LAYER ADHESION INVESTIGATION OF 3D PRINTER PLATFORM

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in fulfillment of the requirement for the degree of
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DECLARATION

I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged.

Signature : ....
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Date : ....

SUPERVISOR DECLARATION

I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for award of the degree of Bachelor of Mechanical Engineering (Design and Innovation).

Signature : ....

Name : Dr Faiz Redza Bin Ramli

Date : ....

DEDICATION

My beloved mother and father

My dearest siblings and fiancé

ABSTRACT

Three-dimensional (3D) printer is a machine used to generate product in 3D drawing using application such as CATIA. This process is also known as additive manufacturing (AM). 3D printer uses heating process to squeeze out melted filament which used to print a product. In printing process, the filament is printed on a platform which applied with certain type of adhesive. This adhesive act as medium to hold the specimen printed. Many type of adhesive had been used in this process which divided into two part which are synthetic and bio adhesive. The use of bio-based adhesive in 3D printing is starting to grow but there are still flaws in the process. In order to overcome this flaws, many research and investigations that can be carry out in order to study in details the problems occur and how to overcome it. One of the highlight problem in this research is warping deformation which occur during printing process on the first layer of specimen. The vertexes of the specimen tend to warp and cause deflection at the side of the specimen. New mixture of plant-based bio adhesive was invented and experimented with the ability of reducing warping deformation while holding the natural friendly criteria of adhesive. In warping deformation, printing using bio based adhesive resulted lower value of vertexes compared to synthetic adhesive. Aside of producing new mixture of plant-based bio adhesive, the viscosity of the adhesive also been investigate in order to ensure that this mixture is suited to be used in 3D printer application. Provided that a new mixture had been done, comparison between the available adhesive which is UHU glue as synthetic adhesive was made in order to identify which adhesive has the strongest criteria of adhesive. This comparison was done by going through tensile test using Universal Tensile Machine Dynamic 8872. From all the result obtained, it is concluded that synthetic adhesive shows the highest strength for tensile test compared to bio adhesive. In overall result, synthetic adhesive is stronger than bio adhesive.

ABSTRAK

Pencetak tiga dimensi (3D) adalah mesin yang digunakan untuk menjana produk dalam lukisan 3D menggunakan aplikasi seperti CATIA. Proses ini juga dikenali sebagai bahan tambahan pembuatan (AM). Pencetak 3D menggunakan proses pemanasan untuk mengeluarkan filamen cair yang digunakan untuk mencetak produk. Dalam proses percetakan, filamen dicetak di atas platform menggunakan jenis pelekat yang tertentu. Tindakan pelekat sebagai medium untuk memegang spesimen yang dicetak. Banyak jenis pelekat telah digunakan dalam proses ini yang dibahagikan kepada dua bahagian iaitu pelekat sintetik dan bio. Penggunaan pelekat berasaskan bio dalam percetakan 3D mula berkembang tetapi masih terdapat kelemahan dalam proses ini. Dalam usaha untuk mengatasi kelemahan, banyak kajian dan penyiasatan yang boleh menjalankan untuk mengkaji dengan terperinci masalah berlaku dan bagaimana untuk mengatasinya. Salah satu masalah kemuncak dalam kajian ini adalah ubah bentuk meleding yang berlaku semasa proses mencetak pada lapisan pertama spesimen. Bucu spesimen cenderung untuk meleding dan menyebabkan pesongan ditepi spesimen. Campuran baru berasaskan tumbuhan pelekat dicipta dan dieksperimen dengan keupayaan untuk mengurangkan ubah bentuk meleding sambil mengekalkan kriteria pelekat yang mesra alam. Dalam ubah bentuk meleding, mencetak menggunakan pelekat berasaskan bio memberikan nilai yang lebih rendah berbanding pelekat sintetik. Selain menghasilkan campuran baru berasaskan tumbuhan bio pelekat, kelikatan pelekat juga telah disiasat untuk memastikan bahawa campuran ini adalah sesuai untuk digunakan dalam penggunaan pencetak 3D. Dengan syarat bahawa campuran baru terjadi itu, perbandingan antara pelekat sedia ada iaitu gam UHU sebagai pelekat sintetik telah dibuat untuk mengenal pasti pelekat mempunyai kriteria pelekat yang kuat. Perbandingan ini dilakukan dengan melalui ujian tegangan menggunakan Universal tegangan Mesin Dynamic 8872. Dari semua keputusan yang diperolehi, dapat disimpulkan bahawa pelekat sintetik menunjukkan kekuatan tertinggi untuk ujian tegangan berbanding pelekat bio. Dalam keputusan keseluruhan, pelekat sintetik adalah lebih kuat berbanding pelekat bio.

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LIST OF ABBREVIATIONS

AM	Additive Manufacturing
FFF	Fused Filament Fabrication
ABS	Acrylonitrile-Butadiene-Stryene
PLA	Polylactic Acid
STL	Stereo Lithography
SLA	Stereo Lithography Apparatus
FDM	Fused-Deposition Modeling
CAM	Computer-Aided Manufacturing
LOM	Laminated-Object Manufacturing
SLS	Selective Laser Sintering
DTM	Desk Top Manufacturing
PE	Polyethylene
PEI	Polyetherimide
PC	Polycarbonate
PS	Polystyrene

LIST OF SYMBOL

c	=	Damping coefficient
ξ	=	Damping ratio
F_e	=	Excitation force
E	=	Modulus of elasticity
ε	=	Strain
σ	=	Stress

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

3D printer is also known as additive manufacturing (AM) which used to generated product in three-dimensional using three-dimensional Computer Aided Design software (3D CAD). The product producing process only consists of direct fabrication without any process planning due to the simplification done by the AM technology (Gibson, Rosen, & Stucker, 2010). 3D printing or AM technology nowadays uses a process called fused filament fabrication (FFF). Heated plastic filament squeezed out through a nozzle. This heated filament melt down and from the nozzle, layers by layers part were made with each layer as a thin cross-section. This cross section is derived from the original data produced using CAD. The cooled filament then form a solid object after it fuse together to form strong bond. Producing good three-dimensional product affected by certain characteristics such layer thickness, the material used, bonding process of layers and time taken for each production (Evans, 2012).

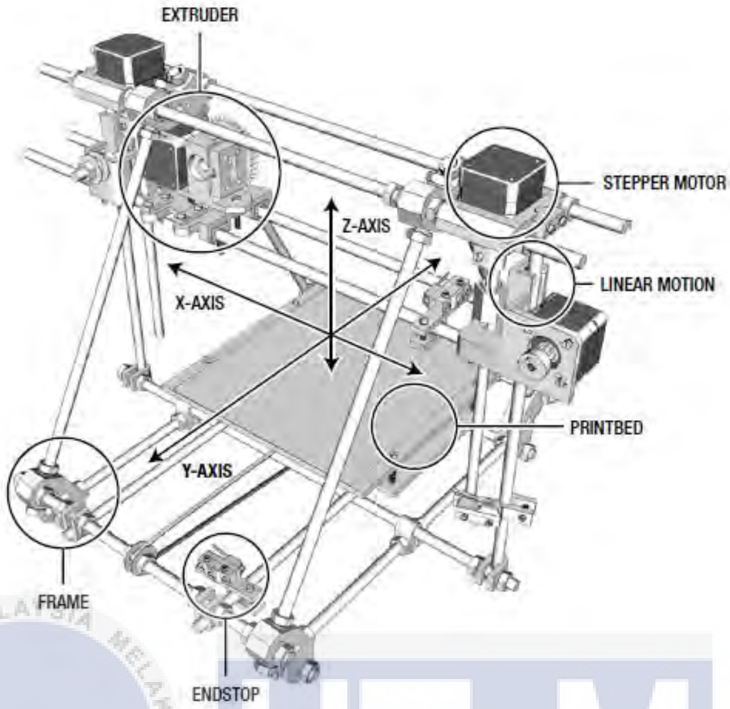


Figure 1.1: 3D printer's parts

Fused Deposition Modelling (FDM) is on the most used extrusion-based from the AM technology. FDM uses filament which was a polymer that been liquidize through a heating chamber. Parts or products produced using FDM are one of the strongest polymer parts due to the range of material used and effective mechanical properties of the parts produced. FDM machine can be used to produce wide range of applications including functional testing models. It operated with different layer of thickness produce from different diameters of nozzle. This nozzle is changeable according the diameter needed for specific build. This machine is widely used and the common material chosen for it process is ABS (acrylonitrile butadiene styrene). According to Stratasys data sheet, apart from using ABS, ABSi, ABSplus and ABS/PC also can be used as side materials due to it characteristics that fulfilling the requirements for FDM machine (Gibson, Rosen, & Stucker, 2010).

In 3D printing process, layer adhesion is the bond between the first layers of product printed with the platform of the printer. Platform or print bed is where the layers of material printed to produce a solid product. Platform need to provide better adhesion in order to avoid or reduce the possibilities of damage to the product. Among problems related to the layer adhesion on platform is warping. Warping is where the underside part of the product bend producing curve corner due to lack of adhesion and also the cooling process happened too quickly. Nowadays, the available solution is by applying glue stick on the platform or covered it with tape. The tape uses mostly made of mixture chemical such as polyimide tape and polyester silicon tape. Other than synthetic adhesive, plant-based bio adhesive also available which more futuristic if 3D printing process will be used in different kind of industry such as printing food using 3D printing in food industry.

Figure 1.2: Warping

1.2 PROBLEM STATEMENT

The material chosen for the experiment are PLA and ABS. During printing process, those filaments tend to make problems when it is extruded from nozzle. The layers produce tend shrink or producing warping at the underside part. This shrinking and warping will then cause the first layer that should be in contact with the platform to be improperly adhesive to the platform. The curving at the underside will cause the product to be differs than the design that already been decided and the production process will be a failure. The structure of the product will also be disturbed due to problem with the first layer of product.

