MECHANICAL PERFORMANCE OF WOOD FIBER/POLYPROPYLENE COMPOSITE SANDWICH STRUCTURE FABRICATED BY FDM PRINTING TECHNIQUE

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Faculty of Industrial and Manufacturing Technology and Engineering

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MUHAMMAD DANISH BIN YAZID

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in fulfillment of the requirements for the degree of
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2024

DECLARATION

I declare that this Choose an item. entitled “Mechanical Performance of Wood Fiber/Polypropylene Composite Sandwich Structure Fabricated by FDM Printing Technique” is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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Date : 10/1/2024

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 (BMIW) with Honours.

Signature : ....

Supervisor Name : DR NUZAIMAH BTE MUSTAFA

Date : 6 Feb 2024

DEDICATION

To my beloved mother and father thank you for always supporting me throughout this Final year project.

To my supervisor, Dr NUZAIMAH BTE MUSTAFA who always helped me finish this project and always make sure I am on the right track and following all the formats for this report.

Assalamualaikum, first thanks to Allah SWT because with HIS grace I was able to complete this final project on time. Also, thank you to both my parents Yazid bin Ahmad and Zaiton binti Mohamad for always supporting everything I do in life. Thank you for helping me a lot to become someone who can do everything if there is effort. Thank you for funding my studies a lot since I was from semester 1. For this final project, they also spent a lot of money to realize the product that I created for this final project.

Not forgetting also to my Supervisor, Dr Nuzaimah for always patiently waiting for every progress from me. Thank you for understanding me and always giving me words of encouragement so that I don’t give up. Thank you for the encouragement and guidance of Dr, I was able to complete this project on time.

ABSTRACT

FDM fabrication provides the flexibility to produce complex geometric sandwich structures. This study investigated honeycomb, rhombus and square sandwich structures constructed using 3D printing using filament made of wood fiber and recycled Polypropylene (r-WoPPC). The filaments were produced with single extruder by incorporating 1 wt%, 3 wt%, 5 wt% wood fiber into recycled polypropylene (PP) matrix. SolidWorks software was used to develop the sandwich structure model and which was then converted into STL files for 3D printing. The mechanical performance of the sandwich was investigated for tensile and flexural strength, as well as the filament's morphological and water absorption characteristics. The square sandwich structure had the highest tensile and flexural strength when compared to the rhombus and honeycomb structures, which had 30% and 17% higher tensile and flexural strength, respectively. Meanwhile, 3 % wood fiber loading in r-WoPPC filament resulted in the highest tensile and flexural strength for all three structures. Furthermore, the surface morphology for the filament with 3% wood fiber revealed a smooth surface with good wood fiber and PP matrix adhesion. Additionally, the filament containing 3% of wood fiber had the lowest percentage of water absorbed, indicating that the r-WoPPC filament has fewer voids that prevent water from absorbing into the composite.

