MECHANICAL PROPERTIES OF ORIGINAL-PLA, WOOD-PLA AND METAL-PLA FILAMENTS BY FDM

MUHAMMAD AMIN BIN ALIAS

BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PRODUCT DESIGN) WITH HONOURS

2024

Faculty of Industrial and Manufacturing Engineering Technology

Mechanical Properties of Original-PLA, Wood-PLA and Metal-PLA Filaments by FDM

Muhammad Amin Bin Alias

Bachelor of Manufacturing Engineering Technology (Product Design) with Honours

2024

Mechanical Properties of Original-PLA, Wood-PLA and Metal-PLA Filaments by FDM

MUHAMMAD AMIN BIN ALIAS

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology (Product Design) with Honours

Faculty of Industrial and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this thesis entitled "Mechanical Properties of Original-PLA, Wood-PLA and Metal--PLA Filaments by FDM" is the result of my own research except as cited in the references. The Mechanical Properties of Original-PLA, Wood-PLA and Metal--PLA Filaments by FDM has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Name	:	Muhammad Amin Bin Alias
Date	:	18/01/2024

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Product Design) with Honours.

Signature	:	
Supervisor Name	:	Ts. Hassan Bin Attan
Date	:	18/01/2024

DEDICATION

I, hereby, dedicates this thesis and reasearch on Mechanical Properties of Original-PLA, Wood-PLA and Metal-PLA Filaments by FDM to the people who have played an indispensable role in my academic journey. Their unwavering support, encouragement, and belief in my abilities have been instrumental in the completion of this research work.

ABSTRACT

Additive manufacturing (AM) has revolved from conventional method called, subtractive manufacturing (SM) process. In additive manufacturing, there are several types of method can be conducted based on the types of material, size of product and the purpose of production. One of the methods is Fused Deposition Modelling (FDM) specialized in thermoplastic printing. The study is done on Polylactic Acid (PLA), PLA-wood and PLA-metal filaments by Fused Deposition Modelling (FDM) as one of the AM processes. The mechanical propertiess of both type of the filaments such as tensile strength and flexural are differ to each other's. The differences of these filaments are convenient to its purpose and functionality. Tensile strength and flexural analysis are the two factor that is analyzed to make something resistant to the pressure or loads. Different type of materials used has its own strength to be used at a certain situation according to the number of loads acted on it. To identify the strength of the material, there are a few experiments or test that can be conducted such as Tensile and Flexural Test. Other than that, Finite Element Analysis (FEA) is also can be used to obtain the data analysis of tensile strength and flexural of the product. Both of this plan will be done at the same time to ensure that the result analysis of both processes is correctly interpreted.

ABSTRAK

Pembuatan aditif (AM) telah berubah daripada kaedah konvensional yang dipanggil, proses pembuatan tolak (SM). Dalam pembuatan aditif, terdapat beberapa jenis kaedah yang boleh dijalankan berdasarkan jenis bahan, saiz produk dan tujuan pengeluaran. Salah satu kaedah ialah Fused Deposition Modeling (FDM) khusus dalam percetakan termoplastik. Kajian dilakukan terhadap filamen asli Polylactic Acid (PLA), PLA – Wood dan PLA - Metal oleh Fused Deposition Modeling (FDM) sebagai salah satu proses AM. Ciri-ciri mekanikal kedua-dua jenis filamen seperti kekuatan tegangan dan ubah bentuk adalah berbeza antara satu sama lain. Perbezaan filamen ini sesuai dengan tujuan dan fungsinya. Analisis kekuatan tegangan dan ubah bentuk adalah dua faktor yang dianalisis untuk membuat sesuatu produk tahan terhadap tekanan atau beban. Jenis bahan yang berbeza yang digunakan mempunyai kekuatan tersendiri untuk digunakan pada keadaan tertentu mengikut bilangan beban yang bertindak ke atasnya. Bagi mengenal pasti kekuatan bahan tersebut, terdapat beberapa eksperimen atau ujian yang boleh dijalankan seperti Ujian Tegangan dan Ubah Bentuk. Selain itu, Analisis Elemen Terhad (FEA) juga boleh digunakan untuk mendapatkan analisis data kekuatan tegangan dan ubah bentuk produk. Kedua-dua pelan ini akan dilakukan pada masa yang sama untuk memastikan analisis hasil kedua-dua proses ditafsirkan dengan betul

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for the financial assistance.

My utmost appreciation goes to my main supervisor, Ts. Hassan Bin Attan, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will be remember. My special thanks go to En. Kamaruddin as assistant engineer of rapid manufacturing laboratory for all the help and support I received from them.

Last but not least, sincerely a gratitude to thank my beloved parents for their endless support, love and prayers. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

TABLF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Additive Manufacturing (AM) is a process of making three-dimensional objects from a digital file. The technology was first introduced in the 1980s, and it has since evolved rapidly, becoming more efficient and affordable. The process of 3D printing involves creating a digital design using computer-aided design (CAD) software. The design is then processed by a 3D printer, which creates the object layer by layer by adding material to each layer until the final object is produced. AM encompasses various technologies and processes that use different materials and techniques to create objects. Some common AM processes include fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), and powder bed fusion (PBF). Each process has its own strengths and is suitable for different applications. In this study, Fused Deposition Modelling is one of the main proses used.

Fused Deposition Modeling (FDM) is one of AM process based on the principle of extruding thermoplastic materials layer by layer to build up the final product. FDM is widely utilized in various industries and has gained popularity due to its simplicity, cost-effectiveness, and versatility. FDM is utilized in a wide range of industries and applications. It is commonly employed in prototyping to quickly produce concept models, functional prototypes, and validation parts. FDM is also utilized for low-volume production of end-use parts, tooling, jigs, fixtures, and customized components across industries like automotive, aerospace, consumer goods, medical, and education.

printing to reduce costs, increase efficiency, and create unique and customized products.

Material used in this study is original-Polyactic Acid (PLA), metal-PLA and wood-PLA. PLA is a widely used material in additive manufacturing. It is a biodegradable thermoplastic derived from renewable resources, primarily cornstarch or sugarcane. When it comes to additive manufacturing, PLA offers several advantages that make it a popular choice for both hobbyists and professionals. PLA is an environmentally friendly material as it is derived from renewable resources and is biodegradable. PLA is known for its excellent printability, making it ideal for beginners and hobbyists. It has a relatively low melting temperature, which means it can be easily extruded by the 3D printer. It also has minimal warping and shrinkage during the cooling process, resulting in fewer print failures.

Metal-PLA is a type of 3D printing filament that contains metal particles or compounds, giving the printed objects a metallic appearance. Metallic PLA is created by mixing PLA with metal powders, flakes, or compounds, such as bronze, copper, brass, or aluminum. Metallic PLA filaments produce 3D printed objects with a metallic shine, making them visually appealing.

Wood PLA is a type of composite filament that combines PLA (Polylactic Acid) with finely ground wood particles. The addition of wood fibers gives the 3D printed objects a wood-like appearance and some of the physical properties of wood. Wood PLA provides a unique and natural appearance to 3D printed objects. The visible wood fibers in the filament create a texture and finish resembling wood, making it suitable for decorative or artistic prints. Different Wood PLA filaments may use various types of wood particles, such as pine, birch, or bamboo.

1.2 Problem Statement

Mechanical propertiess of 3D printed objects can vary significantly based on several factors, including the 3D printing technology, the material used, the printing parameters, and the object's design. The strength of a 3D printed object refers to its ability to withstand an applied force without breaking or deforming. It is influenced by the material's inherent properties, layer adhesion, and infill density.

In this thesis, the material's mechanical propertiess is observed by using the same build paramaters setting. The propertiess of three different type of filaments which are original PLA, wood - PLA and metal - PLA are observed and investigated. Both of the material has its own properties and specialty in thier own used and functionality. The sample tested using Tensile Test and Flexural Test. FEA analysis also conducted to gather the data based on Computer Aided Engineering (CAE).

Experimenting with different type of materials in 3D printing requires some trial and testing. Manufacturers often provide recommended usage of the product based on the desired print quality and functionality.

1.3 Research Objective

The main aim of this research is to study the mechanical properties of 3D printed product. Specifically, the objectives are as follows:

a) To study the mechanical propertiess between original-PLA, Wood-PLA and Metal-PLA.
b) To investigate maximum stress, tensile strength and elastic force of original-PLA, Wood-PLA and Metal-PLA.used in AM by undergo tensile test and flexural test.
c) To analyze the von Mises stress of tensile specimen and flexural specimen based on Finite Element Analysis (FEA).

1.4 Scope of Research

The scope of this research are as follows:

- Studying the mechanical properties of original-PLA, Wood-PLA and Metal-PLA filament used in AM.
- Investigating the maximum stress, tensile strength and elastic force of original-PLA, Wood-PLA and Metal-PLA.used in AM.
- Explore and investigate the comparison between the mechanical properties between original-PLA, Wood-PLA and Metal-PLA.
- Analyze von Mises stress of tensile specimen and flexural specimen based on Finite Element Analysis (FEA).
- Observing the physical properties of the 3D printed sample product based on the type of filaments used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Additive Manufacturing has gained significant popularity and advancements in recent years. Additive manufacturing process builds three-dimensional objects by adding layers of material, typically from a digital design file. There are some key aspects of AM as it stands today which are technology and processes, materials, industrial applications, rapid prototyping, customization and personalization, complex geometry and lightweight design, sustainability and the most important thing is advancements in technology. There are a few method of manufacturing process in additive manufacturing and one of them is Fused Deposition Modelling (FDM)

2.2 Fused Deposition Modelling

FDM is one of the most well-liked and frequently applied AM techniques (Mohamad O.A et al.). Following the 1989 patenting of his FDM technique by Stratasys co-founder Scott Crump (Crump S), FDM became commercially available in the early 1990s. The FDM procedure prints layers of material to construct the part using a continuous supply of thermoplastic filament from a spool. Figure 2 illustrates how the filament material is heated to a semi-liquid phase using heating elements in the liquefier head after it is continually accessible. The semi-liquid thermoplastic is then extruded onto the print bed platform via the extrusion nozzle. The fundamental idea behind FDM is that semi-liquid thermoplastic filament materials are extruded from the build platform's nozzles and do not instantly solidify; instead, they do so before curing or solidifying into layers. It is the merging of plastic into specific building layers. One component was stacked at room temperature (Ngoa T.Det al.).

The main advantages of FDM are process simplification, high print speed and low cost. On the other hand, the drawbacks of FDM technology are the process parameter dependent mechanical properties (or anisotropic mechanical properties), poor surface finish, lamellar appearance of parts, and because thermoplasticity is an essential property, FDM The printing material is limited to thermoplastic polymers only. Materials 3D printed with FDM technology (Mohamad O.A et al., Stansbury J.W. et al.). This is because the quality and mechanical properties of FDM printed parts fundamentally depend on the correct (or optimal choice) of process parameters. Therefore, to make FDM suitable for mass production and more acceptable in the industry, it is of utmost importance to find the optimal combination of process parameters that improve part quality and mechanical properties (Dey A et al.).

The ideal parameters are an 80% infill percentage, a minimum layer thickness, and a 45 degree build orientation to yield the maximum compressive strength. It's beneficial for the development of clever structural applications that utilise 0.200 mm as the lowest, medium, and maximum layer thickness. Orientation of construction and 80% infill. The layers are extruded at a temperature of 200–220 degrees Celsius and have a thickness of 0.2 mm. There is a cubic infill. main factors plot the same outcome. Achieving the ideal tensile strength requires a coating that is only 0.1 mm thick, as thin as possible. enhanced layer adhesion. The infill pattern and layer thickness both have an impact on Tensile strength of PLA made of carbon fibre. This impact is amplified the higher. (Murali. S et al)

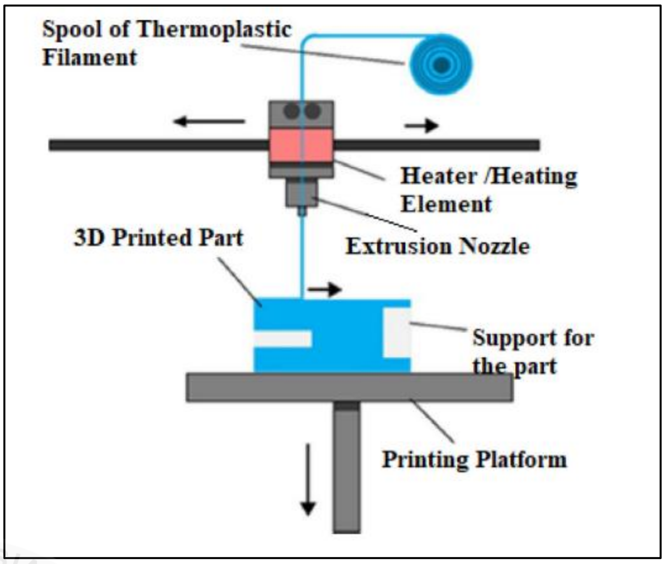


Figure 2-1 Setup of FDM process (Sheoran A.J et al.)