Warping is one of the most common problems happen related to the adhesion problem. Warping may occur due to factors like barometric pressure, humidity and temperature. In this project, warping problem is investigated relating to how adhesion on platform will cause it. Mostly, method such as applying tape and synthetic glues is done to ensure that warping does not happen. This method shown that is functional but a more natural friendly material need to be used. Hence, a plant-based bio adhesive will be purpose to replace those synthetic adhesive.

1.3 OBJECTIVE

The objectives of this project are as listed:

1. To produce new mixture of plant-based bio adhesive.
2. To investigate the viscosity characteristics of plant-based bio adhesive in 3d printer application.
3. To make a comparison between the synthetic adhesive and plant-based bio adhesive in 3d printer application.

1.4 SCOPE OF PROJECT

The scopes of this project covers:

1. The type of 3D printer used in this project is low cost 3D printer.
2. Types of materials used for the filament printing testing are ABS and PLA.
3. The strength of the bio adhesive will be measured at the first layer of 3D printer part.

CHAPTER 2

LITERATURE REVIEW

2.1 Rapid Prototyping

Rapid prototyping is one of the modern process used to fabricate prototypes using computer-aided design (CAD) as the base design. This process tends to be choose due to its fabrication process that used lesser time compared to traditional methods. The availability of rapid prototyping is due to the demand of using physical model instead of drawing of design. Rapid prototyping divided into two types which are material removing manufacturing and additive manufacturing or also called three-dimensional printing (Groover, 2010). In general, material removing is where the material cut in order to shape the product. Among the processes involve are drilling and milling whether using conventional or non-conventional machine. In this project, focusing on additive manufacturing, it divided into three prototyping systems which are: -

i. Liquid-Based Rapid Prototyping.
ii. Solid-Based Rapid Prototyping.
iii. Powder-Based Rapid Prototyping.

2.1.1 Liquid-Based Rapid Prototyping

Liquid-based rapid prototyping is one of the rapid prototyping technology which also known as Vat Photo Polymerization. In 1980, Charles (Chuck) Hull discovered that solid polymer patterns could be produced using layer by layer process which give the idea of stereo lithography technology. It is call liquid-based due to the material state that been used in this process which is full liquid without melting solid process. The material that is commonly used is photopolymer. There are few processes that involve in the liquid-based process which have been selected to be focused on: (1) stereo lithography and (2) solid ground curing.

2.1.1.1 Stereo Lithography (STL)

Stereo lithography which also known as STL is a common rapid manufacturing and prototyping technology. STL was discovered around 1986 by the same inventors that had found the liquid-based rapid prototyping technology, Charles W. Hull. This system was first exposed to the world by 3D Systems, Inc around 1988 which has been awarded with international patents. This process had been widely used in liquid-based 3D-printing which involve in the use in ultra violet (UV) light and photopolymer, type of resin to initiate the photopolymerization. Photopolymerization is a process at which resin undergo a chemical reaction to become solid when they were irradiated by UV range of wavelength. Process of photopolymerization perform a cross-linked which will give advantages in 3D-printing as it will not melt during the process.

Stereo lithography apparatus (SLA) is the device used for the stereo lithography process. It consists of platform that can be moved vertically in order to be dipped into the resin placed inside a container. This platform is supported by an elevator that moved it upward and downward during the curing process by laser beam. Type of laser uses for the process is UV ray which will be directed during the curing process. This beam can be move in x-direction and y-direction. The process involve in the use of photo-curable liquid resin where the parts build in a vat fill with it and solidified layers by layers starting from the first layer by exposing it to laser radiation.

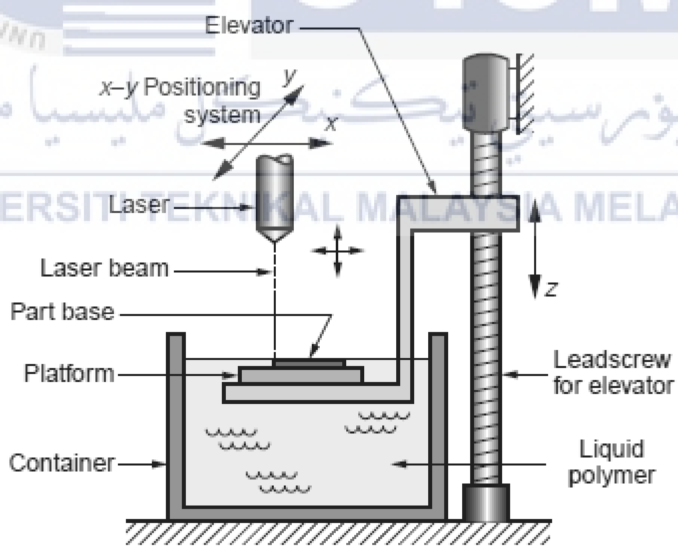


Figure 2.1 Stereo lithography apparatus (SLA)

Processes involve in stereo lithography are: -

i. The product drawn in three-dimensional software such as CATIA or SolidWorks in CAD data which then converted into STL file.
ii. Proprietary software is used to slice the model into a series of fine layers, with support structures.
iii. The STL file is then sent to print on the Stereo Lithography (STL) machine.
iv. Initially, the build platform is deep about 0.05 mm to 0.15 mm into liquid resin bath to form the first layer.
v. Using a UV laser beam, the first cross section of the STL file is traced out onto a platform, placed within the vat of photo-curable resin. This resin will harden as it meets the laser.
vi. Once the first layer has been completed, the platform is lowered by 0.05 mm to 0.15 mm with a fresh layer of resin covering the build surface.
vii. The next layer is then traced out, curing and bonding the resin to the layer below.
viii. The stereo lithography process repeats layer by layer until the model and any support structures are "fully grown" in the resin.
ix. Once complete the platform is raised, allowing excess resin to drain away before the model is removed from the platform.

2.1.1.2 Solid Ground Curing

Solid ground curing is one of the system that using liquid-based rapid prototyping system. This process is registered as Solider system under Cubital Ltd. which began in 1987 which placed in Israel. Various types of resin used in the solid ground process including liquid resin. Solid ground curing uses the same concept as in stereo lithography which is solidified using UV light but only through mask. By through mask means this process uses laser beam to create mask according to the design wanted. The UV light exposed by electrostatically charging the surface of liquid polymer producing hardened part based on the mask placed. Using solid ground curing system, it produces its own support through the wax used during the building process. This wax is a support for the overhanging or fragile parts during fabrication process. As stated, solid ground curing process uses the same process as stereo lithography which uses computer-aided design model as its data to produce product. It also does not need any post curing process.

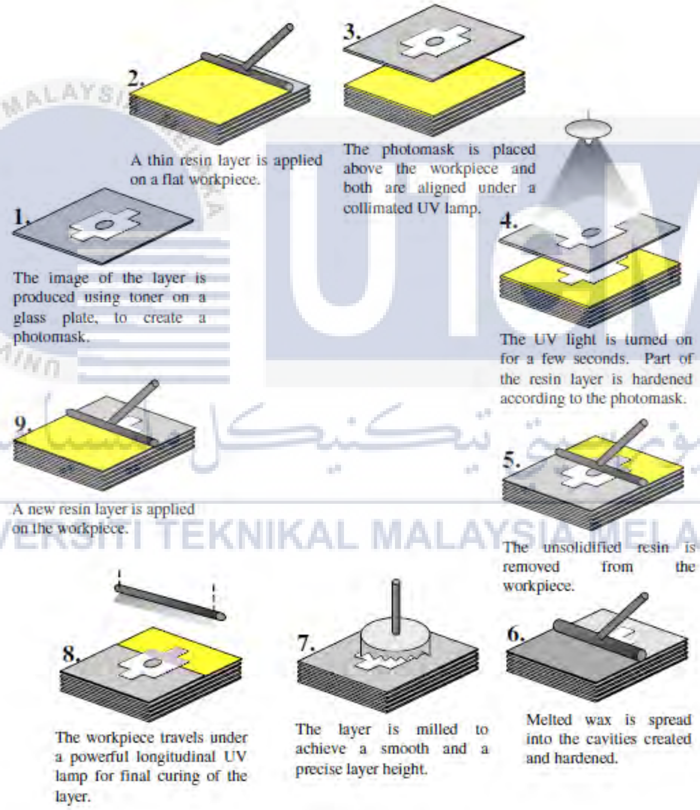


Figure 2.2 Solid ground curing process

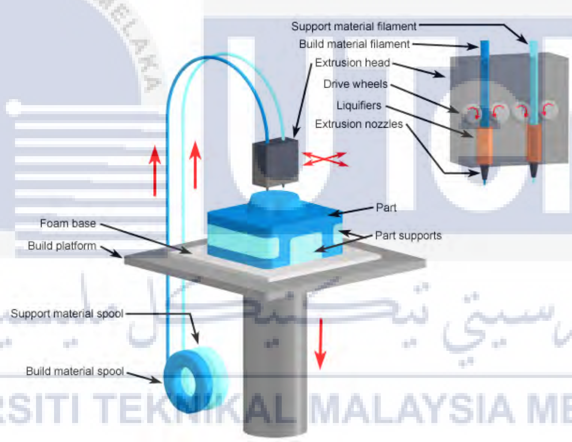
2.1.2 Solid-Based Rapid Prototyping

Solid-based rapid prototyping is one of the rapid prototyping process that uses all type of materials which in solid form as its starting material. Among this materials are wire and sheet. This material undergoes melting and solidification before being used for the building process. There are few processes that involve in the solid-based process which have been selected to be focused on: (1) fused-deposition modeling and (2) laminated-object manufacturing.