ABSTRAK

Fabrikasi FDM menyediakan fleksibiliti untuk menghasilkan struktur sandwic geometri yang kompleks. Kajian ini menyiasat struktur sarang lebah, rombus dan sandwic segi empat sama yang dibina menggunakan cetakan 3D menggunakan filamen yang diperbuat daripada gentian kayu dan Polipropilena kitar semula (r-WoPPC). Filamen dihasilkan dengan penyemperit tunggal dengan memasukkan 1 wt%, 3 wt%, 5 wt% gentian kayu ke dalam matriks polipropilena (PP) kitar semula. Perisian SolidWorks telah digunakan untuk membangunkan model struktur sandwic dan yang kemudiannya ditukar kepada fail STL untuk pencetakan 3D. Prestasi mekanikal sandwic telah disiasat untuk kekuatan tegangan dan lentur, serta ciri-ciri morfologi dan penyerapan air filamen. Struktur sandwic segi empat sama mempunyai kekuatan tegangan dan lentur yang paling tinggi jika dibandingkan dengan struktur rombus dan sarang lebah, yang masing-masing mempunyai kekuatan tegangan dan lenturan 30% dan 17% lebih tinggi. Sementara itu, 3% pemuatan gentian kayu dalam filamen r-WoPPC menghasilkan kekuatan tegangan dan lentur yang paling tinggi untuk ketiga-tiga struktur. Tambahan pula, morfologi permukaan filamen dengan gentian kayu 3% menunjukkan permukaan licin dengan gentian kayu yang baik dan lekatan matriks PP. Selain itu, filamen yang mengandungi 3% gentian kayu mempunyai peratusan air yang paling rendah diserap, menunjukkan bahawa filamen r-WoPPC mempunyai lebih sedikit lompang yang menghalang air daripada menyerap ke dalam komposit.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
%	-	Percent
Kg	-	Kilogram
rPP	-	Recycled Polypropylene
µm	-	Micron meter
PP	-	Polypropylene
NaOH	-	Sodium Hydroxide
ml	-	Milliliter
WF	-	Wood Fiber
D,d	-	Diameter
r-WoPPC	-	Recycled Wood Dust Polypropylene Composite
mm	-	Millimetre
Mpa	-	Megapascal
Rpm	-	Revolutions per minute
mm/s	-	Millimeters per second
psi	-	Pound per square inch
A	-	Ampere

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CHAPTER 1

INTRODUCTION

1.1 Background

With the increasing concern about the environmental impact of human activities, there has been a growing interest in using natural fibers as an alternative to synthetic fibers for reinforcement in composites, including plastic composites. Natural fibers offer several potential benefits in terms of sustainability, reduced carbon footprint, and overall environmental impact. natural fiber thermoplastic composites have gained more attention from industries, including the wood and plastic sectors. These materials offer some advantages over conventional reinforcement materials, making them attractive for various applications.

Polypropylene was selected as the matrix because it is one of the main commodity plastics that can be processed at temperatures in the region of 150°C and a melting point at 160-170°C. At low temperatures of -70°C or lower, PP fibers remain their excellent flexibility. At high temperature (about 200°C). Wood fiber material are widely used throughout the world in packaging applications because of their strength and cost. Wood fiber is a natural structure composed of cellulose fibers that contain numerous hydroxyl groups (-OH), which make them strongly hydrophilic. Wood fiber used in thermoplastics can give a lot of advantage such as low hardness, minimal abrasiveness, and good weight ratio. These characteristics help wood fiber thermoplastic composite function effectively.

The main interest of this project is to leverage the unique capabilities of additive manufacturing to create complex, lightweight, and highly efficient structures. At the end, sandwich structure will be fabricated using 3D printer and it will be tested. As to get the results analysis, several test will be carried out where the universal testing machine used.

1.2 Problem statement

The manufacturing techniques of composite sandwich panels were classified into nine main groups; hybrid composite, corrugated method, interlocking method, molds with inserts, laminating on flat core, flat core reinforced with pins, 3D printing method and metal and wood sandwich manufacturing. Comparisons between the various manufacturing techniques were performed based on bending strength. Unlike traditional methods of manufacturing products, 3D printing has many advantages: the use of low-cost and portable equipment for customizable production.

The material used in this study is Polypropylene (PP). Recycled PP can be used as an FDM material, except that it hasn't optimized the extrusion process (Stoof & Pickering, 2018). However, there are some potential issues to consider when using PP such as high shrinkage rate, which can affect the deformation of 3D printed part. By adding coupling agent such as wood fiber can overcome the problem. The addition of wood fiber and PP can improve the mechanical properties of the resulting composite, such as stiffness, strength, and impact resistance.

The ratio of composite will affect the filament and the result. The wood content of the material may vary up to more than 80% (Klyosov, 2007). Testing is the best way to determine and identify the ratio of wood fiber from 60 wt% to 85 wt%. Thus, 3 types of sandwich structure has been chosen in this research paper to investigate that it can improve the mechanical properties of the composite, such as tensile strength , flexural strength and Young's modulus.

1.3 Research objective

The main aim of this research was focused on a study of composite structure of wood fiber and recycled polypropylene. Specifically, the objectives are as follows:

1) To produce 3D printing filament with the material made of wood fiber and recycle Polypropylene.