Table 2-1 Different FDM process parameters and its description (Sheoran A.J et al.)

Sr. No	Various FDM Process parameter	Description
1	Layer thickness	It is the height (or thickness) of layers deposited after extrusion from nozzle tip measured along Z-direction (or the vertical direction of the FDM machine). It is usually lesser than the extruder nozzle tip diameter [20]. It is dependent on: 1) Extruder nozzle tip diameter [1]. 2) Material. [1]
2	Build Orientation	It is how the part is positioned (oriented) within the build platform with respect to X-direction, Y-direction or Z-direction of the FDM machine and also the angle at which the part would be printed [1,20].
3	Raster Angle/ Raster Orientation	It is the angle (direction) with respect to X-direction of build platform, in which extruded material is deposited. It is the raster pattern angle measured with respect to X-axis. Usually, raster angle varies from 0° to 90° [1,20].
4	Air Gap	The distance (or gap) between 2 adjacent tool paths (or rasters) on a single layer of the FDM printed part [1,20].
5	Extrusion temperature	The temperature to which the thermoplastic filament materials heated inside the nozzle before extrusion in the FDM process. This parameter depends upon the print speed and type of thermoplastic material being printed [20].
6.	Print Speed	It is the speed of the traveling nozzle tip as it traverses in the XY plane of the build platform for depositing material [20].
7	Infill pattern	The pattern in which material is deposited to form the internal structure of the FDM printed part is the infill pattern. Commonly utilized infill patterns are diamond, cross, honeycomb and linear infill patterns [20]. Honeycomb infill pattern has a higher mechanical load resisting capacity than other infill patterns [50].
8	Infill density/Interior infill percentage	The outer layers of FDM printed parts are generally solid, but the inside structure is not necessarily solid but can be sparse and of varying infill patterns, sizes and shapes. Thereby, infill density implies the solidity of the internal structure of the FDM printed part [20,50].
9	Nozzle diameter	Diameter of nozzle tip of the extruder [50].
10	Raster width	It is the width of the beads deposited along the extruder tool path (which forms the raster). It depends mainly on the diameter of the extruder nozzle tip [1,20].
11	Number of contours	It is the number of solid outer layers, that surrounds the internal infill pattern (or internal structure) of the FDM printed part [1].
12	Contour width	The thickness of the outer layers (contour layers) surrounding the internal structure [1].
13	Contour to contour Air gap	It is the distance or air gap between the solid outer layers (or contours) [1].

2.3 Filaments

PLA (Polylactic Acid) filament is a material used in 3D printing. It is a biodegradable and bioactive thermoplastic made from renewable resources, such as corn starch or sugarcane. PLA is commonly chosen for its ease of use, low odor during printing, and environmentally friendly properties. A variety of materials like thermoplastic polymers, concrete, metal, and ceramics can be 3D Printed. AM also called 3D printing, was initially utilized as a rapid prototyping technique (Ankita J S et al).

2.3.1 Polyactic-Acid (PLA)

Because PLA is biodegradable and biocompatible, it is a common thermoplastic material used in fusion deposition modelling (FDM) with a wide range of medical applications. Penumakala et al. claim that despite having less plasticity than ABS, it is stronger. Compared to petroleum-based plastics like ABS, polyethylene, and polypropylene, PLA is a more environmentally friendly polymer (Wang Y et al). Compared to ABS, PLA has a stronger structure. It melts around 180–220 °C, which is colder than ABS (Gokhare V. G. et al.). When printing in inadequately ventilated environments, PLA does not provide the same health dangers as ABS.

To create polylactic acid, a thermoplastic polymer, lactic acid must condense in the absence of water (Ponshanmurakumar A et al., Rajeshwaran M et al.). There are several uses for polylactic acid. The fundamental equation for this is. Lactide, a cyclic dimer of repeating units, can also be generated via ring-opening polymerization (Santhi G.B, et al.). Lactide can be polymerized through ring-opening. Among those bases is FDM. Because polylactic acid, or PLA, is a kind of polyester, its name can be confusing and unclear (Kumar A.M, et al.). PLA can be made using a variety of production techniques.

. The two most commonly used major monomers are lactic acid and cyclic lactide diesters (Ayyasamy L.R, et al.).

2.3.2 Composite filament

The FDM filament materials have a significant role in determining the properties of the final part produced, such as mechanical properties, thermal conductivity, and electrical conductivity. As of this now, there are numerous various materials for FDM filaments that have been created. Pure thermoplastics, composites, bioplastics, and composites of bioplastics are among the materials used to make filaments. To enhance the FDM construct part qualities, various reinforcements, including fibres, particles, and nanoparticles, are mixed into the composite filaments (Dey A et al). Manufacturing of composite filament aspires to solve this problem by combining the matrix and reinforcements to achieve a system with more useful structural or functional properties non attainable by any of the constituent alone (Panagiotis M A et al).

2.4 Mechanical Properties

The aim of this paper is to understand the mechanical behaviors of FDM-printed product with different type of filaments which are wood, metal and plastic filaments. In addition to the type of PLA composites, mechanical properties are comprehensively investigated and analyzed from fracture surfaces of tensile and flexural tests. Mechanical properties refer to the set of characteristics that describe how a material responds to applied forces or loads. These properties provide insights into how a material behaves under various conditions and are essential for understanding its performance in different applications. The mechanical properties of a material help to predict how it will deform, break, or withstand external forces. In order for the materials to be used successfully, it is necessary to know the mechanical properties, and if necessary, these properties should be improved according to the usage area. When the mechanical properties of the material are mentioned, tensile strength, impact strength, elastic modulus, yield strength, fatigue strength, hardness, etc., features come to mind (Cevik U et al)

Table 2-2 Summary of previous researches findings

No.	Literature Title	Author	Year	Country
1.	Analyzing the Impact of Print Parameters on Dimensional Variation of ABS specimens printed using Fused Deposition Modelling (FDM)	Krishna Mohan Agarwal et al.	(2022)	Amity University Uttar Pradesh, India
2.	Effect of process parameter on tensile properties of FDM printed PLA	L. Sandanamsamy et al	(2023)	Universiti Malaysia Pahang, Malaysia
3.	Effect of Process Parameters on the Mechanical Behavior of FDM and DMLS Build Parts	Praveen Kumar Nayak et al	(2019)	National Institute of Technology Rourkela, Odisha, India
4.	Experimental and FEA analysis of flexural properties of 3D printed parts	Chetan Y. Bachhav et al.	(2022)	Maharashtra, India
5.	Experimental and theoretical analysis of FDM AM PLA mechanical properties	B. Kartikeyan et al.	(2022)	Sri Sairam Institute of Technology, India
6.	Experimental investigation and optimization of the FDM process using PLA	Sujata Sahoo et al.	(2022)	Indira Gandhi Institute of Technology, India
7.	Mechanical characteristics of wood, ceramic, metal and carbon fiber-based PLA composites fabricated by FDM	Xiaobing Liu et al.	(2019)	Wuhan University of Technology, China
8.	Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Review and reflection on present research	Sheoran A J and Kumar H	(2020)	National Institute of Technology Delhi, India
9.	Impact of multiple infill strategy on the structural strength of single build FDM printed parts	Ramisha Sajjad et al.	(2023)	University Islamabad, Pakistan
10.	Investigation of impact strength at different infill rates biodegradable PLA constituent through fused deposition modeling	G. Dharmalingam et al.	(2022)	Institute of Science & Technology, India

11	Study on the significance of process parameters in Improvising the tensile strength of FDM printed carbon fibre reinforced PLA	M. Venkateswar Reddy et al.	(2023)	R Institute of Technology, Hyderabad, India
12	A Review on Filament Materials for Fused Filament Fabrication	Cevik U and Kam M	2020	Düzce University, Turkey
13	A Review Study on Mechanical Properties of Obtained Products by FDM Method and MetalPolymer Composite Filament Production	Dey A et al.	2021	North Dakota State University, USA
14	Functional fillers in composite filaments for fused filament fabrication	Angelopoulos P M et al.	2019	School of Mining and Metallurgical Engineering, Greece
15	Fast, precise, safe prototypes with FDM	Crump, S. S.	1991	
16	Optimization of fused deposition modeling process parameters: a review of current research and future prospects. Advances in manufacturing	Mohamed, O. A et al.	2015	University of Technology, Hawthorn, Melbourne, Australia
17	Additive manufacturing (3D printing): A review of materials, methods, applications and challenges	Ngoa T.Det al.	2018	University of New Orleans, USA
18	Experimental and theoretical analysis of FDM AM PLA mechanical properties	Kartikeyan B et al.	2022	Institute of Technology, Chennai, , India
19	Additive Manufacturing and Characterization of Metal Particulate Reinforced Polylactic Acid (PLA) Polymer Composites	Ved S. Vakharia et al.	(2021)	University of California, San Diego, USA

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, mechanical properties of the 3D printed product in this study was evaluate by the tensile test, flexural test and FEA analysis. Overall methodology recorded in Figure:

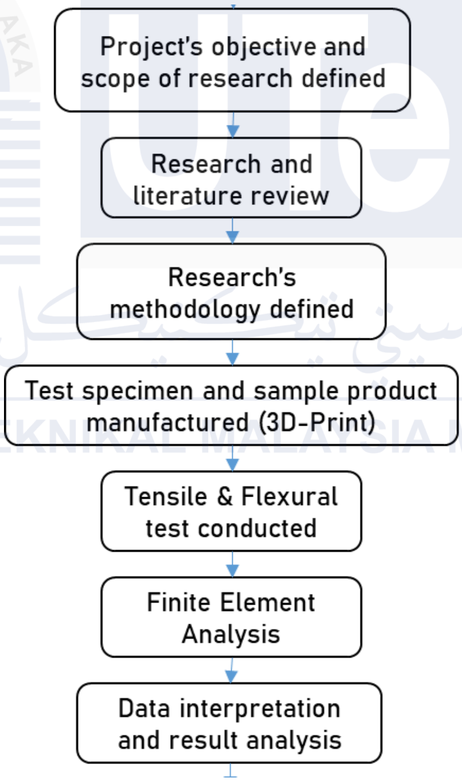


Figure 3-1 Methodology Flowchart

3.2 Material

Filaments used in this study pure PLA filament, metal-PLA filaments and wood-PLA filament. Pure-PLA filament consist of 100% PLA while metal-PLA and wood-PLA consist of 30% of each metal and wood particles composite with 70% of PLA.

3.3 Sample Design

This thesis included two type of sample design, ASTM D638 for tensile test and ASTM D790 for flexural test. For each test, three samples from each type of filaments prepared to make sure the obtained results of mechanical properties are reliable.

3.3.1 ASTM D638

Used for determining Tensile strength, Youngs modulus. The Specimen shown in Figure 3-1.

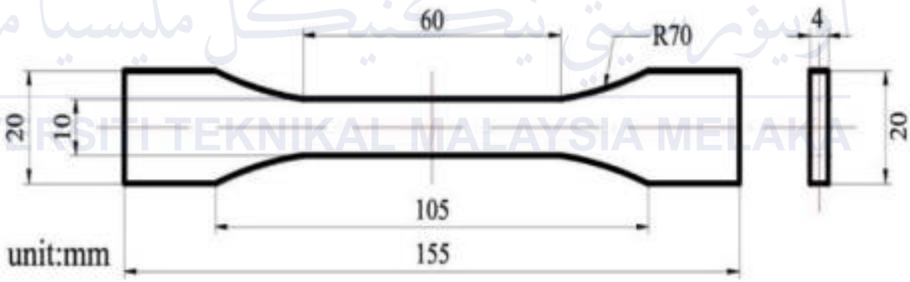


Figure 3-2 ASTM standard for tensile test (unit: mm). (Kartikeyan B. et al.)

3.3.2 ASTM D790

The bending resistance of a bar with the following measurements: 125 mm in length, 12.70 mm in breath, and 3.20 mm in thickness. The Specimen shown in Figure 3-2.

Figure 3-3 ASTM standard for flexural test (unit: mm). (Kartikeyan B. et al.)

3.4 Proposed Methodology

To investigate the mechanical properties, three different filament, wood filament, metal filament and PLA filament used. The experimental results from the testing compared to the FEA analysis done in Solidworks software.

Figure 3-4 Tensile Test and Flexural Test Specimens

For this thesis, the methodology conducted divided into two parts which are preparation part and experimental and analysis part. the methodology conducted during preparation part are CAD modelling and FDM process. Meanwhile for the experimental and analysis part, methodology involved are tensile test, flexural test and FEA analysis.

3.4.1 CAD Modelling

For CAD modelling, SOLIDWORKS 2021 is the programme of choice. The user interphase of SolidWorks is quite simple to use, intuitive, and quick to get the hang of. By specifying and manipulating design parameters, users of SolidWorks can build and alter designs thanks to the usage of parametric modelling. This functionality facilitates quick design revisions, seamless iterations, and effective exploration of many design possibilities. Advanced surfacing capabilities, sheet metal design, weldment design, mould design, and many more features are just a few of the robust design tools and features available in SolidWorks. These tools facilitate the creation of complicated and complex geometries while meeting a variety of design requirements.