2.1.2.1 Fused-Deposition Modelling (FDM)

Fused-deposition modelling is one the most common technology used in 3D printing system. 3D printer with fused-deposition modelling technology is widely used and placed in most institutions due to its ease of material changing and the system produce minimal wastage. In general, fused-deposition modelling is an additive process which producing product by laying down material in layers. Fused-deposition modelling involve in depositing melted filament with various option of material onto a platform to form a layer. The molten material will immediately harden after it been extruded from the nozzle. Materials that usually used in this technology are acrylonitrile-butadiene-styrene (ABS) and polylactic acid (PLA). This materials have wide range of colour choices. Stratasys Inc. is one of the company that produce many products or machines that uses fused-deposition modelling as its base technology. This technology was first developed by Scott Cramp in the late 1980s which lead to the exposure of fused-deposition modelling technology and discovered of the company in 1989.

Fused-deposition modelling also uses CAD data that converted into STL file as it design data. This CAD data can be generate using various software such as CATIA and SolidWorks. Converted file will be transfer into the system to undergo slicing process before the building process started. Workhead of the system hold the nozzle used to extrude the molten filament. This workhead can be move in x-direction and y-direction during the material extrusion and in z-direction to build next layer on top of existing parts. Nozzle of the machine is numerically control by computer-aided manufacturing (CAM) software which acts as a controller of tools by giving instructions in coding. Building process started by depositing layer by layer of material from the bottom to the top.



2.3 Deposition of material through nozzle

The nozzle consists of heaters which function as temperature control. The temperature of material will be kept above the melting point to keep in term of molten state. This is to ensure the ease of depositing it during building process. Referring to Figure 2.3, the platform will lower down after a layer had been fully formed to start another layer of product. Accuracy of product produce using FDM technology is mainly depends on the extruder die diameter which refer to the size of the extrusion. Comparing FDM to SLA, the properties for material used in FDM technology does not change with environmental exposure which lead to strength and toughness that can be retain no matter the environment exposed.

2.1.2.2 Laminated-Object Manufacturing (LOM)

In general, laminated-object manufacturing (LOM) involve in cutting and joining method. In details, laminated-object manufacturing is a process where series of adhesive-coated sheets stack together by layers to be bond. The sheets then cut by using laser beam according to the design created in 3D software. Materials that can be used in the laminated-object manufacturing process is in sheet shape such as paper or plastic. There are three phases involve in this process which are pre-processing, building and post-processing. Pre-processing is where the data required was designed using 3D software which then converted into STL file. This file will be imported into the machine to undergo slicing process which covered sorting the data to be inserted.

In building process, new layer will be create by tracing the dimension from the CAD data on top of the sheet using laser beam but first, the sheet will be rolled using a heated roller. This roller is to laminate the new sheet onto other existing sheets. All the excessive or unwanted part will also be remove using the laser. This unwanted may be used as a support for the product. The platform that had been placed with the new layer from the previous cutting will lower down and new sheet will be placed on top to be process in the same ways. This process will be repeated until the product is completed. The last phase is post-processing where the finishing process is undergoes. LOM process may consume fewer build time compare to other processes and have high precision in its final product but parts produce by this system have weakness in its strength and have problem to withstand uncontrolled mechanical loading.

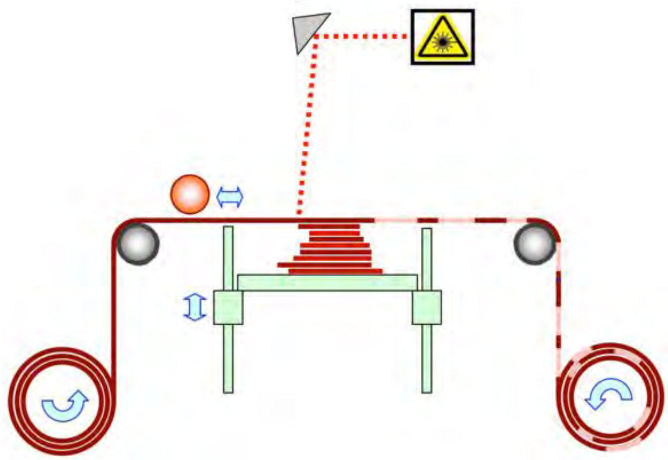


Figure 2.4 Laminated-object manufacturing

2.1.3 Powder-Based Rapid Prototyping

Powder-based rapid prototyping is one of the part in rapid prototyping. It named after the starting material used which is powder that is based on solid state but process into grain-like form. There are few processes that involve in the powder-based process which have been selected to be focused on: (1) selective laser sintering.

2.1.3.1 Selective Laser Sintering (SLS)

Carl Deckard had developed the selective laser sintering technology in 1980s with the collaboration of an undergraduate student from University of Texas. In continuation of the development, Carl Deckard involve himself in foundation of one of the first 3D printing startups, Desk Top Manufacturing (DTM). In selective laser sintering technology, high-power laser shoot form a laser beam is use to fused powder to become solid form. This powder might be form in tiny particles of materials such as plastic that is commonly used. The laser will sinter the corresponding area of the powder depends on the drawing that had been made. One of the laser that can be used in this process is carbon dioxide (CO_2) laser and the laser beam is control by computer command. After each layer had been made, a new layer of powder will be spread on the surface using roller mechanism to start over the sintering process. As the previous technology, before proceed with building process, a computer-aided design (CAD) geometrical model will be made in a 3D software such as CATIA. This CAD data will be import into the machine passing through steps such as converting into STL file for slicing process.

2.2 Thermoplastic

Thermoplastic is a material in a long chain of either linear or branched polymers linked by van der Waals force or intermolecular interactions. This material will change to uniform liquid upon heating, harden through cooling process and change to glass-like material when it undergoes freezing process. This process is reversible which give advantages to thermoplastic as it can be recycle for further usage with reshaped process. As stated by Biron (2007), thermoplastic is a material that has sensitivity to environmental restriction such as temperature and moisture which can be affected by additional materials. Thermoplastic can be classified into two types of structure as it differs in term of intermolecular interactions which are amorphous structure and crystal structure. Amorphous structure appeared as a wrap-kind of structure and structure that involve in elasticity while crystal structure arrange in linear arrangement with either in rectangular or spherical form.

There are various types of thermoplastic that had been widely used in the engineering area such as acrylic, acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyethylene (PE), polyetherimide (PEI), polycarbonate (PC) and polystyrene (PS). 3D printing process had involved in the use of thermoplastic as its material for a very long time due to the end performance of product using plastic as material. Among materials that had been widely use as the filament are ABS and PLA. Those materials which based on plastic had been used in injection moulding process and prove to produce good finishing as 3D printing produce complex design using depositing process and by using plastic, complex part can be produce (Fischer, 2008).

2.2.1 Acrylonitrile-Butadiene-Styrene (ABS)

Acrylonitrile-Butadiene-Styrene (ABS) is one of the thermoplastic which classified in amorphous structure. It consists of the combination of three different monomeric chemicals which are acrylonitrile (A), butadiene (B) and styrene (S). This chemical's combination blending thermal enhancement, higher impact strength and firmness with shiny surface. Way of producing ABS can be divided into two methods which generate different characteristics of plastics. ABS can be produce by mechanical blending of styrene-acrylonitrile copolymer resin with butadiene-based elastomer or by joining styrene and acrylonitrile onto polybutadiene (Rutkowski & Levin, 1986). ABS classified as a high toughness material with good resistance toward heat even in low temperature condition. Despite the toughness of ABS, at temperature above 280 °C, it will lose it toughness due to damage happen in the structure during the rubber phase (Kulich, Gaggar, Lowry, & Stepien, 2001).

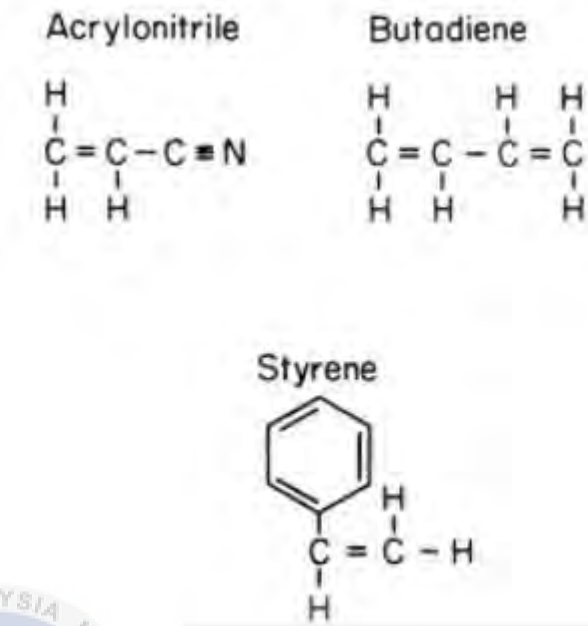


Figure 2.5 Chemical structures of acrylonitrile, butadiene and styrene

2.2.2 Polylactic Acid (PLA)

Polylactic acid (PLA) is one of the thermoplastic-based materials and placed in amorphous structure which derived from renewable raw materials (Avérous, 2011). It is aliphatic polyester which is common to be classified in α-hydroxy acids and made up from lactic acid. PLA had been around for many years mainly for biodegradable products such as biodegradable plastic bag. PLA made up of molecules with helical structure and produce from compound of faming resources such as corn starch (Avinc & Khoddami, 2010). Processing PLA can be made with different kind of steps and it is also cheaper in price.

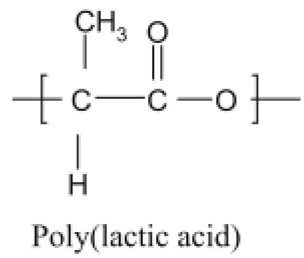


Figure 2.6 Structure of PLA

Figure 2.7 Lactic acid structure produce from corn

2.3 Adhesive

In general, adhesive is a glue or sticky substances used to hold two or more materials together. Adhesive also describing properties of how a substance is physically or chemically formed or how some materials been joined and under which conditions it may be apply. Adhesive is mainly known in two different types which are synthetic adhesive; made using synthetic material such as vinyl and bio-based or natural adhesive; made using starch or dextrin which derive from cereals or roots.