2) To investigate mechanical properties of 3D printer sandwich structure sample made of wood fiber and recycle Polypropylene.

1.4 Scope of research

The scope of this research are as follows:

1) The compounding of the PP (matrix) with Wood Fiber (filler) using Z-blade mixer.

2) The materials were mixed together by using 180 °C with speed of 50 rpm for about 30 minutes or until the mixture is homogenous.

3) Tensile tests evaluate the mechanical performance of the wood fiber and polypropylene reinforced epoxy hybrid composites.

4) Analyze the structure of the sandwich composite using 3D printing method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The section starts by outlining the fundamentals of the research of 3D printing as well as the most widely used plastics in use today, which are used to make the filaments for 3D printing. I'll then go over the available natural fiber and composite materials used in 3D printing. In-depth analysis of the manufacturing process utilized to produce the filament as well as some theoretical information on the other method used in the experiment were also presented.

2.2 Composite structure

A composite structure is a material made up of two or more different materials that are combined to create a new material with improved properties. In the context of this paper, composite sandwich structures are discussed, which are made up of two thin outer layers (called skins) and a thicker inner layer (called the core) that is sandwiched between them (Al-Khazraji et al., 2023) .The skins are typically made of a strong, lightweight material such as carbon fiber or fiberglass, while the core can be made of a variety of materials such as foam, balsa wood, or honeycomb. The combination of these materials results in a structure that is strong, lightweight, and has good stiffness and impact resistance.

A composite structure is a material made up of two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components (Ichihara & Ueda, 2023). In this case, the composite structure is made up of carbon fiber and a polymer matrix. The framework proposed in the paper utilizes local latticing to improve the toughness of the composite structure.

2.3 Wood fiber

Wood fibers are commonly used as a filler material in wood-polymer composites, which are composite materials made by combining wood fibers with a polymer matrix, such as polypropylene. The type of wood fiber source used in the manufacturing process can have an impact on the physical and mechanical properties of the composites (Butylina et al., 2010).

2.4 Wood fiber treatment

The term "Fillers" refers to a wide range of inorganic and organic solid particle materials that are utilised in relatively high-volume loadings in plastics and can have irregular, acicular, fibrous, or plate-like shapes. The several inorganic and organic chemicals employed as fillers have a wide range of chemical structures, forms, shapes, sizes, and intrinsic qualities. The wood fiber must be treated before proceeding through the main process of making composites. In this study, there are numerous treatments for wood fiber that can be used. Silane treatment, Alkali, tannic acid, and Fe2+solution was often used (Nattakarn Hongsriphan, 2016)(Elsheikh et al., 2022a). To improve the interfacial bonding between composite materials, study was using a solution of silane and malleated coupling agents to treat PP/WF/rubber WPC (Elsheikh et al., 2022b).

Figure 2.1 The Alkali and MPS treatment (Nattakarn Hongsriphan, 2016).

2.5 Recycled Polypropylene

2.5.1 Recycled polypropylene in composite

Recycled polypropylene (rPP) is a type of polypropylene that was used as the matrix material for producing eco-friendly composites. The characteristics of polypropylene, even recycled polypropylene, remain unchanged. Due to increasing polypropylene demand over time, recycled polypropylene is produced. Thus, recycled polypropylene is produced for solving both the potential environmental issues that may arise in the future and the continued demand for the usage of polypropylene (Brachet et al., 2008). The recycled polypropylene composites also demonstrated a comparatively greater elastic modulus, pointing to possible environmentally friendly applications for waste materials in building construction (Ramos et al., 2020).

