highest lap shear strength of 5.90 MPa was achieved by Specimen 2.

Apart from that, the results of the lap shear strength showed a deviation of value within 3 different duration of testing due to environmental effect occurred on the specimens for 5 days of humidity test. However, the average value obtained from each condition did not influenced the performance of the adhesive's durability since it is still in compliance with the theory of adhesive properties whereby lower humidity would contribute in higher shear strength.

Besides, the surface topography of the specimens after tested under the humidity test at 85℃/40RH for 5 days were also observed after completed the lap shear tensile test. Based on Figure 4.23, it can be analyzed that the maximum average peak-to-valley height (Rz) is about 73.8765 μm with irregularities pattern on the surface curvature. The height distributions obtained was much lower than the previous height distributions for 3 days analysis due to the environmental effect which led to instability of the surface profile for the tested specimens.

Table 4.10: Result of tensile lap shear test for humidity test at 85°C/40RH (5 days)

No. of Specimen	Area (mm^2)	Max Force (N)	Elongation @ Peak (mm)	Lap Shear Strength (MPa)	Average Lap Shear Strength (MPa)
1	322.58	1644.77	1.75	5.10	4.80
2	322.58	1903.77	1.95	5.90	
3	322.58	1097.27	1.44	3.40	

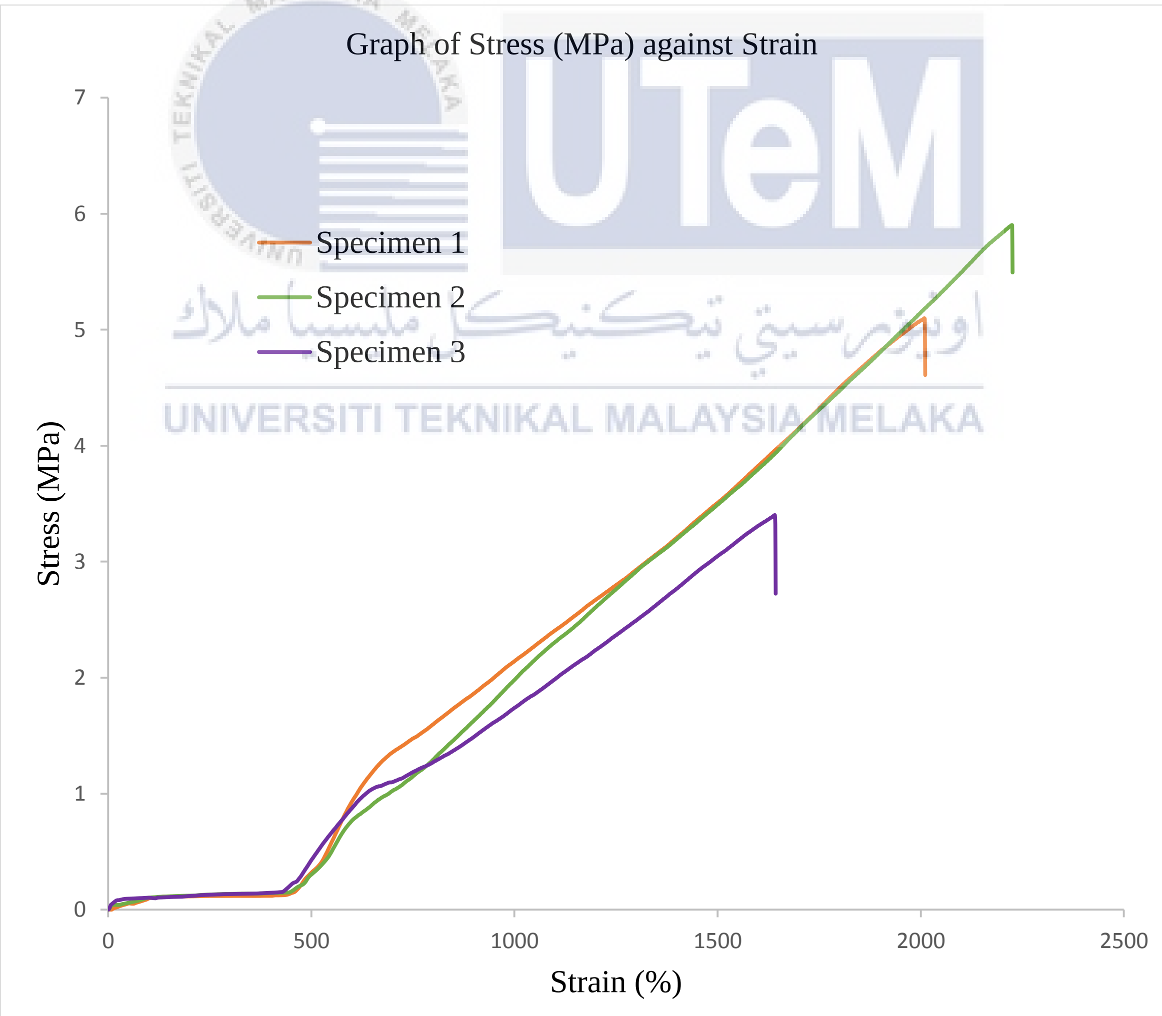

Figure 4.22: Graph of stress against strain of joints bonded for humidity test at 85°C/40RH (5 days)

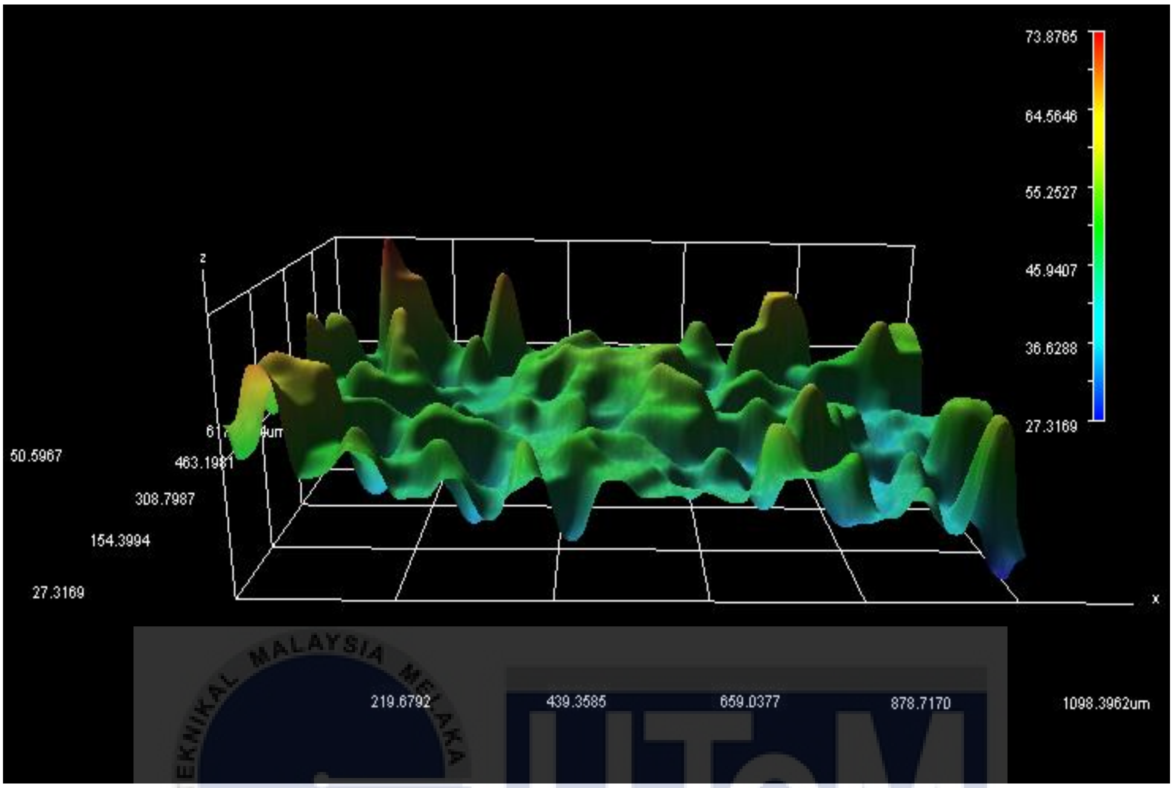

Figure 4.23: Surface topography after lap shear tensile test of joints bonded for humidity test at 85℃/40RH (5 days)