2.3.1 Synthetic Adhesive

Synthetic adhesive is made with the combination of chemicals such as polymers to produce glue. Most synthetic adhesives were made based on vinyl, classify in one polymers family tree. This materials had been used widely in coating and adhesive industry and had produce wide range of adhesives with specific properties. Among the adhesive produces were for textiles, leather, pipes, wood and paper applications adhesive. Synthetic adhesive classified as one of the thermoplastic type of adhesive. Adhesive in this type of class need to be heated to certain temperature that will give low viscosity of fluid. Synthetic adhesive will cause stress concentrations between the material bonded that lead to shrinking process and damaging the surface. Synthetic adhesive also made up of materials that is not environmental-friendly which if it is applied to the 3D printer surface, it can produce improper smell.

2.3.2 Bio-based Adhesive

Bio-based adhesive is an adhesive made of renewable biomass such as gelatine (vegetables, plants or animals starch) or starch. This biomass is chosen as it is non-toxic material which will not harm the environment. Among the material based on vegetables or plants that are widely used are soy bean, rice starch and cassava plant. Gengsheng et al. (2013) has prepared soy flour-based adhesives by mixing 40 g soy flour, 100 g of water (H_2O) and 8 g of IA-PAE inside 500 mL inside a 500 mL three-neck flask. Additional of sodium hydroxide (NaOH) in the mixture was found to be an effective modifying agent which increase the resistance of adhesive to water. In another study, sago starch also been consider as one of the bio-material that shows promising in adhesive world. Although potato and rice starch were labelled s natural binder and sago starch was technically abandoned, it still shows that it has high viscosity which can benefit it as adhesive and can be used in food and adhesive industry (Jamaludin, Kasim, Abdullah, & Ahmad, 2014).

2.4 Warping

Warping deformation is of the main problem happened during 3D printing process. This problems occur when the filament printed through the nozzle warp as it lays on the platform to form full layer of product. During the stages of forming a fully grown layer, different stages were undergoes which are solid filament goes through melting process inside the nozzle's part and end with solidification due to cooling process. Those stages will cause the deformation due to uneven temperature distribution along the process which will cause the end side of the product will bend upward causes the product to be not parallel to the surface. Warping deformation also occurs due to the unusual deformation subjected by torsional actions that distorted the filament from its original path or plane. Warping deformation issues related to 3D printer had been research by many other researchers (W. Z. Wu et al. (2014) and F. Ramli (2015)).

2.5 Viscosity Test

In general, viscosity test is a process where a viscosity of liquid tested using a viscometer. Viscosity itself is a condition where certain liquid been place under force and its resistance to produce a movement or flow is the measure to be consider. Viscosity also been called as coefficient of dynamic which explains in term of ratio of both rate of shear and shear stress.

$$Viscosity = (Shear\ stress)/(Rate\ of\ shear)$$

Viscosity test is one of the process done in order to determine the effectiveness of the adhesive to be use in the industry. By doing this test, the viscosity can be obtain. Having a high viscosity adhesive will provide an ideal adhesive as it will have high flow rate of movement due to its viscous condition.

2.6 Tensile Test

Tensile test is the most common testing held in a mechanical field which is done in order to know the characteristic of a substance, specimen or material. Those characteristic also include the strength and the elasticity of a substance as it been pull apart during the test. From the test, a stress-strain diagram can be obtain where the ultimate tensile strength (UTS) of the substance can be obtain from the graph. Figure 2.8 shows the stress-strain diagram.

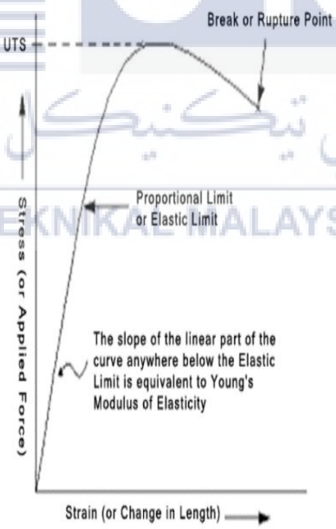


Figure 2.8 Stress-strain diagram

Ultimate tensile strength is the maximum load that a substance can undergoes during the testing before it started to break. In tensile test, Hooke's law is used in order to determine the relationship of force, load and elongation as it obeys the relationship which is in a linear. Elastic deformation also been determine using Hooke's law.

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

Where:

σ = stress, ε = strain, E = modulus of elasticity

2.7 Summary of Previous Study

Referring to few articles related to the objectives of this project, there are few research been held regarding sago-based adhesive product which related to the project. However, there are none articles related to the use of bio-based adhesive for 3D printer application hence the successfulness of this aim will be determine using this project.

2.7.1 Sago starch as binder and pore-forming agent for the fabrication of porcelain foam

This journal which written by Abdul Rashid Jamaludin, Shah Rizal Kasim, Mohd Zulkifly Abdullah and Zainal Arifin Ahmad aimed to prove that sago starch can be a good binder with certain characteristics that had been list out which are the density, strength and viscosity of it. Mixing sago starch into the mixture causes increase of viscosity which prove that the usefulness of sago as a binder need to be viscous enough to be used. The compressive strength also increase as sago starch include into the binder mixture. Seeing this happening, sago starch was labeled as one of the most promising substance that cab be involve in adhesive or binder world.

2.8 Conclusion

To conclude this chapter, a research had been conducted through readings from numbers of articles, books and web sites. From this research, few had knowledge been gained on how to proceeds the project through the previous research and data gain from those resources.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is one of the part of a project where all the actions and activity is list out and arrange in systematic ways. This is to describe in particular how the project flows and the routines used to complete the project. The procedures and steps used to complete the objectives stated are explained in this chapter. The summarization for the flow of the experimental procedure in this project is shown in the flow chart of Figure 3.1.

3.2 Project Flow Chart

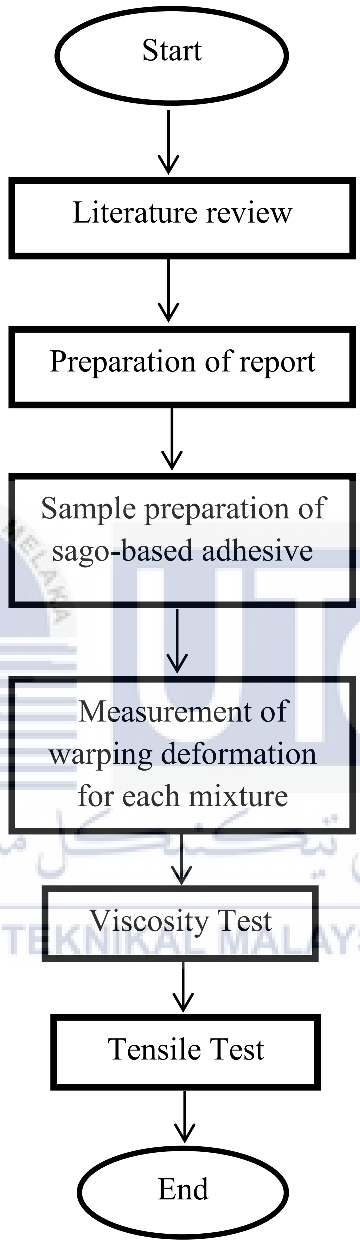


Figure 3.1 Project flow chart

3.3 Sample Preparation

For the first part of the project, sample that going to be used for the project is sago seeds that will be prepares in powder form. This sample preparation is divided into two different parts which are: (1) sago powder preparation and (2) sago-based adhesive preparation.

3.3.1 Sago Powder Preparation

Sago powder can be produce in two different ways which are by crushing it using normal blender or using pestle and mortar. Raw sago will be crush or blend until it becomes powder in structure. There are two different structure of sago powder produce which are fine and course structures. Only fine structure of powder will be use for the sago-based adhesive making process. This adhesive then will be use as the adhesive for the 3D printing processes.

3.3.2 Sago-based Adhesive Preparation

The sago-based adhesive will be prepared using the mixture of hot distilled water and sago powder. Firstly, the distilled water will be heat near to the boiling temperature which approximately 85 degree Celsius to 95 degree Celsius. This distilled water is continuously stir using magnetic stirrer at about 60 rpm. After the water reach that temperature, sago powder were added little by little to ensure that the mixture is mixed evenly. The mixture also been stirred manually to ensure the powder does not coagulate and to sure it is properly mixed. The speed of magnetic stirrer was increase to 100 rpm as the sago powder were added as the mixture become more concentrated. The mixture was left for approximately 15 minutes to 25 minutes to ensure it is properly mixed.

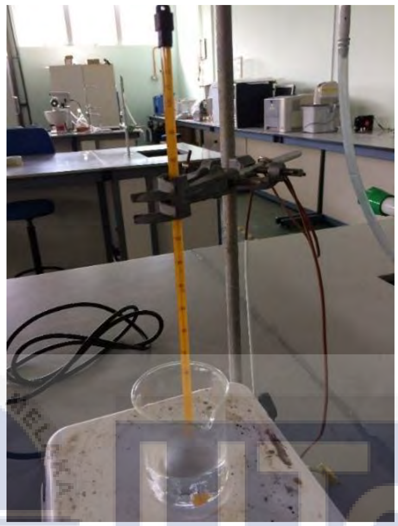


Figure 3.2 Heating distilled water

Figure 3.3 Weighing sago powder

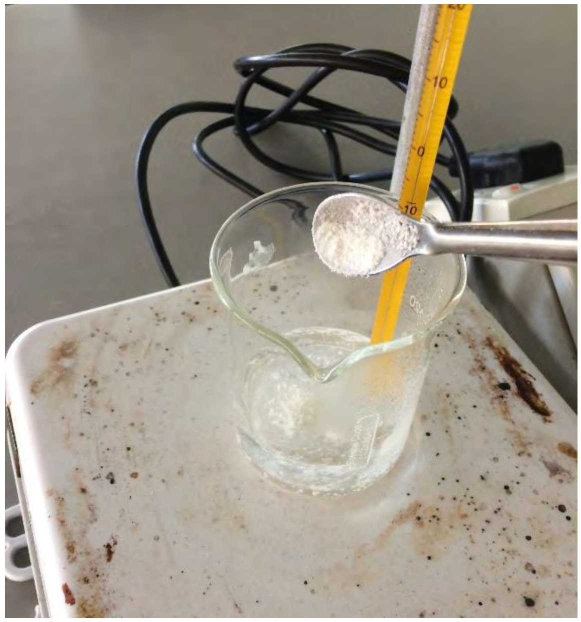


Figure 3.4 Pouring sago powder little by little

3.3.3 Application of Glue on the Platform

The application of glue on the platform held using a printed glue spreader. The glue was spread evenly starting from the left side of the platform to the right side and then from the front side to back side of the platform.