2.5.2 Recycled polypropylene reinforce natural fiber composite

The recycled polypropylene was subjected to extrusion and crushing cycles to simulate the recycling process. The addition of spruce fibers in the recycled polymer matrix caused the appearance of a crystalline phase and increased the polymer crystallinity (Quynh Truong Hoang et al., 2010) . Natural fibers are becoming a more popular option, especially in reinforced polymer composites, probably because the processing needed to create synthetic fibers uses a lot of energy. It is known that natural fibers reinforced with recycled polypropylene have good mechanical properties. The effect of the melt index of PP on the mechanical properties of the composites was also investigated, and maleic anhydride grafted PP was used as a compatibilizer to improve the poor interfacial interaction between the hydrophilic natural fibers and the hydrophobic matrix PP (Kim et al., 2008).

2.6 Extrusion

One of the most popular manufacturing processes in the plastics sector is extrusion. To create a product with a uniform cross section, a continuous process that involves pushing raw plastic through a die under controlled conditions. Extruders are used to create tubes, pipes, a range of building-related profiles, including windows, doors, and frames, as well as aviation-related components and structures. Thermoplastics are the most often used plastics in the extrusion process. According to the Bello & Onilude, (2021), an extruder's hopper, barrel, screw, heating bands, and die are all necessary components for briquette production. The paper discusses the effects of machine factors, material factors, and briquetting operating conditions on the quality of briquettes produced from sawdust admixture using a single-screw extruder. The machine factors include barrel and die configurations, shaft taper angle, and screw-barrel clearance, which significantly affect the extruder performance under steady conditions. The process involves feeding the sawdust admixture into the hopper of the extruder, which then moves the material through the barrel using a rotating screw. The screw applies pressure to the material, forcing it through the die at the end of the barrel, which shapes the material into the desired form. The quality of the briquettes produced is influenced by several factors, including machine factors, material factors, and operating conditions.

2.7 3D Printing

The method of creating three-dimensional solid items from a digital file is known as 3D printing.The creation of a 3D printed object is achieved using additive processes. An object is made using an additive technique by adding layers of material one after the other until the full object is formed. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object (Alaa Jabbar Almaliki, 2015). 3D printing technology was first commercialized in 1980 and has since experienced significant development and expansion into various industries . The technology has been used to create complex walls, endodontic guides, sport shoes, engine parts for the aviation industry, and tumor reconstruction.

The process begins with a CAD drawing, followed by slicing the object into layers, and then printing it layer by layer .There are several types of 3D printing technologies, including binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photo-polymerization (Shahrubudin et al., 2020). Over 350 types of industrial 3D printing machines and 450 materials have been identified in the marketplace. 3D printing technology has been widely applied in industries such as agriculture, biomedical, automotive, and aerospace. In the medical field, 3D printing has been used for personalized hydrogels, prostheses, therapeutic implants, and early detection of cancer.

2.8 Sandwich Structure

Many researchers pay attention to the fact that there is a sandwich structure that is now a strong energy absorption capacity based on good structural stability (He et al., 2023). Most of these sandwich structures are used in industries such as aircraft, satellites and bridges. The use of sandwich structure in construction is growing with advantages such as strength in a complex shape, design that makes it light and good materials for user (Aravindh et al., 2023). Using three-point bending tests, sandwich structures with body-centered cubic lattice cellular cores has been assessed for it strength. Many buildings and structures are considering the explosion resistance performance of structures in the field of construction and research by (Kalubadanage et al., 2021) shows that the absorption of blast energy can be reduced if using a sandwich panel structure. Aircraft and spacecraft structures have widely applied sandwich construction due to its high strength to weight ratio. This type of construction consists of thin, stiff and strong sheets of metal or fiber composite material. Figure 2.1 shows a metal or fiber composite material separated by a thick layer of low density material. There is a thick layer of low density material i.e. the core material may be light foam type as in Figure 2.3(a) or metal honeycomb as shown in Figure 2.3(b) or corrugated as shown in Figure 2.3(c). The core material is usually attached to the face sheet (Ratwani, n.d.).