4.5.4 Summary of the Humidity Test at 85℃/40RH

To summarized, the average lap shear strength will increase during high temperature and low humidity condition. During low humidity condition, there would be less moisture absorption by the adhesive joints. Thus, as shown in Figure 4.24, the results of this experiment led to much higher strength in terms of the adhesive's performance itself as compared to the results of the humidity test at 85°C/85RH in the previous section. The graph of average stress against days showed an increased linear trend line whereby the average stress is increased from the first day until the fifth day with respect to higher lap shear strength produced during high temperature and low humidity condition.

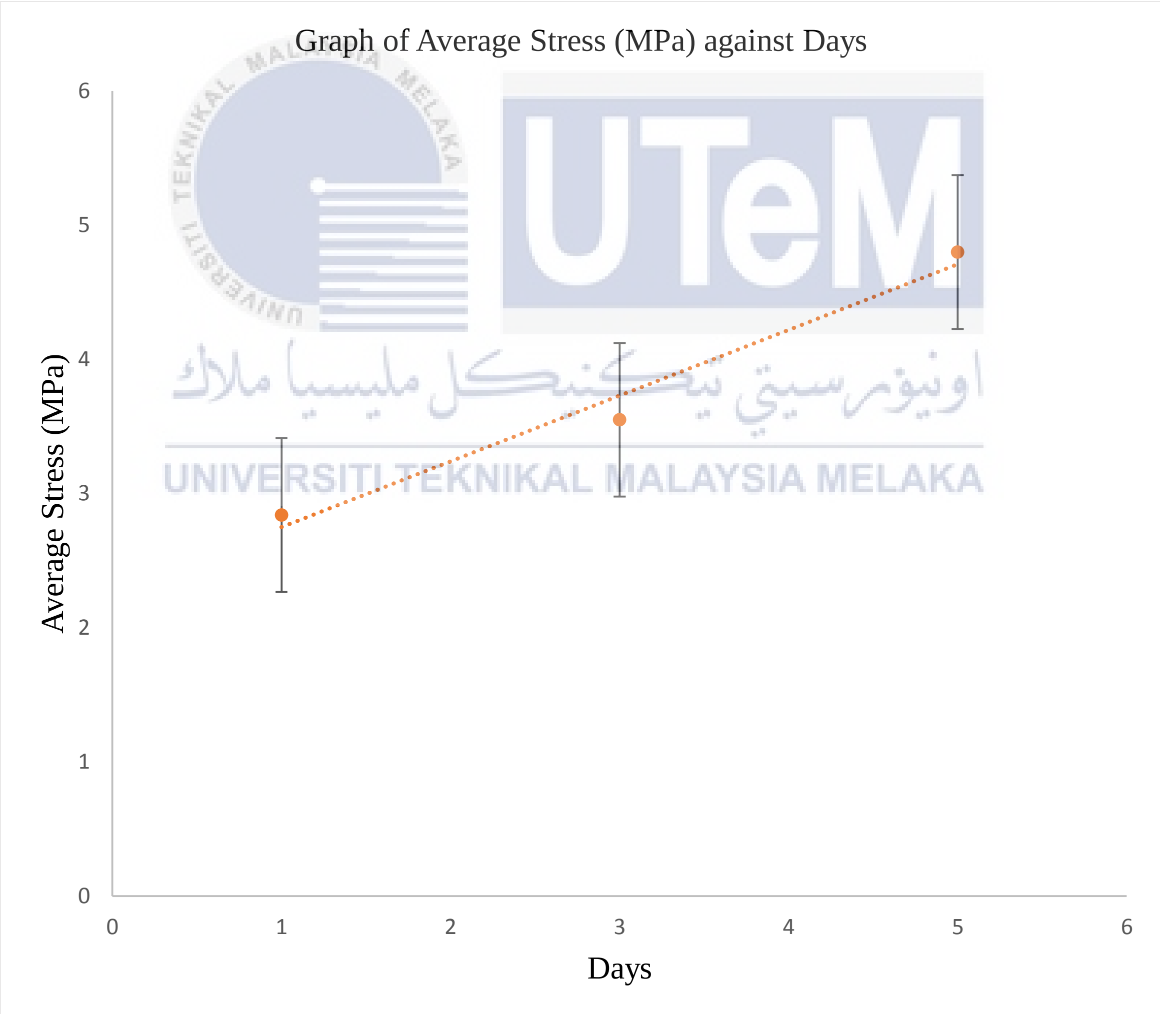

Figure 4.24: Graph of average stress against days for overall humidity test at 85°C/40RH