3.3.4 Specimen Printing

Process of specimen printing involve in the use of PLA and ABS as the material printed from a FDM machine. Along the printing process, using PLA, the platform was used in two different conditions which were with heat bed of 60 degree Celsius and without heat bed. For ABS material, the conditions also were the same but with different heat bed temperature which is 100 degree Celsius. The layer thickness of the specimen is 0.2 mm and the height is 5.10 mm. For PLA, nozzle temperature is set to 200 degree Celsius while for the ABS, the temperature is set to 230 degree Celsius. Figure below shows one of the specimen being printed using ABS.

Figure 3.5 Specimen printing process

3.4 Warping Deformation

Warping deformation is where the vertex of the specimen curved upwards due to lack of adhesiveness on the platform. This warping deformation is one of the way to test the layer adhesion. In this research, this deformation is measure using vernier caliper and a flat glass. This way is one of the method other than using a vernier height gauge. The specimen is place on a clean flat glass. This specimen had been mark at each edges with label A, B, C, D and at the center of the specimen. All of the parts were measured using depth of vernier caliper. The data of all specimens were recorded for comparison purpose. Figure 3.4 shows the measuring process.

Figure 3.6 Warping deformation measuring process

3.5 Viscosity Test

To determine the viscosity level of adhesive, a viscosity test is held using a viscometer. The sample of adhesive made will be used in the system using the same spindle in order to ensure that the adhesive will be process using the same type of spindle. In this process, water bath with different temperature will be used along the process to test the viscosity of the adhesive in different temperature but using the same spindle. Adhesive with higher temperature may be less viscous compare to low temperature of water.

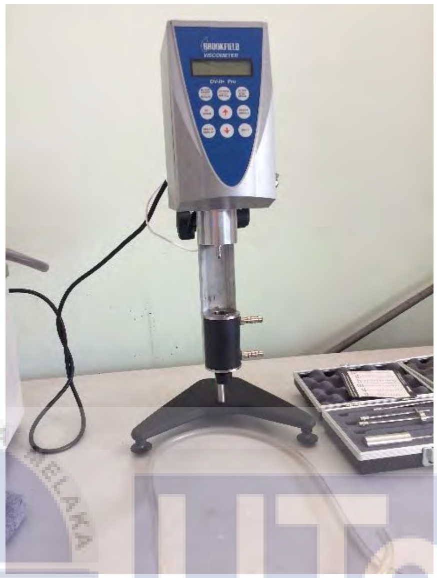


Figure 3.7 Viscometer

3.6 Tensile Test

Comparing the strength of adhesives is one of the process in order to determine which adhesive have strongest criteria. In 3D printing application, the strength of an adhesive is important between the platform and first layer of printing in order to avoid it from warping or peel off from the platform. In this tensile test, the specimen will be test in order observe which adhesive can hold the specimen longer from it is tear from the platform.

The specimen is printed on a glass platform with size of 13 mm x 13 mm x 5 mm using PLA as its material. The adhesive use for the printing process is sago-based adhesive, soy-based adhesive and UHU glue. The upper part of specimen and bottom part of the glass platform were applied with mixture of 2 tons epoxy. This parts were stick permanently with a square solid steel with a size of 12.7 mm x 12.7 mm x 40 mm and a 5.5 mm diameter hole. Next, both solid steel is attach to a shaft which will be connect to the tensile machine. The tensile machine to be used is a Universal Tensile Machine.

Figure 3.8 Instron machine

Figure 3.9 Applying 2 tons epoxy

Figure 3.10 Printed specimen and shaft for testing

CHAPTER 4

RESULT AND DISCUSSION

4.1 Sample Preparation

4.1.1 Sago

Procedure of preparing this adhesive is guide by the ASTM standard. The mixture of sago-based adhesive consist of water and fine structure sago powder with ratio of each one gram sago powder will be mix with 4 liter of distilled water. The preparation of sago-based adhesive started with the making of sago powder from the sago seeds. Firstly, blend the seeds into powder and two structures produce which are fine and course powder. The powder then filter to separate the fine and course structures. Next, weight 10 gram of fine structure sago powder using weighing scale and measure 40 liter of distilled water using measuring cylinder following the ratio between both materials.

Next, boil the distilled water at temperature near to the boiling temperature which approximately 85 degree Celsius to 95 degree Celsius. Magnetic stirrer is place inside the water and set to 60 rpm for the first part of the adhesive making. When the water reach the temperature, pour the sago powder little by little while manually stir the mixture to avoid coagulation of water and sago powder. The speed of magnetic stirrer increase to 100 rpm and leave the mixture to properly cooked and mix for about 15 to 25 minutes.

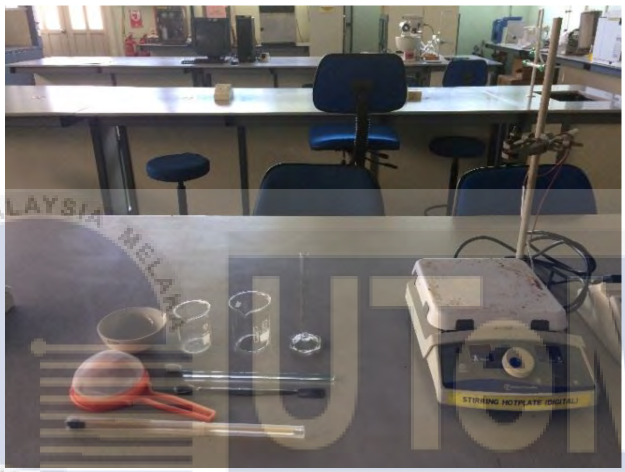


Figure 4.1 Parameter set up

Figure 4.2 Separating fine and course sago powder

Figure 4.3 Heating distilled water to certain temperature

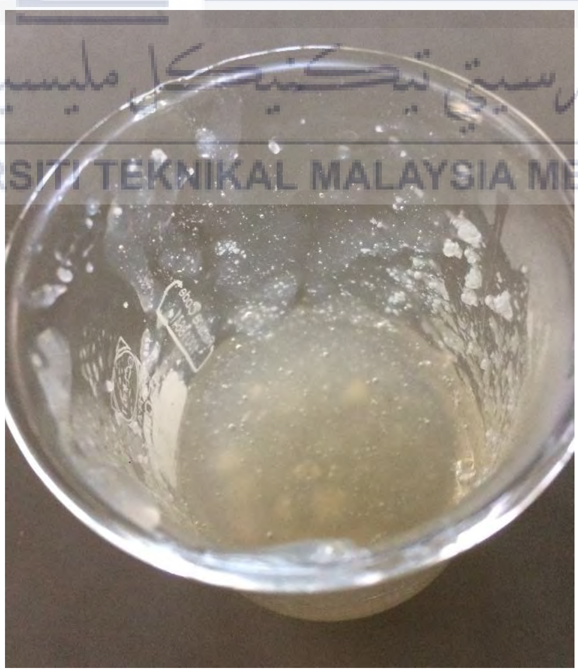


Figure 4.4 Sago-based adhesive

Table 4.1 Ratio of sago-based adhesive mixture

Adhesive	Sago powder (g)	Water (L)
Sago	15.0	60.0

4.2 Warping Deformation

Warping deformation is a problem where the first layer of specimen printed on the platform warps and cause it to bend upwards. This occurs due to less of adhesiveness in particular glue used causes the first layer to stick temporarily and bend as the glue dry out. In this research, warping deformation is one of the criteria used to analyze the bio-adhesive produce whether it is suitable for 3D printing process. Warping deformation is measure from 4 different sides which are four vertexes and those vertexes were labeled with A, B, C and D. figures below show the warping deformation measuring processes.