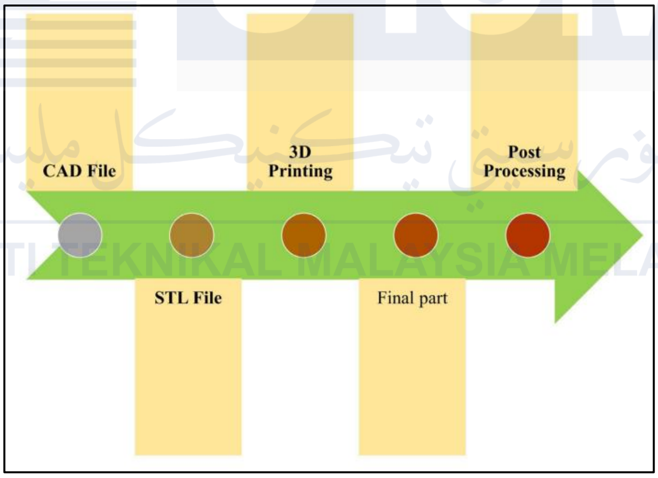


Figure 3-5 (a) Basic AM process (A. Jandyalet al.)

3.4.2 Fused Deposition Modelling (FDM)

As for AM method, the method used is Fused Deposition Method (FDM). FDM is an AM technology that uses thermoplastic materials to create 3D objects layer by layer. Numerous thermoplastic materials are compatible with FDM, such as nylon, PETG (polyethylene terephthalate glycol), PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), and more. Strength, flexibility, heat resistance, and aesthetic possibilities are just a few of the material attributes that can be customised with this variation.Support structures can be produced by FDM printers to facilitate the printing of intricate geometries or overhangs. Good mechanical strength and durability can be demonstrated by FDM products, particularly when high-performance thermoplastics are used. Strong bonds between the printed layers are produced by the layer adhesion in FDM, producing sturdy and useful items. In order to introduce students to 3D printing and product development, FDM is frequently utilised in educational settings.

Finite Element Analysis (FEA)

The next method used are Finite Element Analysis (FEA). FEA is a computational method used to analyze the behavior of structures and components by dividing them into smaller, interconnected elements. It is a numerical technique in engineering and design fields to evaluate the strength, stiffness, and performance of mechanical systems. In this study, mechanical properties, which are the stress-strain analysis, and flexural properties analyzed.

The basic concept of FEA is to represent a complex structure or component as a mesh of finite elements. Each element is a small, geometrically defined shape, such as a triangle or quadrilateral in 2D analysis or a tetrahedron or hexahedron in 3D analysis. The behavior of the structure is approximately by analyzing the behavior of these individual elements and their interconnections.

3.4.3 Tensile Test

A tensile test or tension test, is a mechanical test where a sample is subjected to a controlled tension until failure. For this methodology, tensile test conducted to determine the mechanical properties of materials, which are maximum stress, tensile strength and elastic force. This test is widely used in materials science and engineering to understand how materials behave under axial stretching forces.

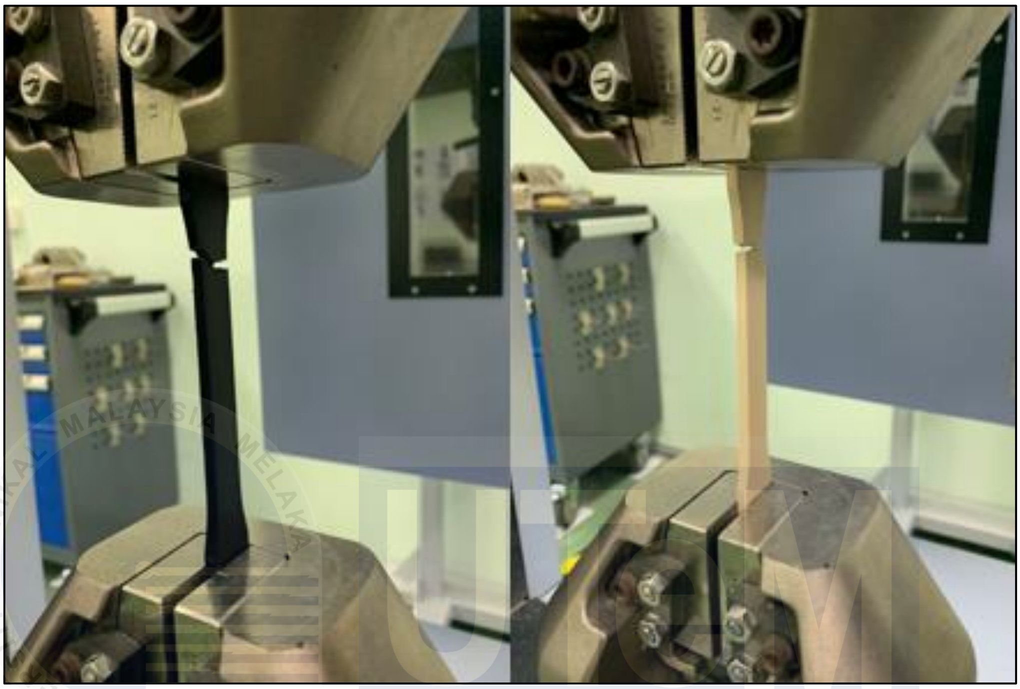


Figure 3-6 Tensile Test

3.4.4 Flexural Test

Flexural test or a bending test or transverse test, is a test used to determine the flexural or bending properties of a material. This test helps assess the material's behavior under applied bending loads and is commonly perform on materials such as metals, plastics, ceramics, and composites.

Figure 3-7 Flexural Test

3.5 Experimental Setup

Experimental setup started with creating 3D model using SolidWork software. The process flow shows as follow:

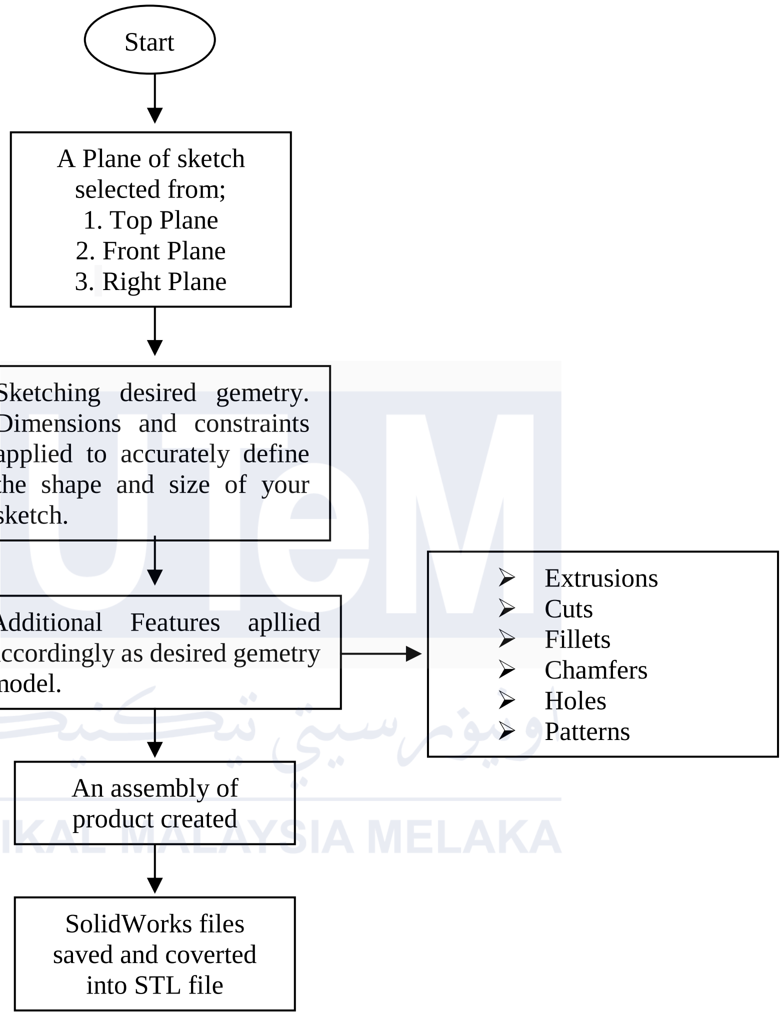


Figure 3-8 (a) CAD modelling steps flowchart

As for FDM, the machine used is Flashforge Creator Pro. This machine has its own capability and limitations that need to be follow while handling the machine during AM process. FDM involves the following steps:

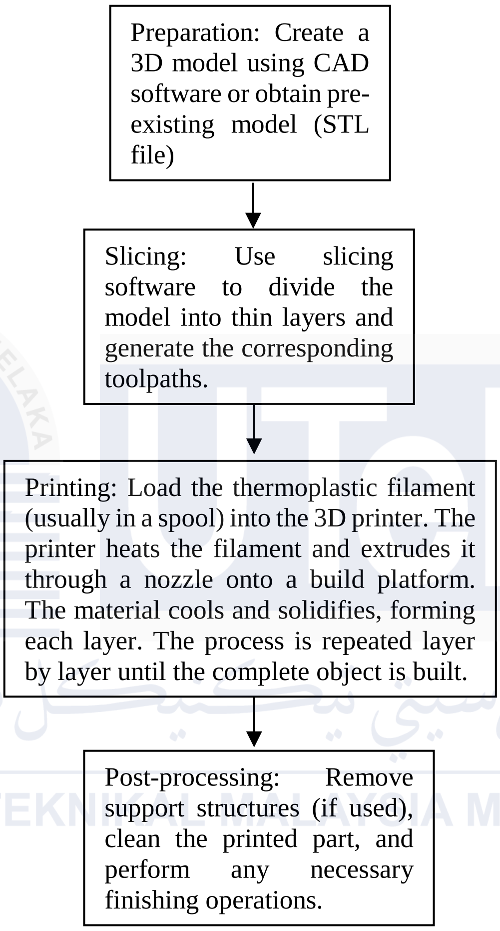


Figure 3-9 (b) Basic step conducting FDM machine

As for Finite Element Analysis (FEA), the software used is SolidWorks. FEA done to get the data on the tensile strength and flexural of the 3D printed product. FEA involves the following steps:

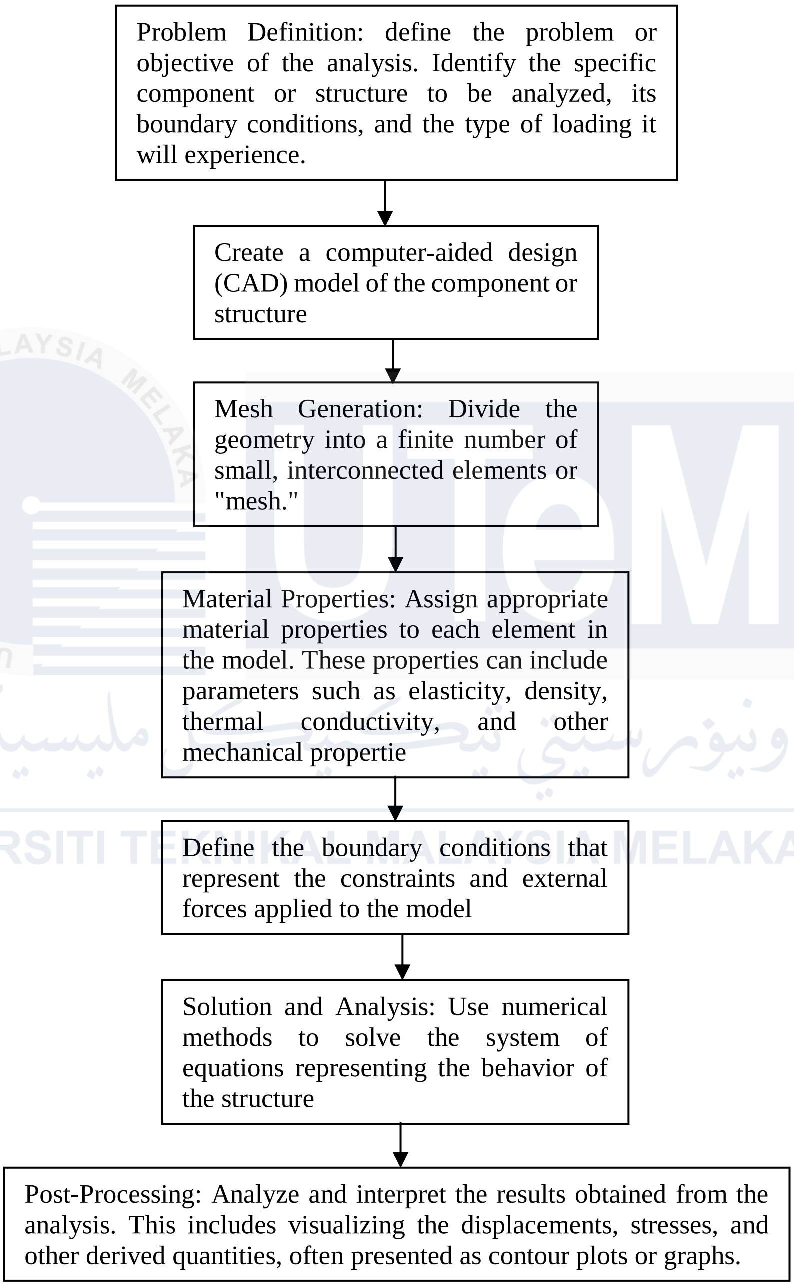


Figure 3-10 FEA process flowchart

3.5.1 Parameters

Table 3-1 Key for 3D printing parameters

Material	Original PLA, wood and metal
Layer height	*0.2 mm*
Extruder diameter	*0.4 mm*
Temperature of Extruder	*200 ℃*
Print Speed	*60 mm/s*
Infill (percentage ; pattern)	*80% ; grid / cubic*
Raster angle	*45°*

3.5.2 Equipment

The FDM printer (Model: Creator Pro, Flashforge Co., Ltd., China) was used in this research. The control accuracy of the printer is about ±0.1–0.2mm. Mechanical properties were tested in a universal testing machine (Model: Autograph AGS-X Series, manufactured by Shimadzu Corporation, Japan) with a load of 100 kN. The samples were loaded up to material failure at a displacement rate of 50mm/min and 10mm/min for tensile tests and flexural tests, respectively. In flexural tests, the support separation was set to 50mm.