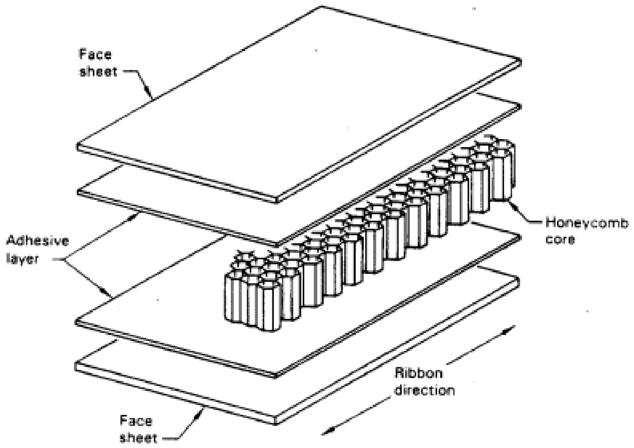


Figure 2.2 A metal or fiber composite material separated by a thick layer (Ratwani, n.d.)

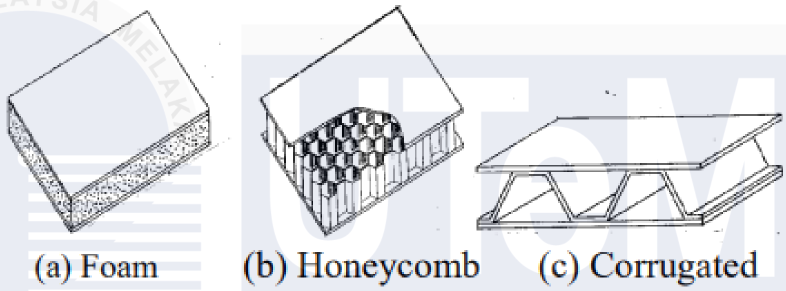


Figure 2.3 Types of core (Ratwani, n.d.)

2.8.1 Type of sandwich structure

The aerospace engineering field is quite popular with honeycomb structures. The regular area's weight is greatly reduced by this solution. Typically, the force elements and outside covering are made of honeycomb panels. Two loaded skins are linked by thin filler in this form of construction. High strain and compression stress are accepted by the skin reinforced with fillers (Kamalieva & Charkviani, 2017). Honeycomb structures may have lower fatigue qualities for cores with greater thickness. Manufacturing honeycomb structures requires careful attention to reduce failures. It is important to use temperature-cured adhesives, as room temperature adhesives tend to creep more than elevated cured adhesives. Stress raisers can become a factor if node attachment is not properly bonded. Honeycomb structures are mostly composed of the weight of the core material, making them relatively heavy (S. N. Abhinav, 2020).