Figure 4.5 Flat glass for warping deformation measurement

Figure 4.6(a) Measuring thickness using vernier caliper

Figure 4.6(b) Measuring depth using vernier caliper

Figure 4.7 Warping deformation measuring process

4.2.1 Sago-based Adhesive

Table 4.2 Warping deformation for specimen of sago-based adhesive

Specimen	A (mm)	B (mm)	C (mm)	D (mm)	Average (mm)
191_13_0.2(1)	0.00	0.05	0.35	0.15	0.14
191_13_0.2(2)	0.10	0.80	0.10	0.40	0.35
191_13_0.2(3)	0.05	0.10	0.70	0.20	0.26
191_13_0.2_60(1)	0.05	0.25	1.90	0.10	0.58
191_13_0.2_60(2)	0.10	0.00	0.55	0.00	0.16
191_13_0.2_60(3)	0.05	0.00	0.80	0.15	0.25
220_13_0.2_100(1)	0.05	0.20	0.05	0.10	0.10
220_13_0.2_100(2)	0.10	0.05	0.00	0.10	0.06
220_13_0.2_100(3)	0.00	0.00	0.00	0.70	0.18

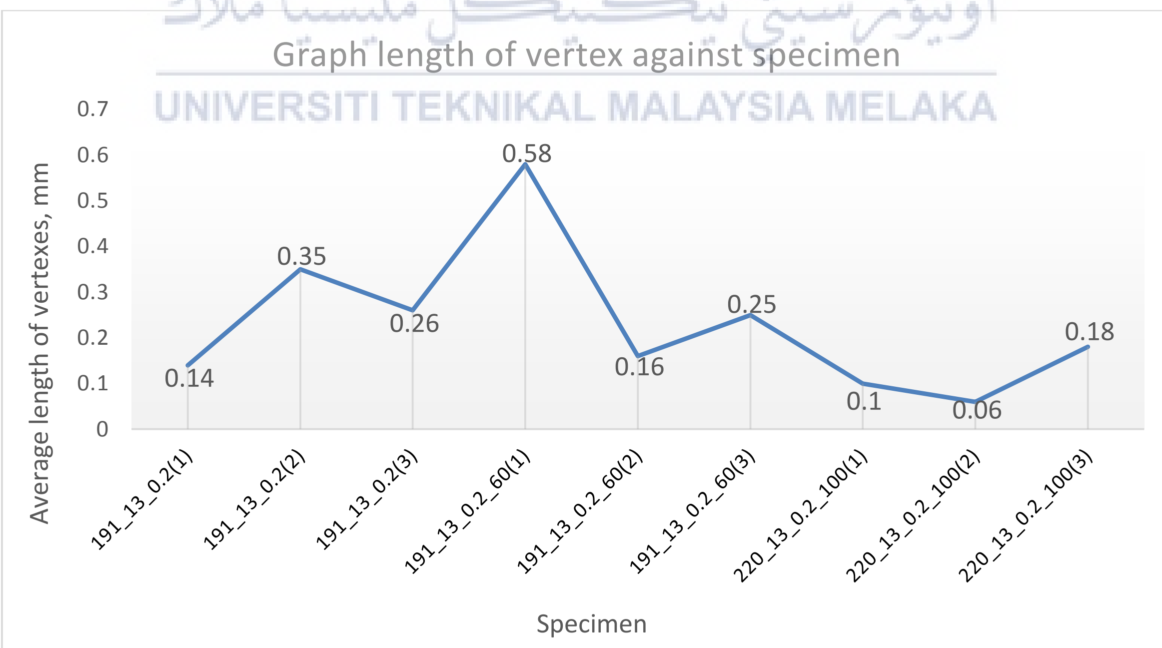


Figure 4.8 Result of the warping deformation for sago-based adhesive

Table 4.2 shows the result of different between thickness and depth of the vertexes for each specimen. Specimen 191_13_0.2 was printed using PLA material without any heat bed. Specimen 191_13_0.2_60 and 220_13_0.2_100 were printed with PLA and ABS respectively with 60°C for PLA and 100°C for ABS. From the graph, for PLA material, we can see that specimen printed without heat bed give lowest length of vertex compare to the one printed with 60°C heat bed. This shows that sago-based adhesive can function much properly without being heat during the printing process. For ABS material, it is clearly that specimen printed without heat bed could not be done. All the ABS printing trial held without heat bed had failed and no data can be recorded but for specimen with heat bed of 100°C, the specimen shows lowest length of vertex even compare to the PLA specimen. This shows that sago-based adhesive can function well using ABS material while printed on a heated platform.

4.2.2 UHU Glue

Table 4.3 Warping deformation for specimen of UHU glue

Specimen	A (mm)	B (mm)	C (mm)	D (mm)	Average (mm)
UHU	0.00	1.00	0.50	0.50	0.50

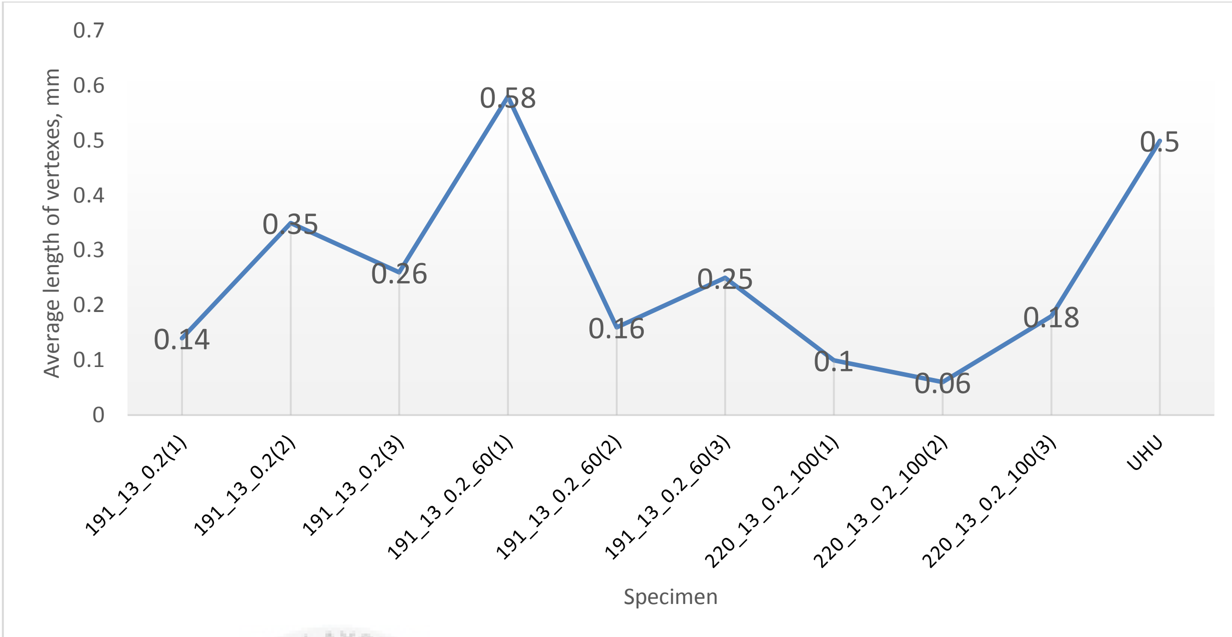


Figure 4.9 Result of the warping deformation for sago-based adhesive and UHU glue

To compare between the results of vertex length of sago-based adhesive with UHU glue, specimen printed with sago-based adhesive obtain lowest length of vertex if compare to UHU glue. Taking the lowest value for sago-based adhesive, the length is 0.06 mm compare to UHU glue which is 0.50 mm. this shows that sago-based adhesive is a strong adhesive which is suitable for the application of 3D printing. This will also reduce the warping problem that had been face by specimen of 3D printing.

4.3 Viscosity Test

For viscosity test, sago-based adhesive was tested in order to observe the level of viscosity of the adhesive with different temperature of water bath around it. Viscous of an adhesive can also be compare with different temperature as it will melt a little as it undergoes hot temperature. Viscosity test was held using a viscometer machine which used to measure the viscosity level of liquid. The type of spindle used for the test is spindle 64 and different speeds were used which are 5 rpm, 10 rpm and 20 rpm. The temperature used for this test started from 18°C, 24°C, 40°C and 60°C.

For 18°C, the speed that can be used for the test is 10 rpm and 20 rpm and speed more or less than that will give error in the reading of viscosity. For 24°C, the speed can be altered to 10 rpm, 20 rpm and 30 rpm and error for other speed. For 40°C, the speed can change to 10 rpm, 20 rpm, 30 rpm, 50 rpm, 60 rpm and 100 rpm and error for other reading. For 60°C, only 5 rpm speed can be used for the test. Other than that, the viscosity will end up giving error reading. To balance the comparison of 18°C, 24°C and 40°C water bath temperature, the data only will be compare between 10 rpm and 20 rpm of speed. For 60°C, the data will be observe from the 5 rpm speed.

Figure 4.10 Result display on viscometer

4.3.1 Sago-based Adhesive

Table 4.4 Sago-based adhesive with speed of 5 rpm

Temperature (°C)	Percentage (%)	Viscosity (cP)
60	73.9	88661
	73.5	88181
	73.4	88061
	73.3	87941
	73.2	87821
	73.1	87701
	73.0	87581
	72.8	87341
	72.7	87221
	72.6	87101

Table 4.5 Sago-based adhesive with speed of 10 rpm

Temperature (°C)	Percentage (%)	Viscosity (cP)
18	60.1	36052
	60.0	35992
	59.8	35872
	59.6	35752
	59.4	35632
	59.2	35512
	59.1	35452
	59.0	35392
	58.9	35332

	58.8	35272
24	51.6	30953
	51.5	30893
	51.3	30773
	51.0	30593
	50.7	30414
	50.6	30354
	50.5	30294
	50.2	30114
	49.9	29934
	49.8	29874
40	32.9	19736
	33.0	19796
	33.5	20096
	33.7	20216
	33.8	20276
	34.0	20396
	34.3	20576
	34.6	20756
	34.7	20816
	34.8	20876

Table 4.6 Sago-based adhesive with speed of 20 rpm

Temperature (°C)	Percentage (%)	Viscosity (cP)
18	88.1	26424
	87.9	26364
	87.6	26274
	87.2	26154

	86.7	26004
	86.3	25884
	86.1	25824
	86.0	25794
	85.9	25765
	85.6	25675
24	73.7	22105
	73.6	22075
	73.5	22045
	73.4	22015
	73.2	21955
	73.1	21925
	72.7	21805
	72.6	21775
	72.0	21595
	71.9	21565
40	44.7	13407
	44.4	13317
	44.0	13197
	43.7	13107
	43.3	12987
	43.1	12927
	42.8	12837
	42.4	12717
	42.3	12687
	42.2	12657