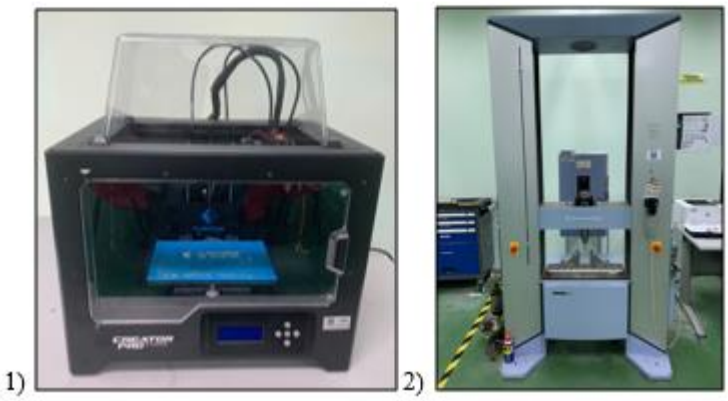


Figure 3-11 1) Flashforge Creator Pro 3D-Printer 2) Shimadzu Universal Testing Machine

3.6 Summary

This chapter presents the proposed methodology used in investigating and identified mechanical properties of different type of filaments. The primary focused of the proposed methodology is to identified the tensile strength and flexural of the product using different type of filaments. This method can be used widely in material testing analysis.

In this chapter, the parameters of proposed methodology are stated. There are a few parameters that need to be follow while handling and conducting AM process. These parameters are important to ensure that the sample produced will provided more accurate data analysis.

In general, the proposed methodology are the experimental setup for a complete AM process and material (filament) testing. Different type of filaments used are differ in terms of mechanical properties by pros and cons.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter presents the results and analysis on the proposed methodology. At the end of the research, result and data analysis for tensile test, flexural test and FEA for each type of filaments is discuss.

4.2 Results and Analysis

Tensile and flexural test for three type of filaments done by using Shimadzu Universal Testing Machine. There are three aspects analyze from each test which are maximum force, tensile strength and elastic force. For each type of filaments, three sample used to get the average data. The detail results of each filaments is shown in tables and figures below.

FEA analysis also done on both specimen to analyze its von Mises stress. Von Mises stress and material's yield strength commonly analyze to assess whether yielding is likely to occur. If the von Mises stress exceeds the yield strength, it suggests that yielding and potential plastic deformation may occur in the material.

4.2.1 Tensile Test Result

Table 4-1 Result of Tensile Test Original-PLA

Original - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	1111.65	1059.15	1122.84	1097.88
Tensile Strength (MPa)	20.5861	19.6139	20.7933	20.3311
Elastic Force (GPa)	1.56971	2.15572	1.40939	1.71161

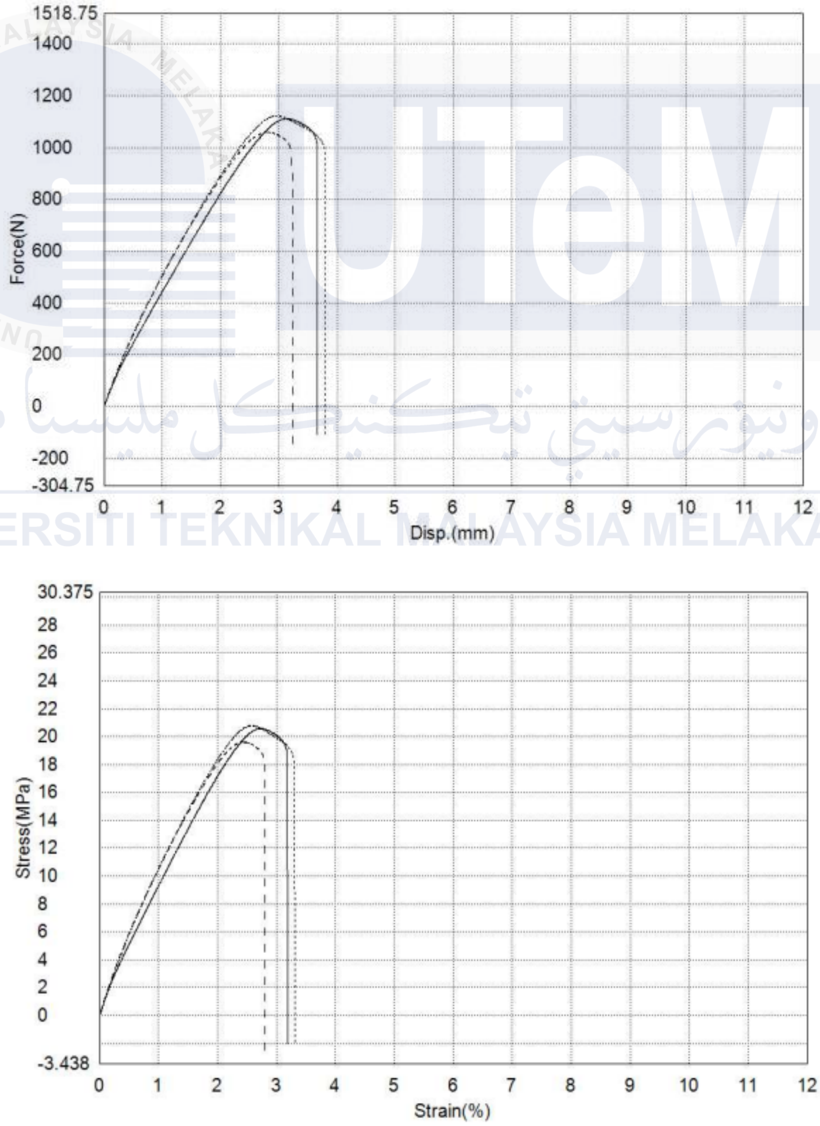


Figure 4-1 Tensile Test Result (Original-PLA)

Table 4-2 Result of Tensile Test Metal-PLA

Metal - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	1008.02	1170.60	1112.62	**1097.08**
Tensile Strength (MPa)	18.6670	21.6778	20.6041	**20.3163**
Elastic Force (GPa)	1.36853	1. 2.11011	1.87887	**1.78584**

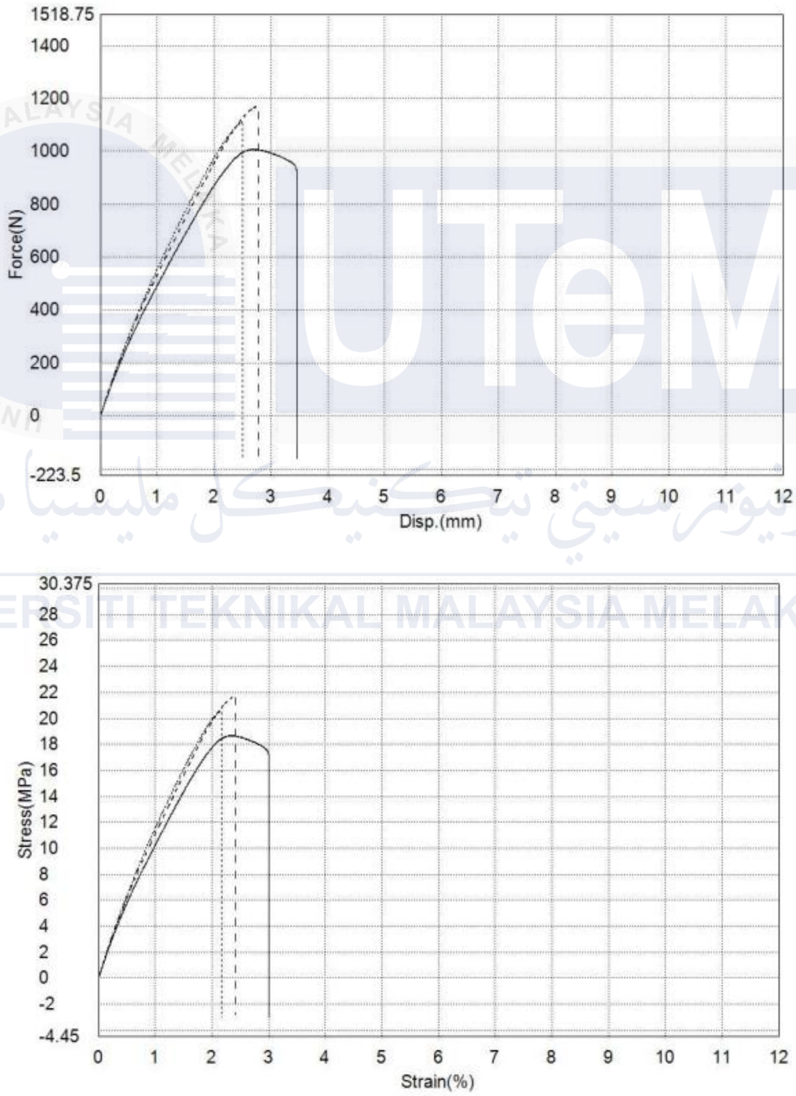


Figure 4-2 Tensile Test Result (Metal-PLA)

Table 4-3 Result of Tensile Test Wood-PLA

Wood - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	590.626	636.260	636.260	**620.900**
Tensile Strength (MPa)	10.9375	11.7826	11.7744	**11.4982**
Elastic Force (GPa)	1.10789	1.59476	1.74790	**1.48352**

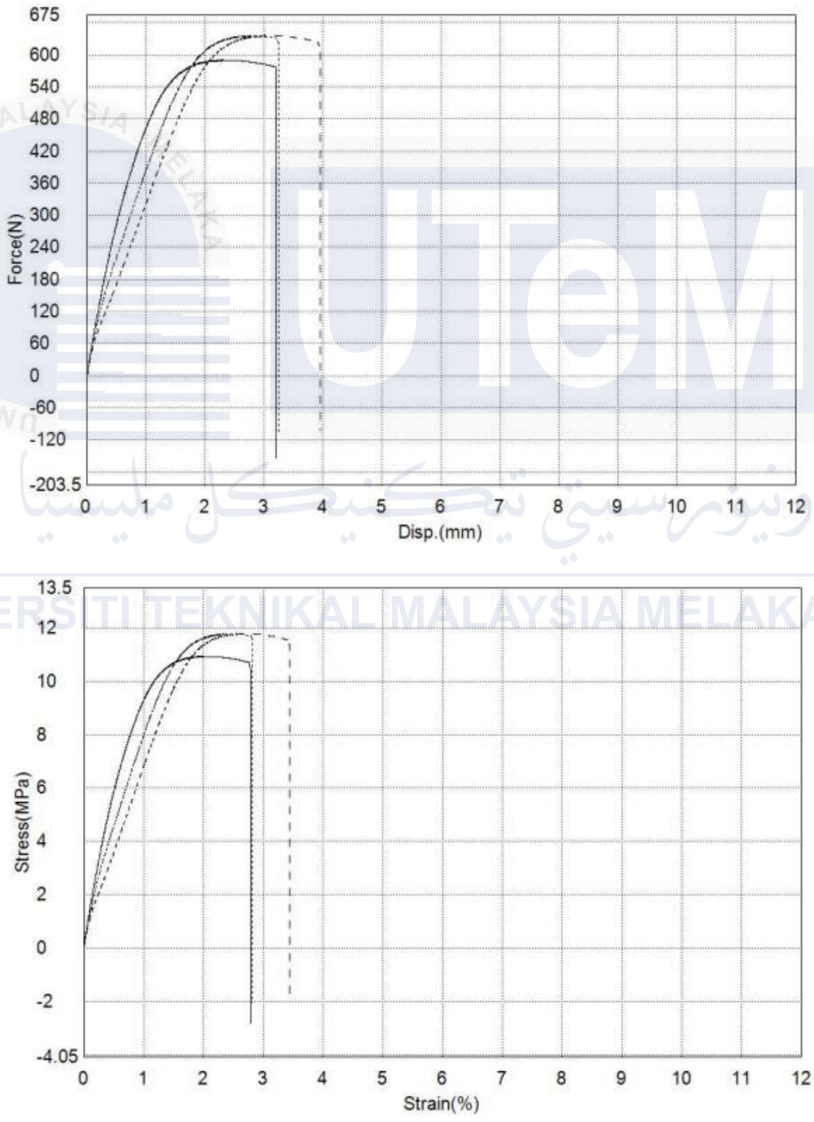


Figure 4-3 Tensile Test Result (Wood-PLA)