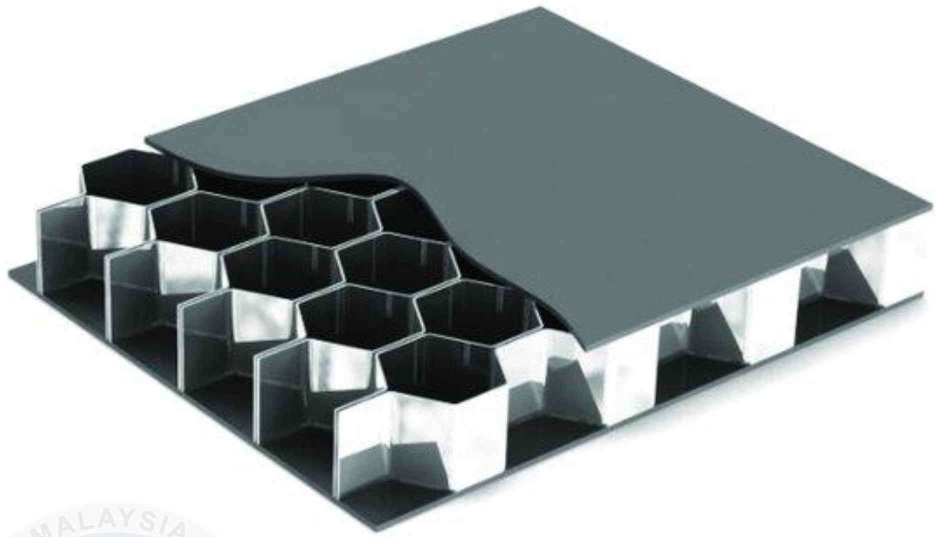


Figure 2.4 The honeycomb structure

The rhombus core shape exhibited the highest maximum load and flexural modulus among all the core shapes. The use of rhombus core shape in the sandwich structures allows for flexible design options to achieve desired strength and stiffness (Sugiyama et al., 2018). Various industries such as marine engineering, automobile and aerospace still using the rhombus core structure. The hexagonal core structure in the sandwich structure has less weight than the rhombus core structure, although the increase in weight is often ignored in terms of safety. The tensile strength and flexural strength capacity of sandwich panels with a rhombus core structure may be slightly lower than sandwich panels without a rhombus core structure (Shariff, 2016).

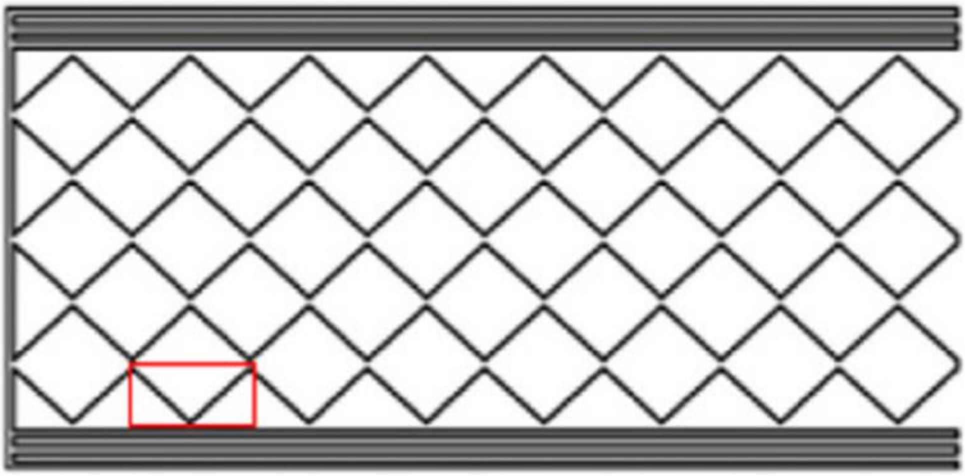


Figure 2.5 The rhombus structure (Sugiyama et al., 2018)

Square honeycomb metallic cores showed excellent shielding capabilities against air blast loading and according to Derseh et al., (2023), the hybrid sandwich structure shows minimal damage and even better is the square woven core. The square sandwich panel structure offers superior compressive properties and weight-saving properties compared to other core topologies. The square structure in sandwich panels provides stability and integrity even after the first crack, making it suitable for engineering applications that require structural durability (Nath & Nilufar, 2022). Square sandwich structure may have experienced significant inelastic buckling and shows major damage and is not strong compared to other structures. A square structure in a sandwich panel may not provide a high energy absorption capacity.

Figure 2.6 The square structure (Nath & Nilufar, 2022)

2.8.2 Sandwich structure built using FDM

Using 3D printing in the production of sandwich structures enables the preparation of thermoplastic-based composites that have better mechanical properties. 3D printing can produce complex geometric shapes as well as intricate designs for sandwich core structures. This allows customization and optimization of the structure based on specific needs (Andrzejewski et al., 2022).

3D printing can produce sandwich structures faster while at the same time increasing efficiency and reducing manufacturing time. 3D printing techniques provide the freedom to realize and design complex geometries, including structures and structures that are difficult to achieve with traditional manufacturing methods. The 3D printed sandwich structure can exhibit better mechanical properties in various mechanical properties such as tensile test, compression test and bending test (Faidallah et al., 2023).

FDM allows the use of various materials such as high-performance thermoplastics. It can be used in applications that are suitable for the production of sandwich structures.

lamination scheme control, such as raster layout can be applied in FDM printing techniques that can influence the mechanical behavior and load-carrying capacity of sandwich structures (Gohar et al., 2021).