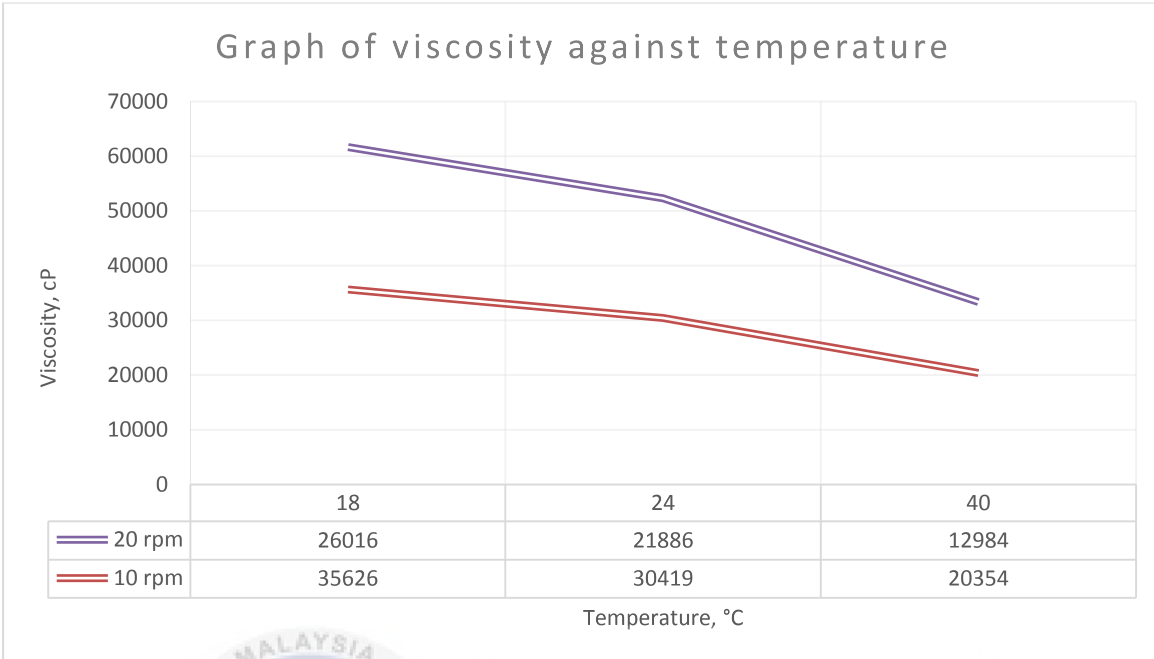


Figure 4.11 Results of viscosity test

Considering that the data can be compare between 10 rpm and 20 rpm speed due to the range of temperature used is the same, a graph is produce to compare the viscosity of sago-based adhesive against the temperature for both speed used. As the result obtained, sago-based adhesive shows higher viscosity with lower temperature compare to testing with only 10 rpm speed. For the temperature, sago-based adhesive gives higher viscosity when it is tested with lower temperature as it reduce the motion inside the adhesive itself.

4.4 Tensile Test

Tensile test was held in order to analyze which adhesives have the highest strength between UHU glue and sago-based adhesive. 3 samples were prepared for the sago-based adhesive specimen in order to get an average result of the tensile test. Both adhesives were tested using an Instron machine, a Universal Tensile Machine Dynamics 8872 (UTM Dynamics 8872) with the same speed for the test. Result needed for the comparison is maximum load (N), tensile stress at maximum load (MPa) and extension at maximum load (mm). From this results, the best adhesives can be rate and the best adhesive can be obtain. Table 4.8 shows overall results of the tensile test.

Table 4.7 Result of tensile test

Type of adhesives	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Extension at Maximum Load (mm)	Rating of Best Adhesive
Sago 1	2.6944	0.0216	0.0620	4
Sago 2	0.9229	0.0074	0.0282	5
Sago 3	11.9954	0.0960	0.8629	2
Sago 4	10.6937	0.0855	0.4244	3
UHU 1	19.9490	0.1596	1.0356	1

From the table, it shows that UHU has the highest strength compare to sago-based adhesive. This is due to the maximum load needed for the glue to tear apart from the glass platform is high compare to other maximum load. 19.9490 N of load needed for the UHU glue to tear apart for a test speed of 1 mm per minute. As for sago-based adhesive, the highest maximum load needed is 11.9954 N and the lowest is 0.9299 N which is quite low compare to other sample of glue. This is due to the use of heat bed during specimen printing which may cause the adhesive layer to be a bit dry and less strength to hold stick on the glass platform.