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusion

This project has been successfully carried out by achieving its objectives in terms of characterization and mechanical properties of adhesive bonding and surface profiling of the adhesive bonding. The first objective of this research is to investigate the effect of humidity on the mechanical performance of joints bonded with electrically conductive adhesive. The humidity condition are set to be at 85°C/85RH and 85°C/40RH within three different duration of testing which are 1 day, 3 days, and 5 days respectively. To analyze the effect of humidity, there are a few methodologies used during the experimental process such as preparation of specimens, preparation of electrically conductive adhesive, and tensile lap shear test.

From the analysis of results, it can be observed that the lap shear strength was improved using surface treatment method. At high humidity condition, when the time duration of exposure increased, the changes of lap shear strength occurs are not very significant. Meanwhile, at low humidity condition, when the time duration of exposure increased, the lap shear strength exhibits an increment. In comparison between high and low humidity condition, higher lap shear strength were obtained at low humidity condition as compared to high humidity condition. Thus, it can be concluded that humidity factor will lead to higher shear strength depends on the type of adhesive used together with the effect of surface roughness.

The second objective of this research is to examine the surface profiling of adhesive bonding taken under 3D Non-Contact Surface Profilometer. The value of roughness amplitude is accounted in this evaluation of surface topography. Besides, it also focuses on the height distribution of the surface in order to analyze the characteristics of adhesively bonded joints. From the analysis of surface profiling, it can be identified that humidity factor will result in different surface textures depends on the shear strength developed from the mechanical properties of adhesive itself.

Apart from that, based on the surface topography, it can be analyzed that during high temperature and high humidity condition (85°C/85RH), the height distributions of surface topography increased as the time duration of exposure to high humidity increased. When the peak of height distribution is high, the lap shear strength obtained is low. This results in ductility on the mechanical properties of joints. Meanwhile, during high temperature and low humidity condition (85°C/40RH), the height distributions of surface topography decreased as the time duration of exposure to low humidity increased. When the peak of height distribution is low, the lap shear strength obtained is high due to the less moisture absorption by the electrically conductive adhesive joints. This caused the mechanical properties of joints to be more brittle.

5.2 Recommendations for Future Research

In this research, the scope of the project only focuses on the characterizations of mechanical properties of electrically conductive adhesive conducted under various humidity level at certain space. However, the results of the research could be improved by using a few suggestions for further research in this field. For example, the effect of surface roughness in this research was justified in enhancing the shear strength of the adhesive. Thus, for future research, it is recommended to improve the effect of surface roughness by using different techniques instead of mechanical abrasion method. Besides, to clarify the trend of results in the analysis of lap shear strength, it is recommended to increase the time duration of exposure to humidity conditions in order to get more date for further analysis. Apart from that, in terms of formulated adhesive as prepared in this project, the future works should identify the composition ratio of the adhesive with different mix ratio to get variation of results in the mechanical performance of adhesive.