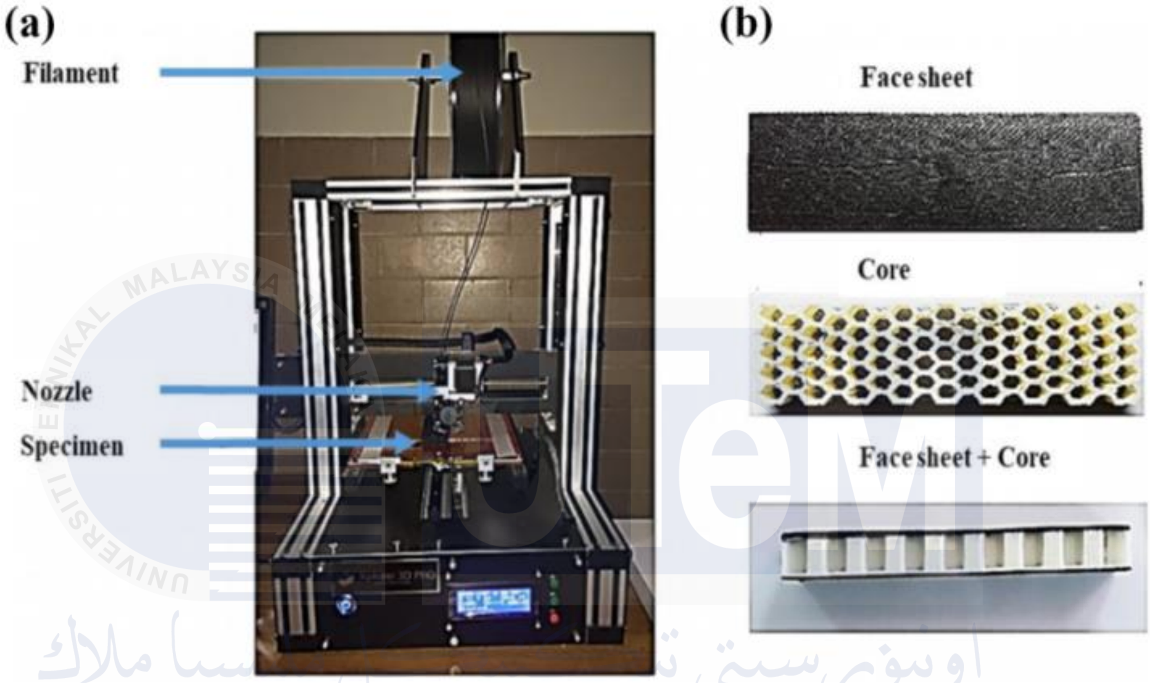


Figure 2.7 (a) 3D printer machine and (b) Exploded view of the sandwich panel using FDM (Gohar et al., 2021)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the research methods used to carry out the study in detail. Research methods presented in this chapter were performed to achieve the objectives of the study. Figure 3.1 shows the flow of the research methodology.