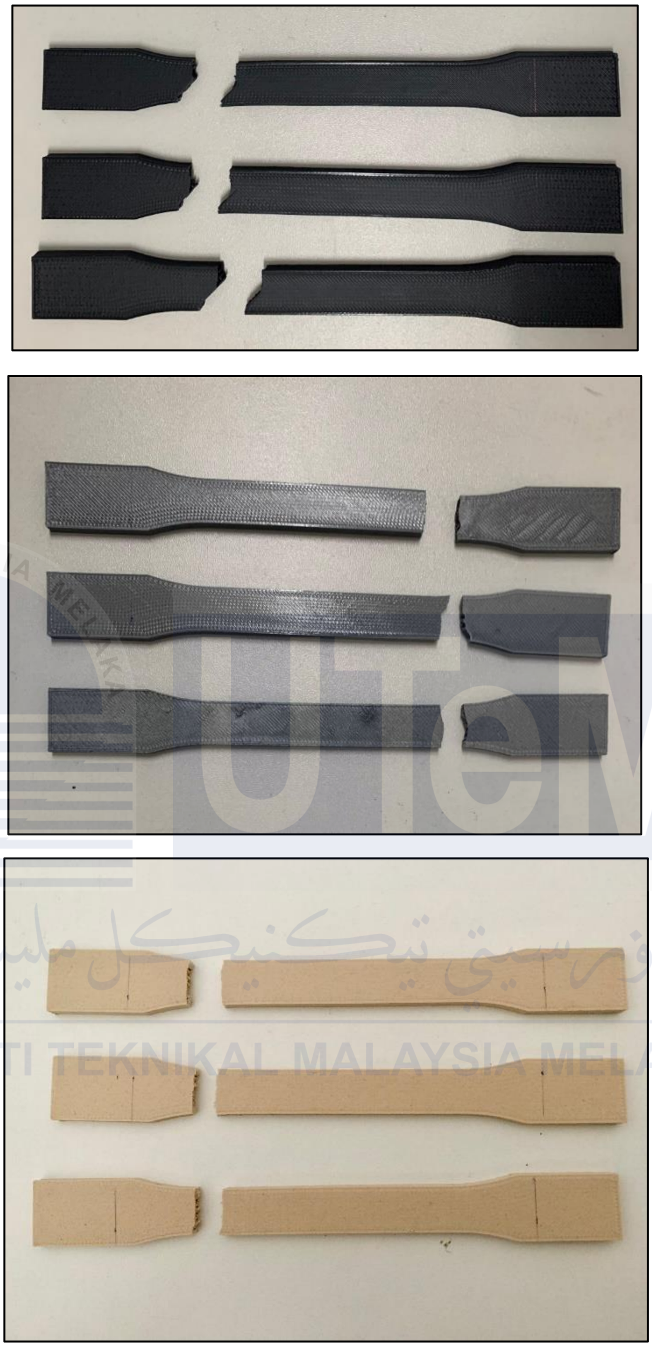


Figure 4-4 Specimen After Tensile Test

Table 4-4 Tensile Test Result Comparison

	Original-PLA	Metal-PLA	Wood-PLA
Maximum Force , N	1097.88	1097.08	620.900
Tensile Strength, MPa	20.3311	20.3163	11.4982
Elastic Force, GPa	1.71161	1.78584	1.48352

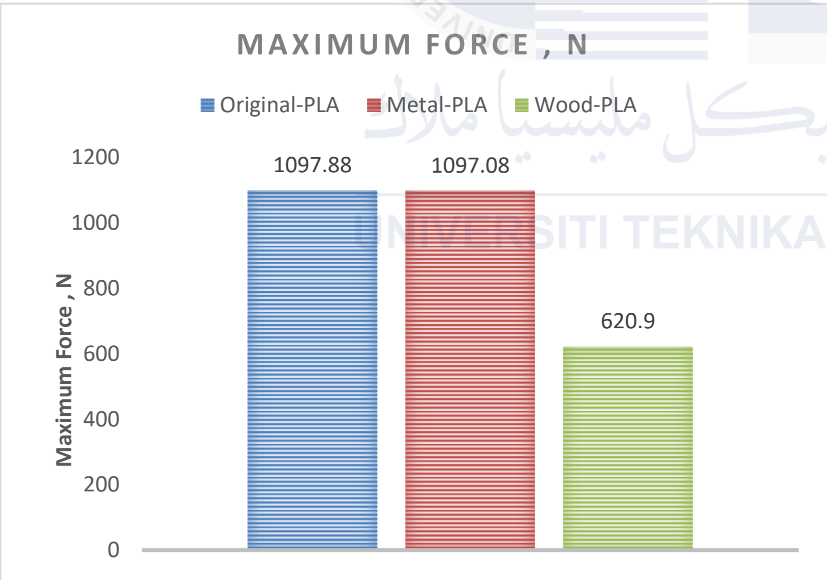


Figure 4-5 Maximum Force , N (Tensile Test)

Based on the graph shown in Figure 4-5, the highest maximum force recorded from tensile test is 1097.88 N for original-PLA. Metal-PLA recorded 1097.08 N of maximum force, which 0.1 N differ from the original-PLA result. However, wood-PLA recorded the lowest maximum force, which is 620.9 N. Percentage difference between metal PLA to original PLA is 0.07% while for wood PLA to original PLA is 55.5%.

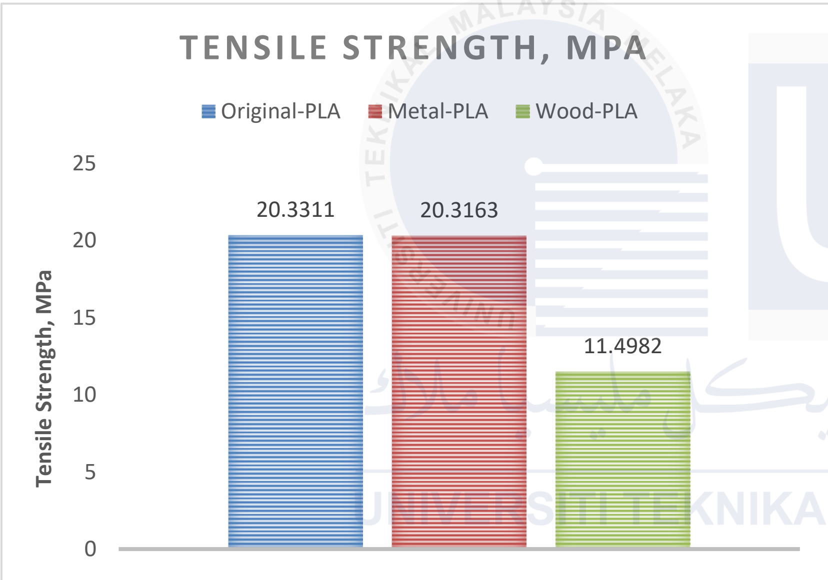
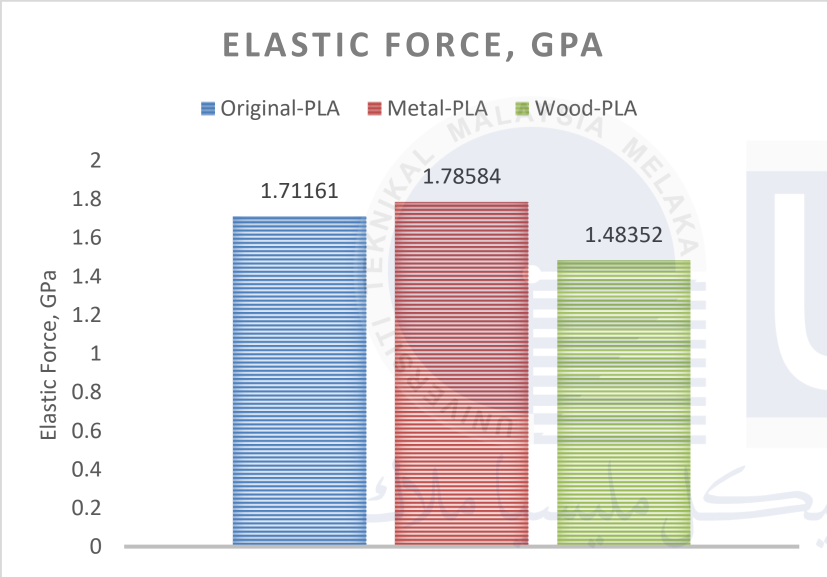


Figure 4-6 Tensile Strength, Mpa (Tensile Test)

Based on the graph shown in Figure 4-6, the highest tensile strength recorded from tensile test is 20.3311 MPa for original-PLA. Metal-PLA recorded 20.3163 MPa of tensile strength, which slightly differ from the original-PLA result. However, wood-PLA recorded the lowest tensile strength, which is 11.4982 MPa. Percentage difference between metal PLA to original PLA is 0.07% while for wood PLA to original PLA is 55.5%.

 *Figure 4-7 Elastic Force, Gpa (Tensile Test)*	Based on the graph shown in Figure 4-7, the highest elastic force recorded from tensile test is 1.78584 GPa for metal-PLA. Original-PLA recorded 1.71161 GPa of elastic force, which slightly differ from the metal-PLA result. However, wood-PLA recorded the lowest elastic force, which is 1.48352 GPa. Percentage difference between metal PLA to original PLA is 4.2% while for wood PLA to original PLA is 14.3%.

4.2.2 Flexural Test Result

Table 4-5 Result of Flexural Test Original-PLA

Original - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	93.6667	70.7626	90.0269	84.8187
Tensile Strength (MPa)	68.6036	51.8281	65.9376	62.1231
Elastic Force (GPa)	2.54443	3.08945	2.90196	2.84528

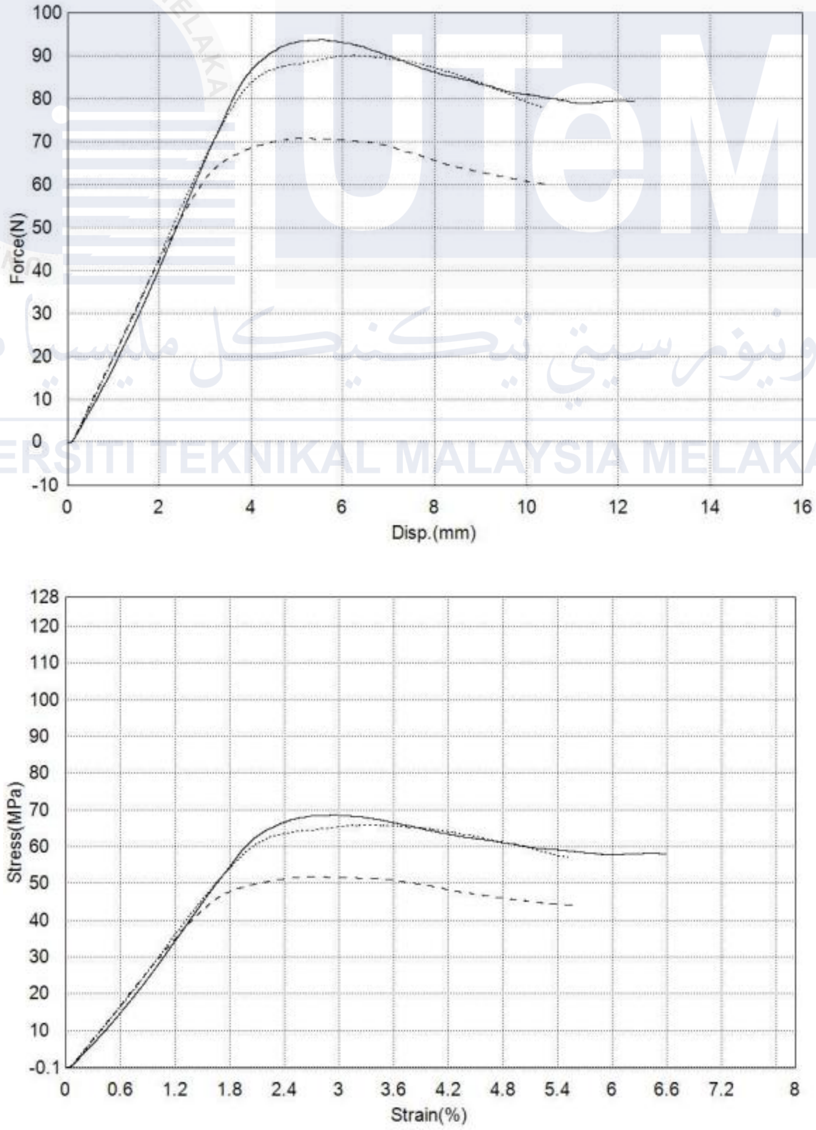


Figure 4-8 Flexural Test Result (Original-PLA)