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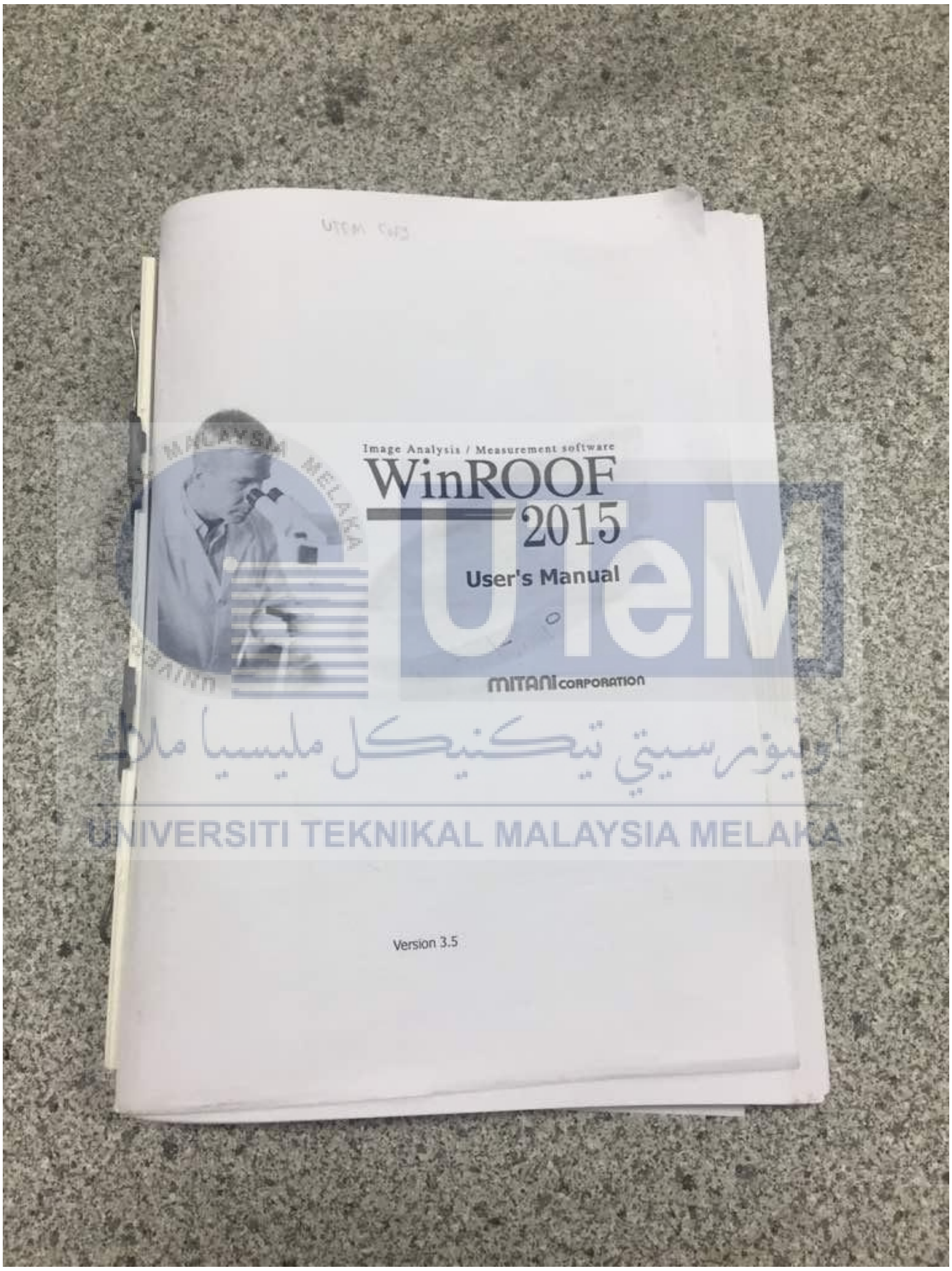
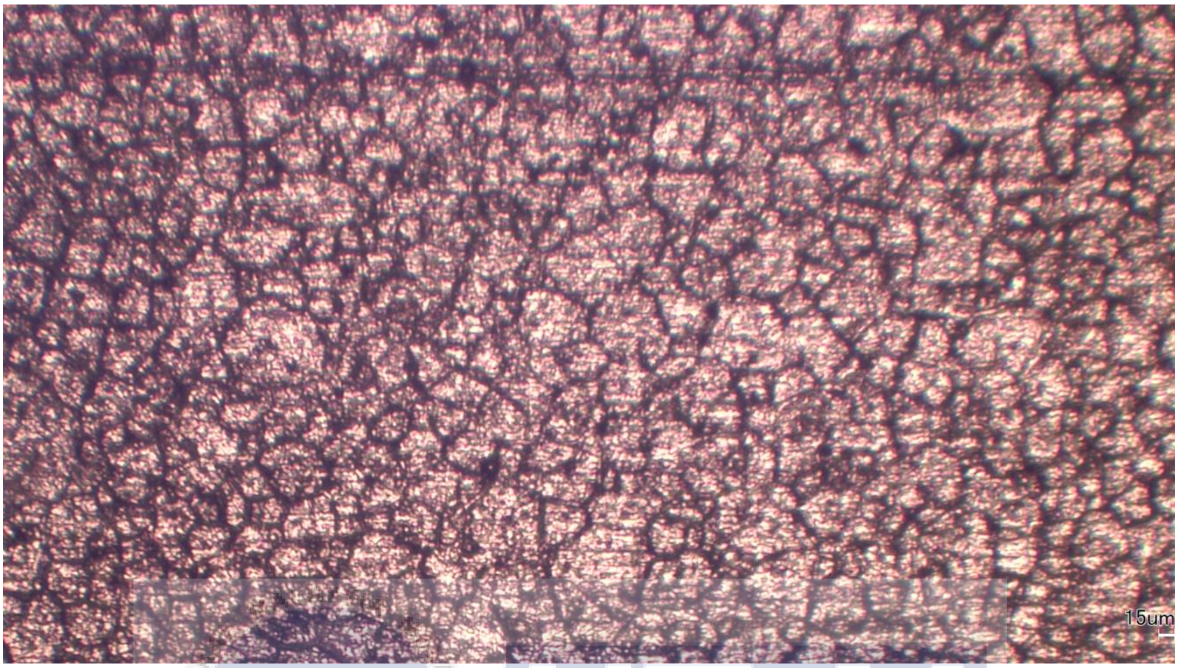
APPENDICES