Figure 4.12 Specimen set up to be test

Figure 4.13 Tensile testing process

Figure 4.14 Result of testing

4.3.1 Graphical Result of Tensile Test

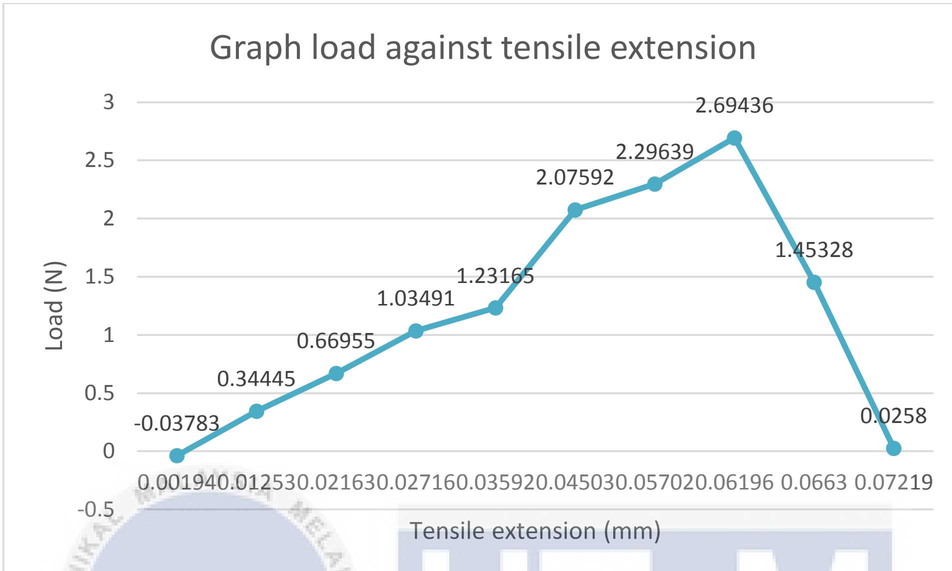


Figure 4.15 Graph for Sago 1

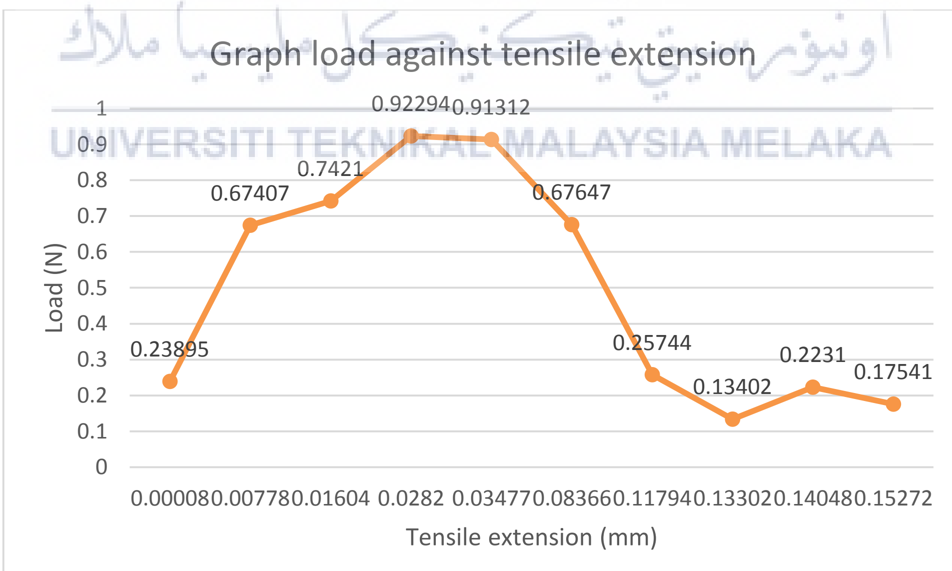


Figure 4.16 Graph for Sago 2

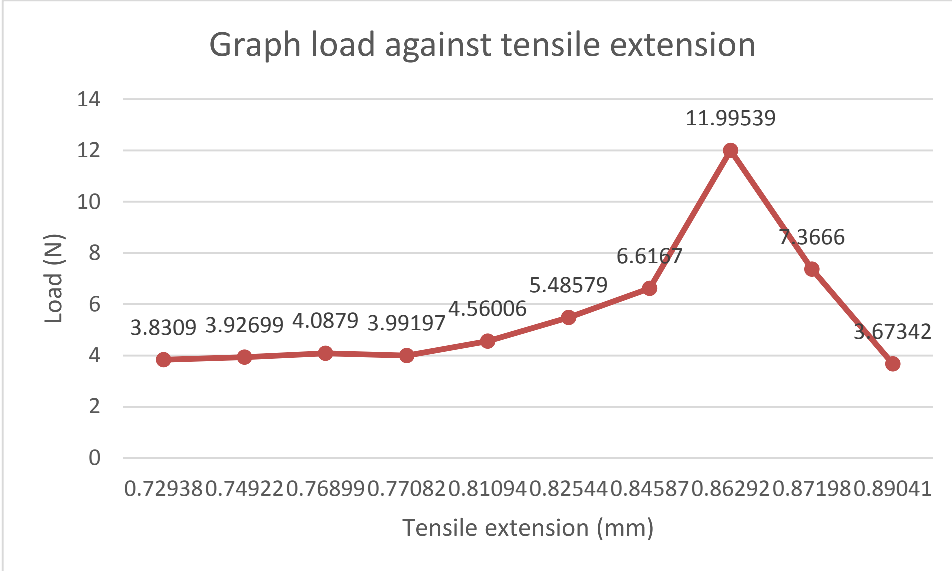


Figure 4.17 Graph for Sago 3

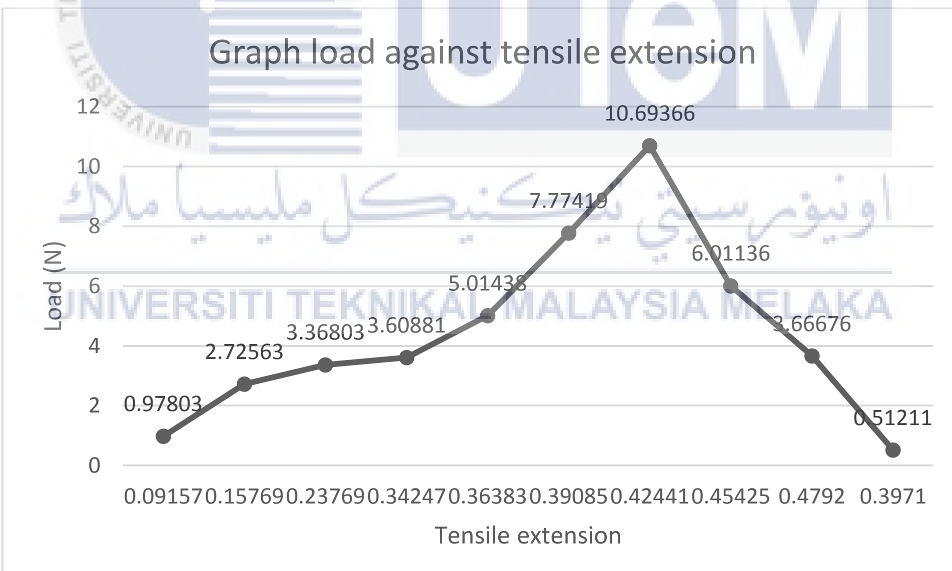


Figure 4.18 Graph for Sago 4

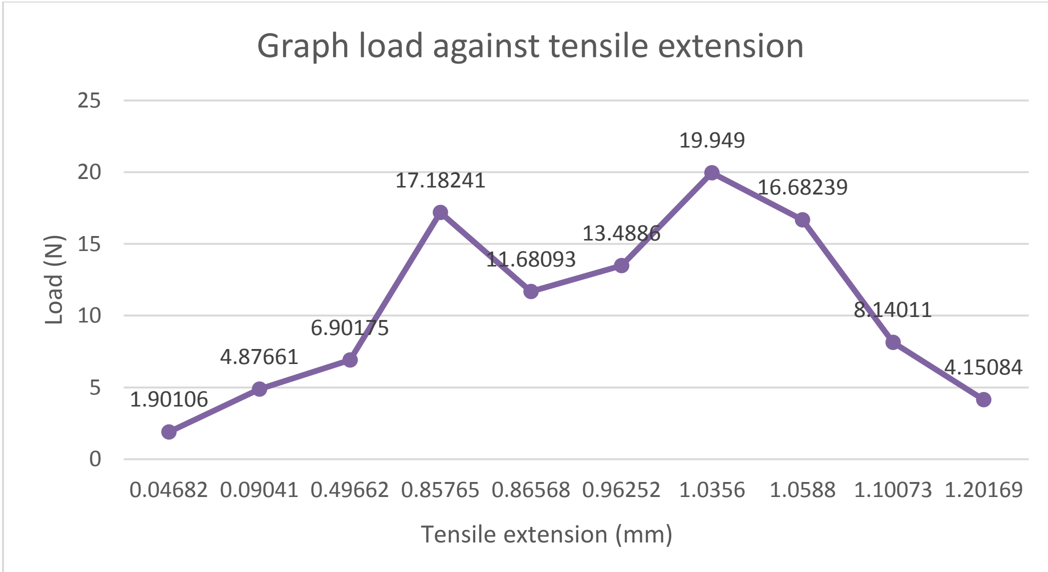


Figure 4.19 Graph for UHU

Based on the graph obtain, each graph shows the maximum load needed for each adhesive or glue to break the adhesive from the glass platform. For UHU, it gain the highest value of maximum load which is 19.949 N while for sago 1, the highest maximum load is 2.69436 N. For sago 3 and 4, the maximum load is 0.92294 N and 10.69366N respectively. For the highest maximum load needed for sago-based adhesive before break apart is 11.99539 N which also count as high but still lower than the value gain by UHU glue.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Based on the result obtained by all tests that had been held during this research, it is found that for warping deformation process, sago-based adhesive was recorded to gain the lowest length of vertexes for all condition which are different materials and with or without heat bed compare to using UHU glue. This shows that sago-based adhesive has the potential to be used continuously in 3D printing industry. For viscosity test, tests with both 10 rpm and 20 rpm show that the viscosity of sago-based adhesive is high when it is applied with lower temperature of water bath. This shows that this adhesive have suitable viscosity for a 3D printing process. As for tensile test, UHU glue shows great strength towards the force use to break apart the glue from the glass platform. Although sago-based adhesive cannot exceed the maximum load gain by UHU glue, it still shows promising result which is 11.9954 N as the maximum load also in high range of value if compare to UHU glue.

5.2 Future Research

In the future, next research can started to cover even wider range of bio-adhesive application. Type of plants can be expand not only related to what had been done before but also inventing new kind of glue with much environment friendly as this project can be applied for the use of food 3D printing.

REFERENCES

Alit, N. A. (2016). *First Layer ABS of Bio Based Adhesion in 3d Printer Machine.* Ayer Keroh: Universiti Teknikal Malaysia Melaka.

Avérous, L. (2011). Polylactic Acid: Synthesis, Properties and Applications. In M. N. Belgace, & A. Gandini, *Monomers, Polymers and Composites from Renewable Resources* (pp. 433-435). Amsterdam: Elsevier.

Avinc, O., & Khoddami, A. (2010). Overview of Poly (Lactic Acid) (PLA) Fibre. *Fibre Chemistry*, 68-78.

Barnatt, C. (2013). *3D Printing: The Next Industrial Revolution.* Nottingham: ExplainingTheFuture.com.

Brock, J. M., Montero, M., Odell, D., & Roundy, S. (2000). *Fused Deposition Modeling (FDM) Material Properties Characterization.* Michigan: Michigan State University.

Chua, C. K., Leong, K. F., & Lim, C. S. (2003). *Rapid Prototyping: Principles and Applications.* Singapore: World Scientific Publishing Co. Pte. Ltd.

Eslah, F., Jonoobi, M., Faezipour, M., Afsharpour, M., & Enayati, A. A. (2016). Preparation and development of a chemically modified bio-adhesive derived from soybean flour protein. *International Journal of Adhesion & Adhesives*, 48-54.

Evans, B. (2012). *Practical 3D Printers: The Science and Art of 3D Printing.* Berkely: Apress.

Fischer, F. (2008). *Thermoplastic: The Strongest Choice for 3D Printing.* Minnesota: Stratasys Ltd.

Gibson, I., Rosen, D. W., & Stucker, B. (2010). *Additive Manufacturing Technologies.* London: Springer.

Groover, M. P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes and Systems.* New Jersey: John Wiley & Sons, Inc.

Gui, C., Wang, G., Wu, D., & Liu, J. Z. (2013). Synthesis of a bio-based polyamidoamine-epichlorohydrin resin and its application for soy-based adhesives. *International Journal of Adhesion & Adhesives*, 237-242.

Jamaludin, A. R., Kasim, S. R., Abdullah, M. Z., & Ahmad, Z. A. (2014). Sago starch as binder and pore-forming agent for the fabrication of porcelain foam. *Ceramics International 40*, 4777-4784.

Jamaludin, A. R., Kasim, S. R., Ismail, A. K., Abdullah, M. Z., & Ahmad, Z. A. (2015). The effect of sago as binder in the fabrication of alumina foam through the polymeric sponge replication technique. *Journal of the European Ceramic Society 35*, 1905-1914.

Kulich, D. M., Gaggar, S. K., Lowry, V., & Stepien, R. (2001). Acrylonitrile-Butadiene-Styrene (ABS) Polymers. In T. C. GE Plastics, *Kirk-Othmer Encyclopedia of Chemical Technology* (pp. 816-846). New York: John Wiley & Sons, Inc.

Kun, K. (2016). Reconstruction and development of a 3D printer using FDM technology. *Procedia Engineering*, 203-211.

Lépine, E., Riedl, B., Wang, X.-M., Pizzi, A., Delmotte, L., Hardy, J.-M., & Da Cruz, M. J. (2015). Synthesis of bio-adhesives from soybean flour and furfural: Relationship between furfural level and sodium hydroxide concentration. *International Journal of Adhesion & Adhesives*, 74-78.

Li, H., Kang, H., Zhang, W., Zhang, S., & Li, J. (2016). Physicochemical properties of modified soybean-flour adhesives enhanced by carboxylated styrene-butadiene rubber latex. *International Journal of Adhesion & Adhesives*, 59-64.

Lin, Q., Chen, N., Bian, L., & Fan, M. (2012). Development and mechanism characterization of high performance soy-based bio-adhesives. *International Journal of Adhesion & Adhesives*, 11-16.

Mittal, K. L. (2003). *Adhesion Aspects of Polymeric Coatings.* Boston: VSP.

Nazan, M. A., Ramli, F. R., Alkahari, M. R., Sudin, M. N., & Abdullah, M. A. (2016). Optimization of warping deformation in open source 3d printer using response surface. *Proceedings of Mechanical Engineering Research Day 2016*, 71-72.

Novakova-Marcincinova, L., & Kuric, I. (2012). Basic and Advanced Materials for Fused Deposition Modeling Rapid Prototyping Technology. *Journal of Modern Engineering Research*, 24-27.

Rutkowski, J. V., & Levin, B. C. (1986). Acrylonitrile-Butadiene-Styrene (ABS) Copolymers (ABS): Pyrolysis and Combustion Products and their Toxicity-A Review of the Literature. *Fire and Materials*, 93-105.

Tong, L., Mouritz, A. P., & Bannister, M. K. (2002). *3D Fibre Reinforced Polymer Composites.* Kidlington: Elsevier.

Wong, K. V., & Hernandez, A. (2012). A Review of Additive Manufacturing. *International Scholarly Research Notices*, 1-10.