Table 4-6 Result of Flexural Test Metal-PLA

Metal - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	88.4851	91.0918	88.5963	89.3911
Tensile Strength (MPa)	64.8084	66.7176	64.8899	65.4720
Elastic Force (GPa)	2.94773	2.64450	3.11536	2.90253

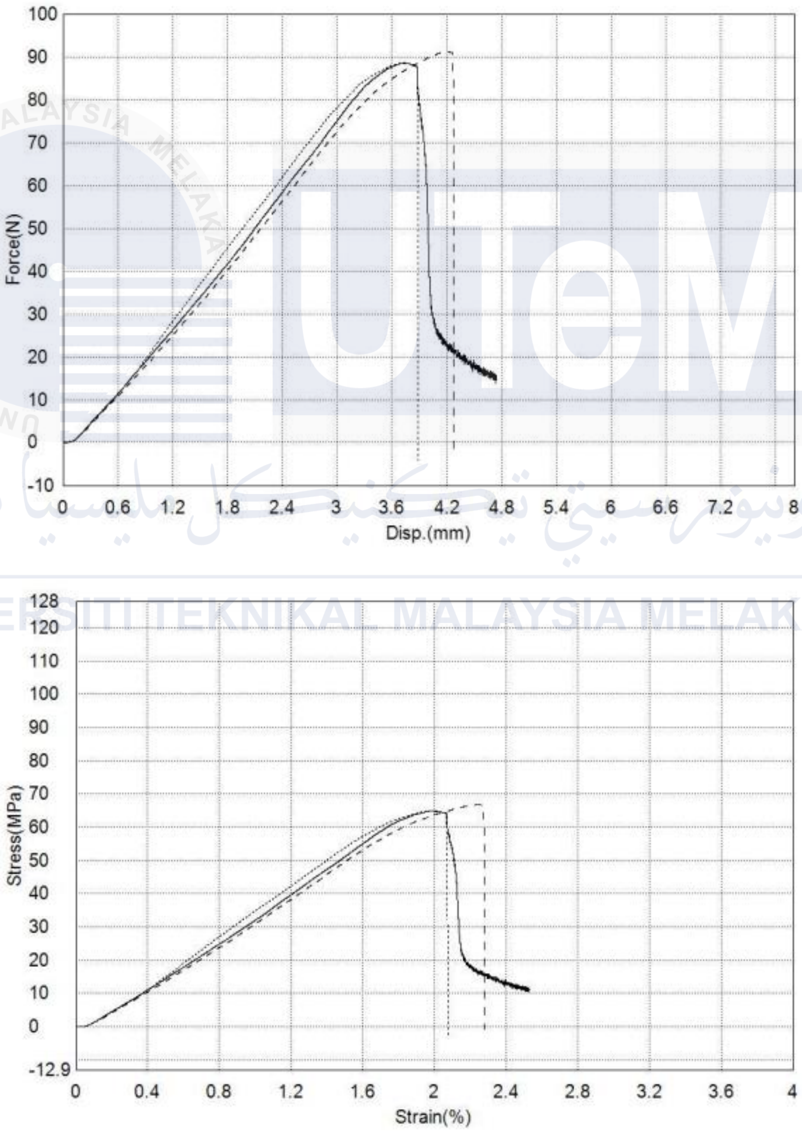


Figure 4-9 Flexural Test Result (Metal-PLA)

Table 4-7 Result of Flexural Test Wood-PLA

Wood - PLA				
	Sample 1	Sample 2	Sample 3	Average
Maximum Force (N)	59.3503	60.6378	58.4602	59.4828
Tensile Strength (MPa)	43.4695	44.4124	42.8176	43.5665
Elastic Force (GPa)	2.02516	2.01253	2.03514	2.02428

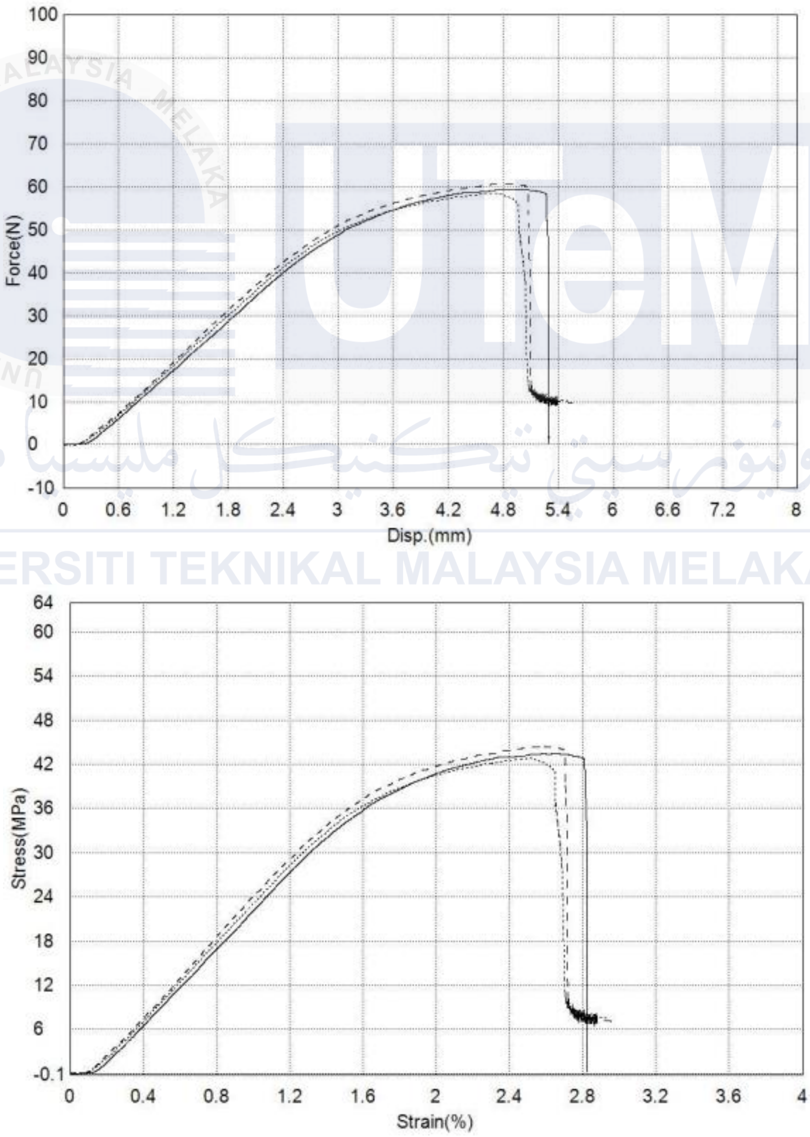


Figure 4-10 Flexural Test Result (Wood-PLA)

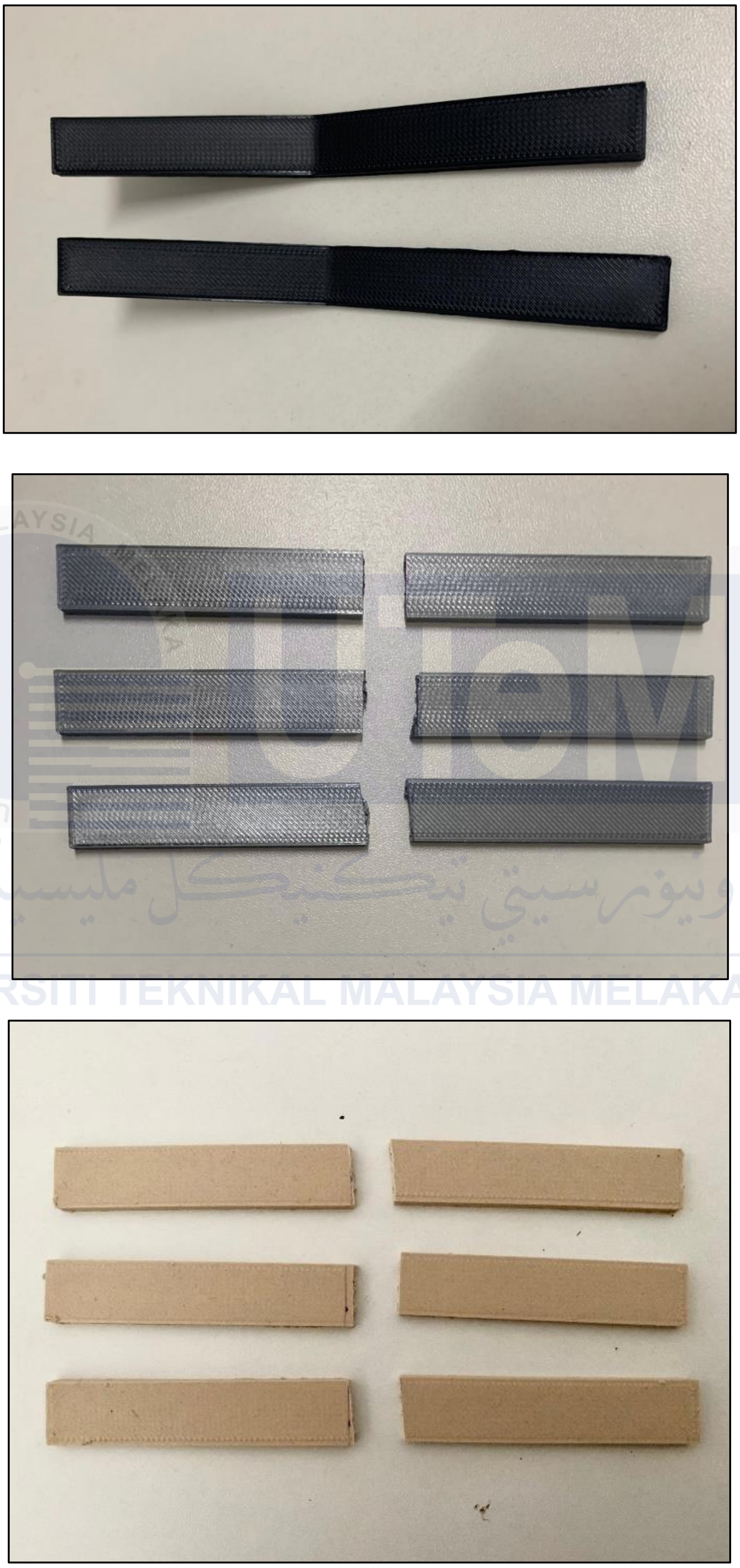


Figure 4-11 Specimen After Flexural Test

Table 4-8 Flexural Test Result Comparison

	Original-PLA	Metal-PLA	Wood-PLA
Maximum Force , N	84.8187	89.3911	59.4828
Tensile Strength, MPa	62.1231	65.4720	43.5665
Elastic Force, GPa	2.84528	2.90253	2.02428