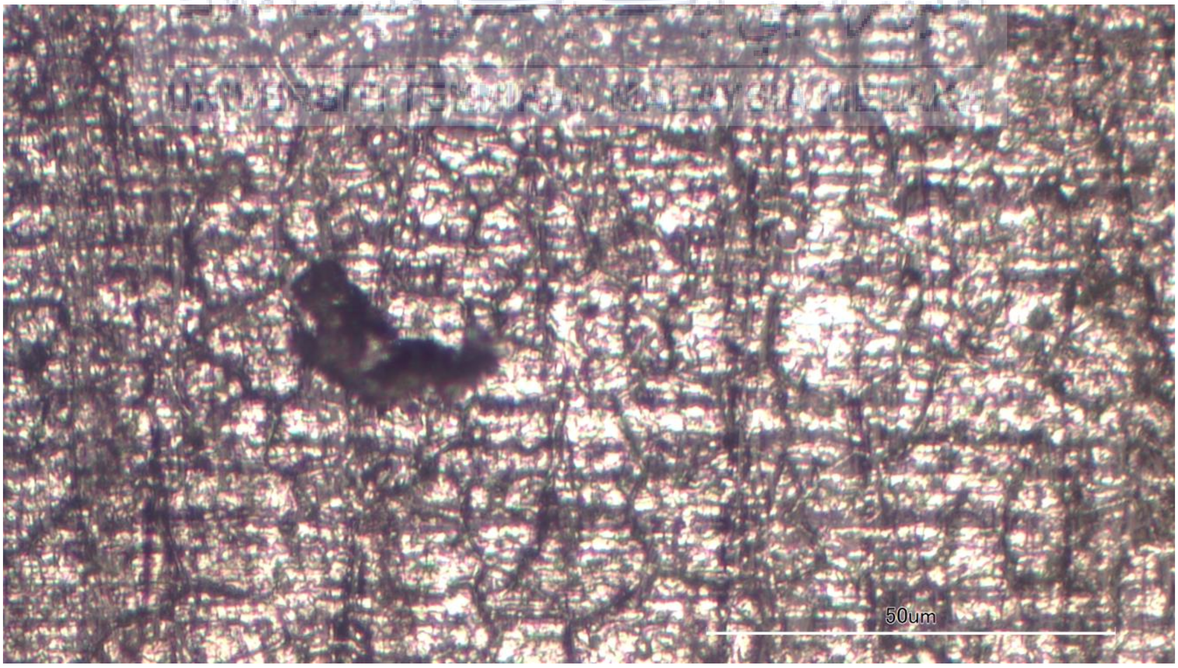
A. Image analysis / measurement software WinROOF 2015 user's manual