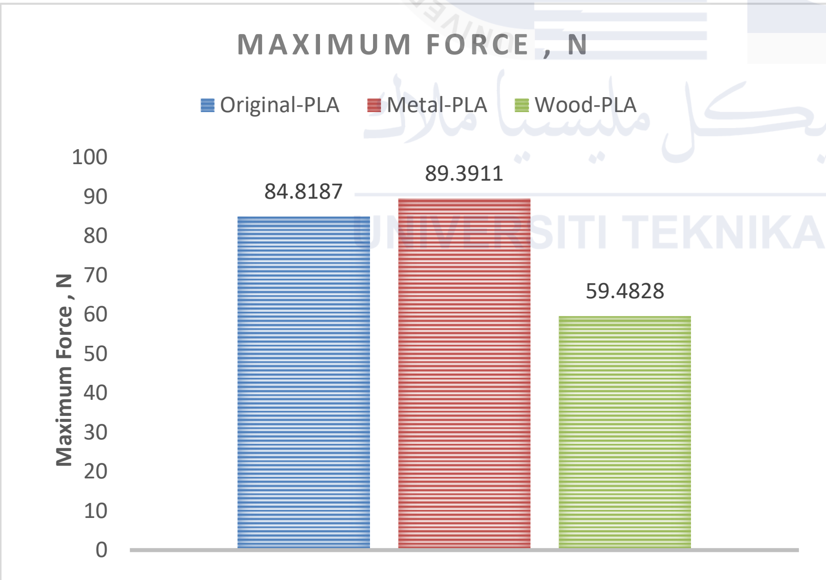
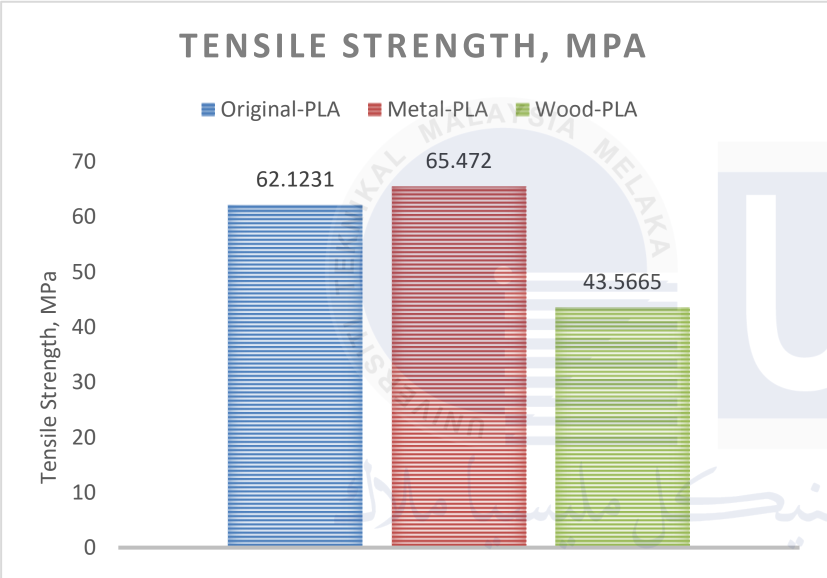


Figure 4-12 Maximum Force , N (Flexural Test)

Based on the graph shown in Figure 4-12, the highest maximum force recorded from flexural test is 89.3911 N for metal-PLA. Original-PLA recorded 84.8187 N of maximum force, which slightly differ from the metal-PLA result. However, wood-PLA recorded the lowest maximum force, which is 59.4828 N. Percentage difference between metal PLA to original PLA is 5.25% while for wood PLA to original PLA is 35.12%.

 *Figure 4-13 Tensile Strength, Mpa (Flexural Test)*	Based on the graph shown in Figure 4-13, the highest tensile strength recorded from flexural test is 65.472 MPa for metal-PLA. Original-PLA recorded 62.1231 MPa of tensile strength, which slightly differ from the metal-PLA result. However, wood-PLA recorded the lowest tensile strength, which is 43.5665 MPa. Percentage difference between metal PLA to original PLA is 5.25% while for wood PLA to original PLA is 35.12%.

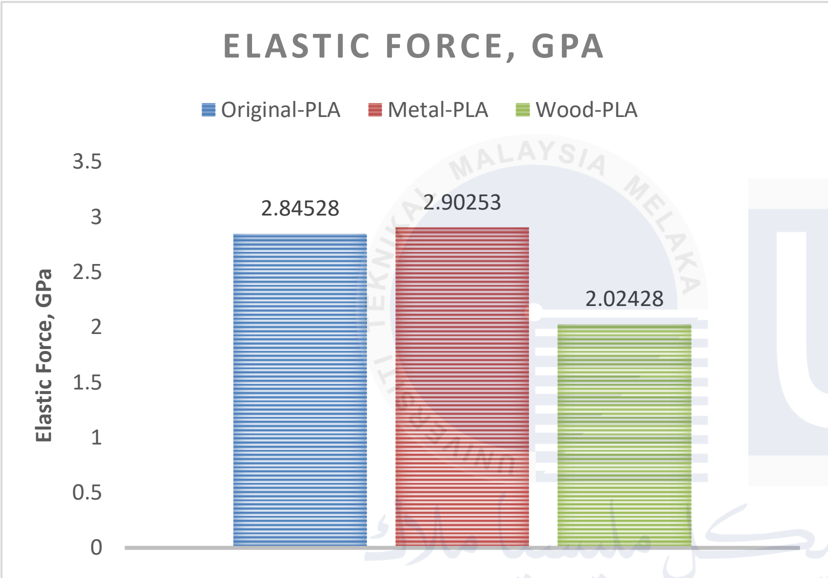


Figure 4-14 Elastic Force, Gpa (Flexural Test)

Based on the graph shown in Figure 4-14, the highest elastic force recorded from flexural test is 2.90253 GPa for metal-PLA. Original-PLA recorded 2.84528 GPa of elastic force, which slightly differ from the metal-PLA result. However, wood-PLA recorded the lowest elastic force, which is 2.02428 GPa. Percentage difference between metal PLA to original PLA is 1.99% while for wood PLA to original PLA is 33.72%.

4.2.3 Von Misses Stress Analysis

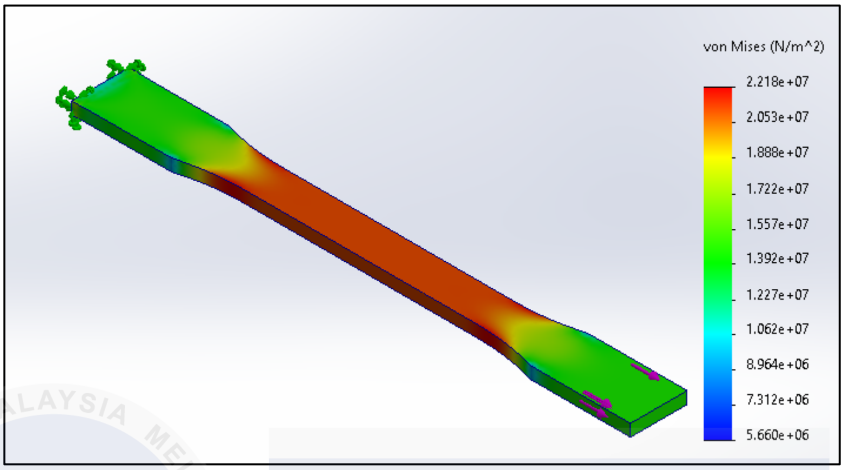


Figure 4-15 Stress Analysis (Original-PLA)

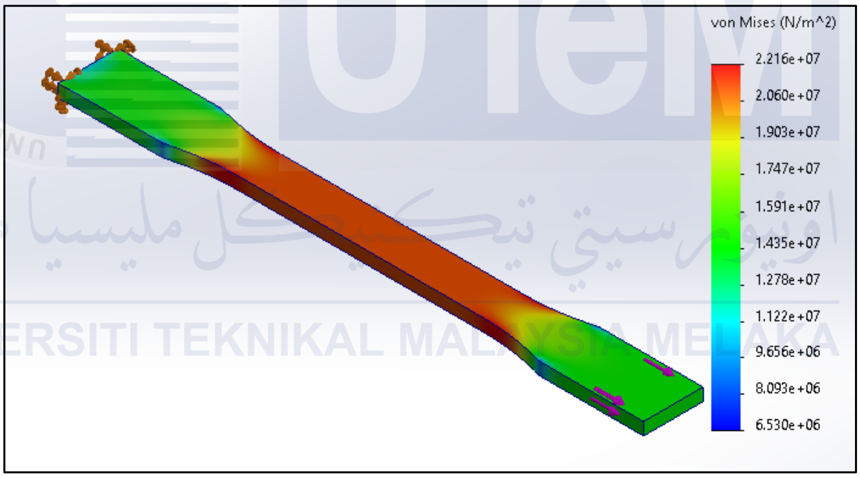


Figure 4-16 Stress Analysis (Metal-PLA)

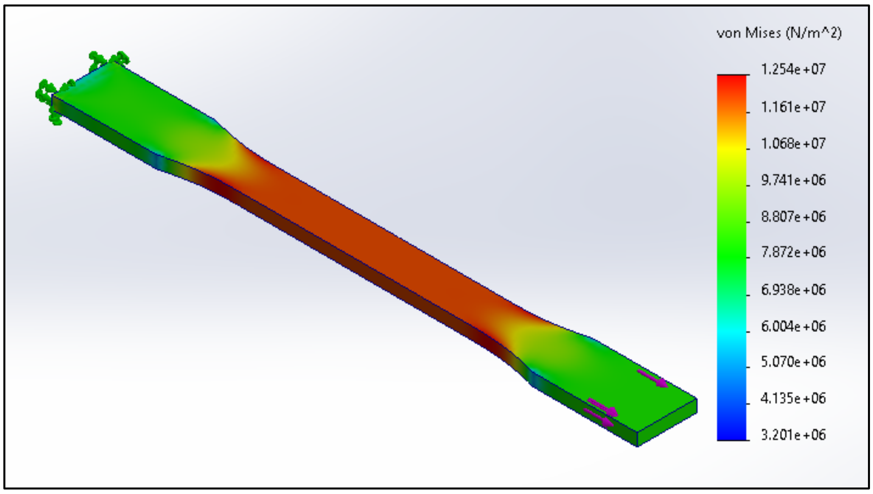


Figure 4-17 Stress Analysis (Wood-PLA)

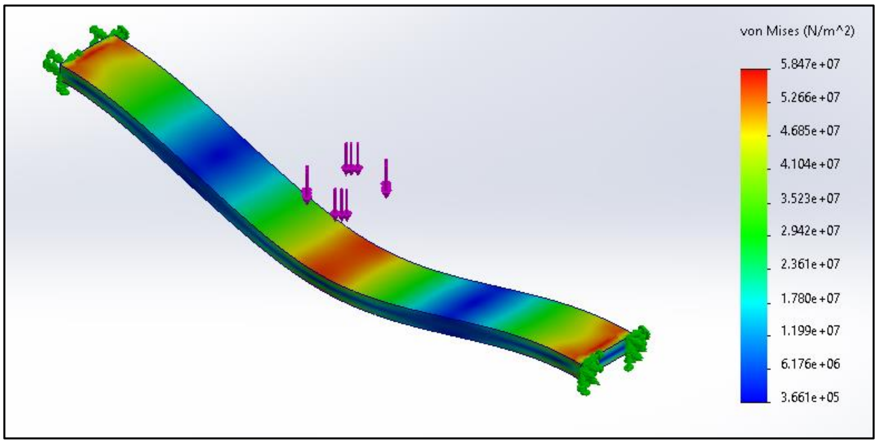


Figure 4-18 Flexural Stress Analysis (Original-PLA)

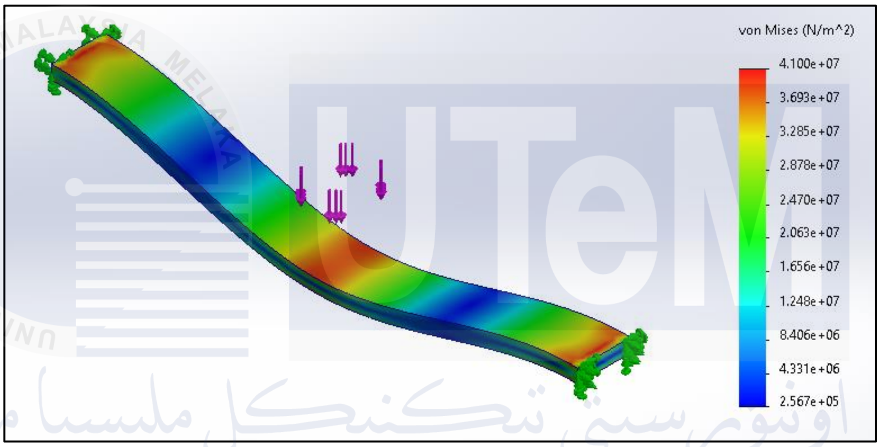


Figure 4-19 Flexural Stress Analysis (Wood-PLA)

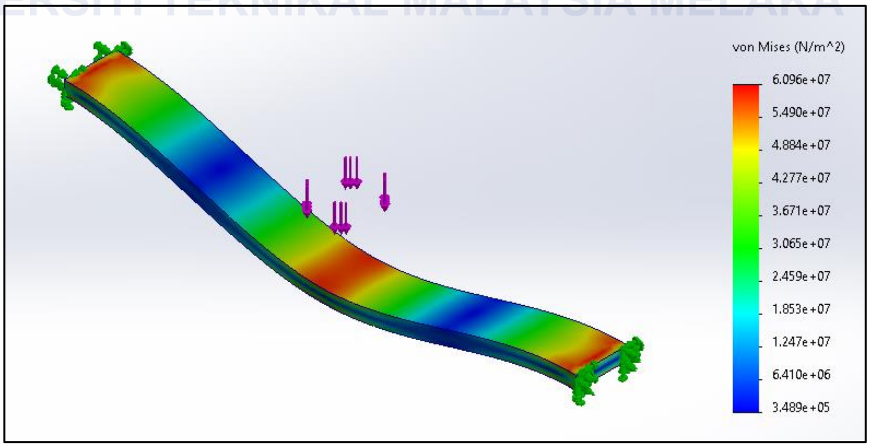


Figure 4-20 Flexural Stress Analysis (Metal-PLA)

Table 4-9 Von Misses Stress *(N / m²)* Analysis

Type of Filament	*ASTM 638*	*ASTM 790*
Original-PLA	2.218e+07	5.047e+07
Wood-PLA	1.245e+07	4.100e+07
Metal-PLA	2.216e+07	6.096e+07

Table 4-9 shows the von Mises stress results of ASTM638 and ASTM790 based on FEA analysis. The von Mises stress is use to assess yielding in materials (filaments). For ASTM638, original-PLA and metal-PLA recorded almost the same value of stress, which are 2.218e+07 N / m^2 and 2.216e+07 N / m^2 while wood-PLA recorded lower stress value, 1.245e+07 N / m^2. Percentage difference between original PLA and metal PLA recorded is 0.09 % while for wood PLA to original PLA is 56.19%. However, in ASTM790, metal-PLA recorded highest value, which is 6.096e+07 N / m^2 followed by original-PLA, 5.047e+07 N / m^2 and wood-PLA 4.100e+07 N / m^2. Percentage difference between original PLA and metal PLA recorded is 18.83% while for wood PLA to original PLA is 20.71%.

4.3 Sample Product

Further analysis also done on sample product printed using the three types of filament. The analysis of sample product concern on the physical properties and appearance of the printed product. As for the product, a replica of a famous landmark in Melaka chosen. The landmark chosen as printed product for physical analysis because of the shape of the landmark. The landmark is shows in Figure 4-31.

Figure 4-21 Melaka Landmark at Dataran Sejarah, MELAKA

Replica of the landmard is modelled using Solidworks and undergo AM process. Setting parameters used also same as mention in Chapter 3. The three types of filaments analyze which are original-PLA, wood-PLA and metal-PLA is used to produced the replica. Each replica was analyze in terms of physical appearance.

Figure 4-22 1) Sample Product (Wood-PLA) 2) Sample Product (Metal-PLA) 3) Sample Product (Original-PLA)

Table 4-10 Physical Analysis for Sample Product

	Original-PLA	***Metal-PLA***	***Wood-PLA***
Surface	*Major string*	*Minor String*	*Blobs*
Appearance	*Glossy*	*Metallic*	*Nature*
Aesthetics Value	*Glossy finish*	*Metal-like finish*	*Wood-like finish*

Based on physical analysis on sample products in Table 4-11, each filaments has their own appearance and finishing goods. The application and used of different type of filament must be considered on the purpose of the product. By choosing certain type of filaments, it can provide additional apperance value to the product itself.

4.4 Challenges and Counter Measure

Process	Challenges	Counter Measure
1. 3D-Printing process	➢ Layer splitting during the printing process	➢ Adjusting table-to-nozzle height and aligned the parameters
	➢ Stringing filaments during the printing process	➢ Configure and adjusting the nozzle's retraction speed and distance
2. Tensile Testing	➢ Specimen break when aligning to the tensile grip	➢ Hold the upper tensile grip during alligning process

4.5 Summary

This chapter presented case studies to mechanical properties of original-PLA, metal-PLA and wood-PLA. Mechanical properties analyze from three method of findings which aretensile tst, flexural test and fea analysis.

For tensile and flexural test, three elements of mechanical properties analyze which are maximum stress, tensile strenth and elastic force. For tensile test, highest maximum force recorded is original-PLA followed by metal-PLA and wood-PLA. As for tensile strength, highest value recorded is metal-PLA followed by original-PLA and wood-PLA. As for elastic force, highest value recorded is original-PLA followed by metal-PLA and wood-PLA. For flexural test, highest maximum force, highest tensile strength and highest elastic force recorded is metal-PLA followed by original-PLA and wood-PLA. Overall result from the tensile and flexural test analysis shows that filaments with metal particles is more ductility compared to pure filaments and filaments with wood particles.

FEA analysis done by interprating von Mises stress for ASTM638 and ASTM790. The result of analysis shows that original-PLA and metal-PLA obtained similar value of von Mises stress while wood-PLA recorded lower value for ASTM638. On the other hand, metal-PLA recorded higest value of von Mises stress for ASTM790 followed by original-PLA and wood-PLA. When compared to yield strength of PLA material, all the specimen will undergo deformation after 1000 N of load.

This chapter also present the physical properties of sample product for each filaments in term of surface, appearance and aesthethics value. Other than that, challenges and counter measure also included in this chapter for future reference.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on this study on mechanical properties of different type of filaments by FDM, it is proven that each filaments analyze which are original-PLA, metal-PLA and wood-PLA has their own mechanical properties and behaviours.

In conclusion, this study has done to identified the mechanical properties of original-PLA filaments compared to composite PLA which contain of metal particles andwood particles. Mechanical properties in terms of tensile strength, maximum forces, elastic force and von Mises stress was analyzed by conducting three methodoology which are tensile test, flexural test and Finite Element Analysis. The data collected from these methodology analyze and compared to identified its mechanical properties and summarize. The results from analysis shows the mechanical properties of original-PLA, metal-PLA and wood-PLA which can be used as references when using composite filament or implementing differerent type of filaments for the product. Physical properties of the sample product from each filaments also recorded for future reference.

Application of additive manufacturing during the preparation of the sample by using FDM process also recorded. Key paramaters of printing process also influenced the mechanical properties of the filaments. Therefore, uniform scaling of key parameters are essentials during the sample production to ensure that the result obtain from analysis is accurate.

5.2 Recommendation

For future improvements, it is possible to used different type of filaments in identifiy and investigate their mechanical and physical properties. The potential of composites filaments in industry are very highly recommended as of now additive manufacturing has been widely used in variables of industry segmentation. Variables of composite filaments can provide more options to the manufacturers to improve their manufacturing capabilities in implementation of variables type of filament into their products.

Composite filament offers several advantages over standard PLA filament due to the incorporation of additional materials. Composite PLA includes additives like metal particles, leading to increased tensile strength and overall durability. This makes it suitable for applications where stronger 3D printed parts are required. While standard PLA is already biodegradable, some composite PLA formulations for example wood-PLA, enhancing this eco-friendly characteristic. This can be important for manufacturers or users who prioritize sustainability and environmental impact. Thus, versatility of composite formulations makes it suitable for a wide range of industrial and functional applications.

REFERENCES

1. Sheoran, A. J, Harish, K (2020). Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Review and reflection on present research, Proceedings 21, 1659–1672. (https://doi.org/10.1016/j.matpr.2019.11.296)

2. Kartikeyan, B, Ponshanmugakumar, A, Saravanan,G, BharathGanesh, S, Hemamalini, V (2022). Experimental and theoretical analysis of FDM AM PLA mechanical propertie. Review, 1-8 (https://doi.org/10.1016/j.matpr.2023.05.105)

3. Nayak, P.K, Anshuman, K.S, Siba, S.M (2020). Effect of Process Parameters on the Mechanical Behavior of FDM and DMLS Build Parts, Proceedings 22, 1443–1451

4. Sandanamsamy, L, Mogan, J, Rajan, K, Harun, W.S.W, Ishak, I, Romlay, F.R.M, Samykano, M, Kadirgama, K (2023). Effect of process parameter on tensile properties of FDM printed PLA, 1-6 (https://doi.org/10.1016/j.matpr.2023.03.217)

5. Dharmalingam, G, Prasad, M.A, Salunkhe,S (2022) Investigation of impact strength at different infill rates biodegradable PLA constituent through fused deposition modeling, Proceedings 62, 551–558 (https://doi.org/10.1016/j.matpr.2022.03.591)

6. Bachhav, C.Y, Sonawwanay, P.D, Naik, M, Thakur, D.G (2022) Experimental and FEA analysis of flexural properties of 3D printed part, 1-9 (https://doi.org/10.1016/j.matpr.2023.02.262)

7. Sajjad, R, Butt, S.U, Saeed, H.A, Anwar, M.T, Rasheed, T (2023) Impact of multiple infill strategy on the structural strength of single build FDM printed parts, Processes 89 , 105–110 (https://doi.org/10.1016/j.jmapro.2023.01.065)

8. Agarwal, K.M, Shubham, P, Bhatia, D, Sharma, P, Vaid,H, Vajpeyi, R (2022) Analyzing the Impact of Print Parameters on Dimensional Variation of ABS

specimens printed using Fused Deposition Modelling (FDM), Sensors International 3, 100149 (https://doi.org/10.1016/j.sintl.2021.100149)

9. Reddy, M.V, Hemasunder, B, Chavan, P.M, Dish, N, Savio, A.P (2023) Study on the significance of process parameters in improvising the tensile strength of FDM printed carbon fibre reinforced PLA. 1-6 (https://doi.org/10.1016/j.matpr.2023.06.330)

10. Sahoo, S. Sutar, H, Senapati, P, Mohanto, B.S, Dhal, P.R, Baral, S.K (2023) Experimental investigation and optimization of the FDM process using PLA, Proceedings 74, 843–847 (https://doi.org/10.1016/j.matpr.2022.11.208)

11. Liu, Z, Lei, Q, Xing, S (2019) Mechanical characteristics of wood, ceramic, metal and carbon fiber-based PLA composites fabricated by FDM, J MATER TECNOL. 8(5), 3741–3751 (https://doi.org/10.1016/j.jmrt.2019.06.034)

12. Farah, S, Anderson, D.G, Langer, R (2016) Physical and mechanical properties of PLA, and their functions in widespread applications, Advanced Drug Delivery Reviews 107, 367–392

13. Vakharia, V.S, Kuentz, L, Salem, A, Halbig, M.C, Salem, J.A, Singh, M (2021) Additive Manufacturing and Characterization of Metal Particulate Reinforced Polylactic Acid (PLA) Polymer Composites, Polymers, 13, 3545 (https://doi.org/10.3390/polym13203545)

14. Dey, A, Eagle, I.N.R, Yodo, N (2021) A Review on Filament Materials for Fused Filament Fabrication, J. Manuf. Mater. Process, 5, 69. (https://doi.org/10.3390/jmmp5030069)

15. Çevik, U, Kam, M (2020) A Review Study on Mechanical Properties of Obtained Products by FDM Method and Metal/Polymer Composite Filament Production, Volume 2020, Article ID 6187149, 9 (https://doi.org/10.1155/2020/6187149)

16. Angelopoulos, P.M, Samouhos, M, Taxiarchou, M (2021) Functional fillers in composite filaments for fused filament fabrication, Proceedings 37 , 4031–4043 (https://doi.org/10.1016/j.matpr.2020.07.069)
17. Crump, S. S. (1991). Fast, precise, safe prototypes with FDM. *ASME*, *PED*, *50*, 53-60.
18. Mohamed, O. A., Masood, S. H., & Bhowmik, J. L. (2015). Optimization of fused deposition modeling process parameters: a review of current research and future prospects. Advances in manufacturing, 3, 42-53.
19. Ngoa, T.D, Kashani, A, Imbalzano, G, Kate T.Q. Nguyen, Hui, D, (2018) Additive manufacturing (3D printing): A review of materials, methods, applications and challenges, Composites Part B: Engineering, Volume 143,Pages 172-196, ISSN 1359-8368 (https://doi.org/10.1016/j.compositesb.2018.02.012)

APPENDICES

Gantt Chart

In Projek Sarjana Muda 1 (PSM 1), the focus of the study was on literature review, definition of the objective, problem statement, scope of work, methodology and preliminary results. Table 5-1 shows the timeline of project implementation in PSM 1.

Table 5-1 Gantt Chart for PSM I

Activity	Week													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Research study based on the title fo PSM I	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Research study on the additive manufacturing		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Scope of reasearch detailed study			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Define background, objective, problem statement, and scope of project (Chapter1) Literature review (Chapter 2)				✓	✓	✓	✓	✓	✓					
Define methodology and design steps (Chapter3)						✓	✓	✓						
First draft submission (Completed Chapter 1, 2 and 3)												✓		
Second draft submission (CorrectionChapter 1, 2 and 3)													✓	
Submit report via e-psm													✓	
Presentation (26th June)														✓

In Projek Sarjana Muda 2 (PSM 2), the focus of the study was on methodology, additive manufacturing activities,material testing, result and data analysis and conclusion. Table 5-2 shows the timeline of project implementation in PSM 2.

Table 5-2 Gantt Chart for PSM II

Activity	Week													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Research study and litterature review	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Defining Methodolgy (Chapter 3)		✓	✓											
Additive Manufacturing – 3D Printing (Chapter 3			✓	✓	✓	✓								
Filaments Testing – Tensile Test , Flexural Test (Chapter 3							✓	✓						
FEA Analysis (Chapter 4)									✓	✓	✓	✓		
Preliminary Findings (Chapter 4)				✓	✓	✓								
Result and Data Analysis (Chapter 4)							✓	✓	✓	✓	✓	✓		
Research Conclusion (Chapter 5)												✓	✓	
Report draft submission (Correction Chapter 1 - 5)													✓	
Submit report via e-psm													✓	
Presentation (16th January)														✓