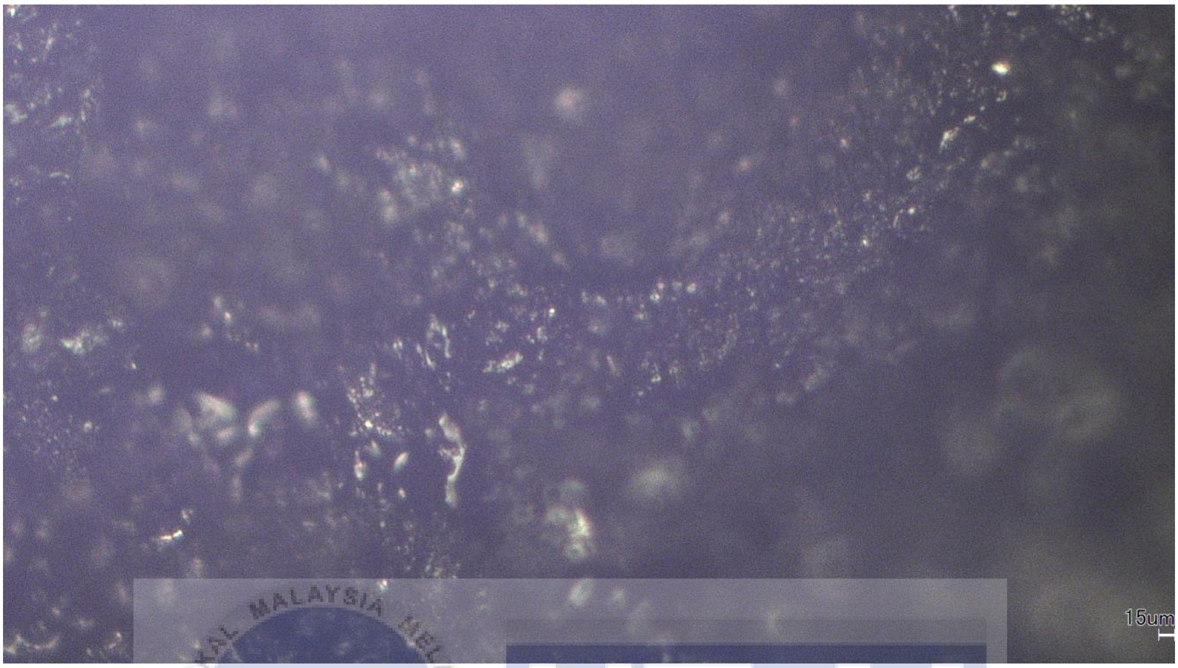
B. Surface image for specimens before surface treatment process



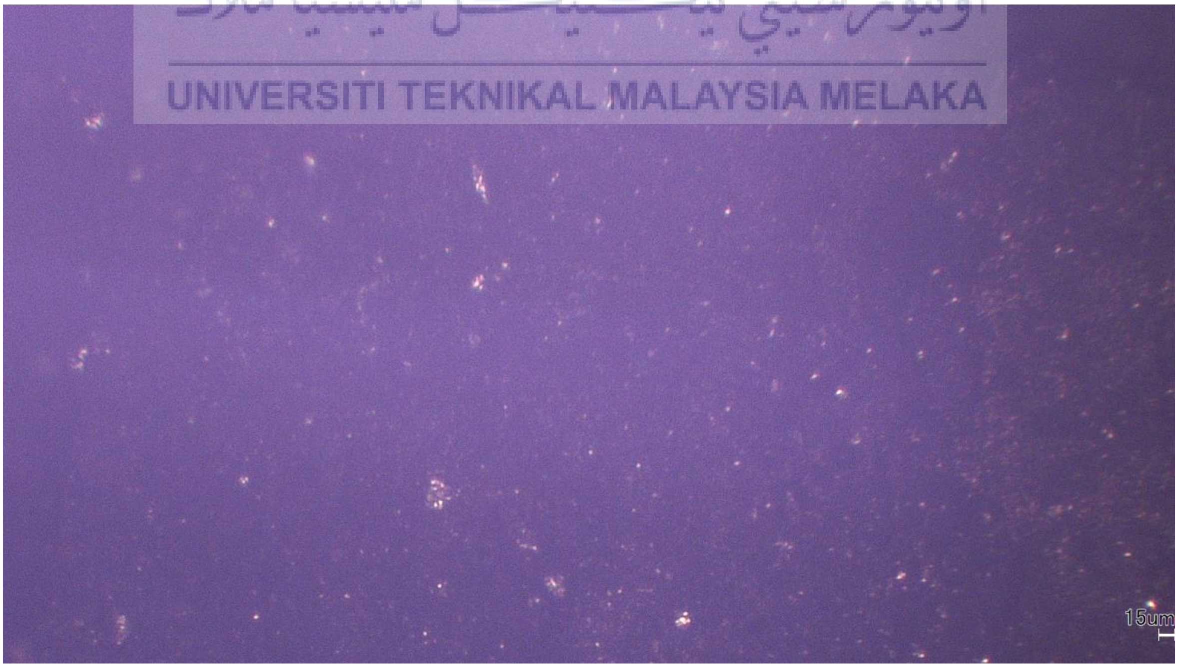
C. Surface image for specimens after surface treatment process



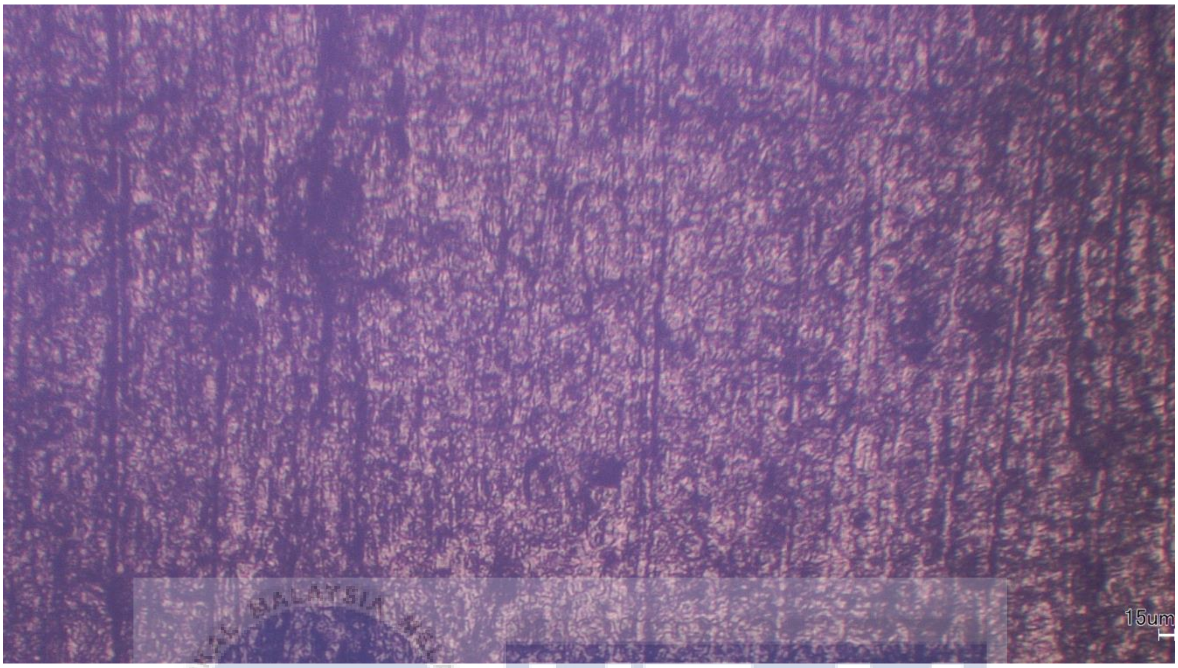
D. Surface image for specimens tested under room temperature



E. Surface image for specimens tested under 85℃/85RH



F. Surface image for specimens tested under 85°C/40RH



G. Sample of specimen's fracture after tensile lap shear test