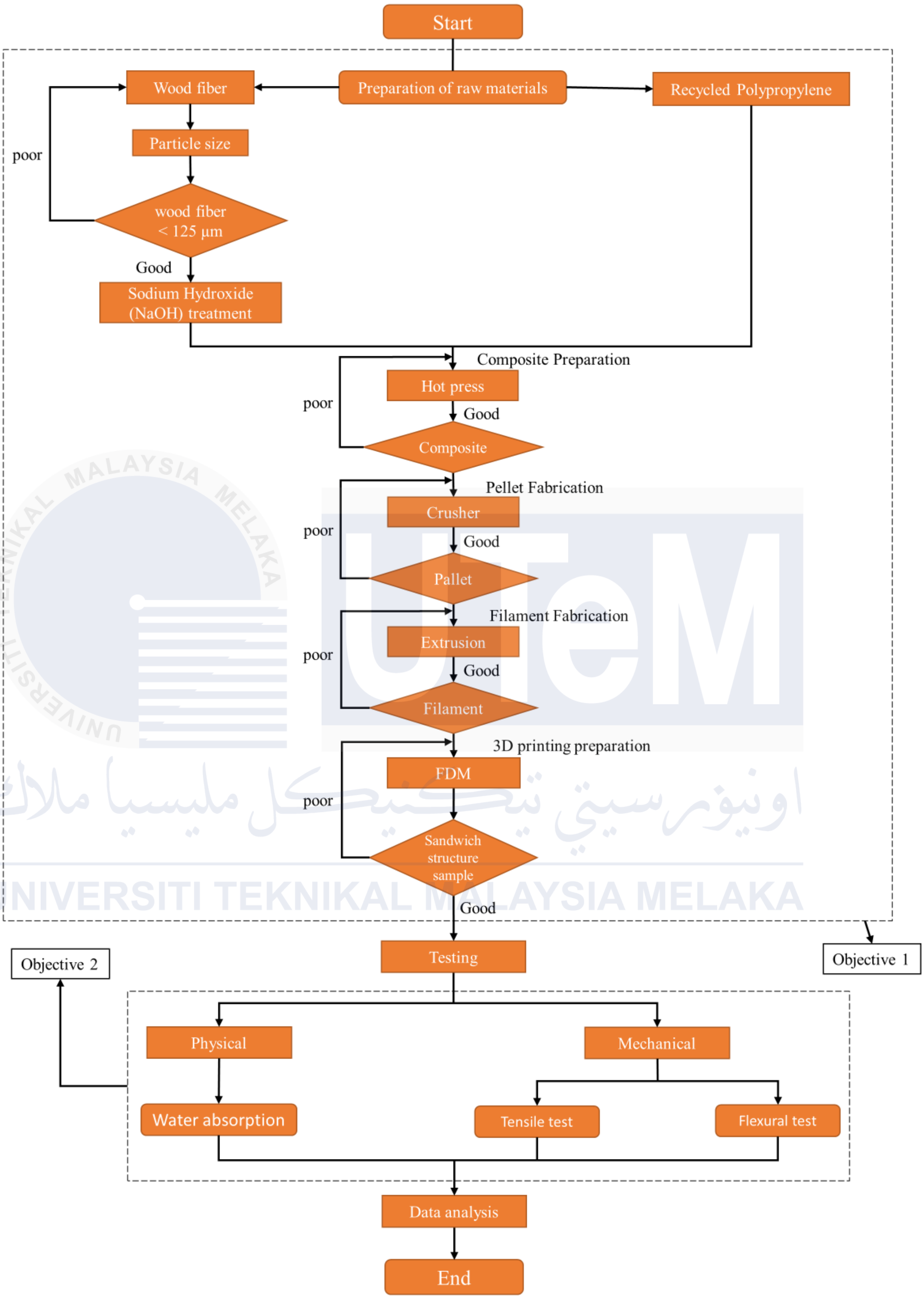


Figure 3.1 The process flow for this study

3.2 Raw Material

In this study, there are three main raw material to combine as composite. There are recycle polypropylene, wood fiber and sodium hydroxide (NaOH). All this material was collected in different condition.

3.2.1 Recycled Polypropylene

The recycled polypropylene was prepared by the lab in pellet condition. Referring to Figure 3.2, shows the matrix in the form of pellets. The product specification of the matrix was shown in Table 3.1

Table 3.1 Specification of recycled Polypropylene

Specification of recycled polypropylene	
Colour	White
Type	Virgin/recycled
Form	Pellet

Figure 3.2 Recycled polypropylene

3.2.2 Wood fiber

Wood Fiber was bought from an online platform called Shopee. In order to crush wood fibers into smaller particles, The wood dust needs to be washed using distilled water for the cleaning process and let it dry for 1 day. Figure 3.3 shows the raw material of the wood dust.

Figure 3.3 Wood Dust Fiber

3.3 Preparation Material

3.3.1 Preparation of wood fiber

The wood fiber used for this investigation was cleaned with distilled water to remove surface dust, then dried in a drying oven at temperatures below 80°C to ensure that its moisture. In this study, the needed size particle of wood dust is 125 µm. In order to crush wood fibers into smaller particles, the sieves process shows in Figure 3.4.

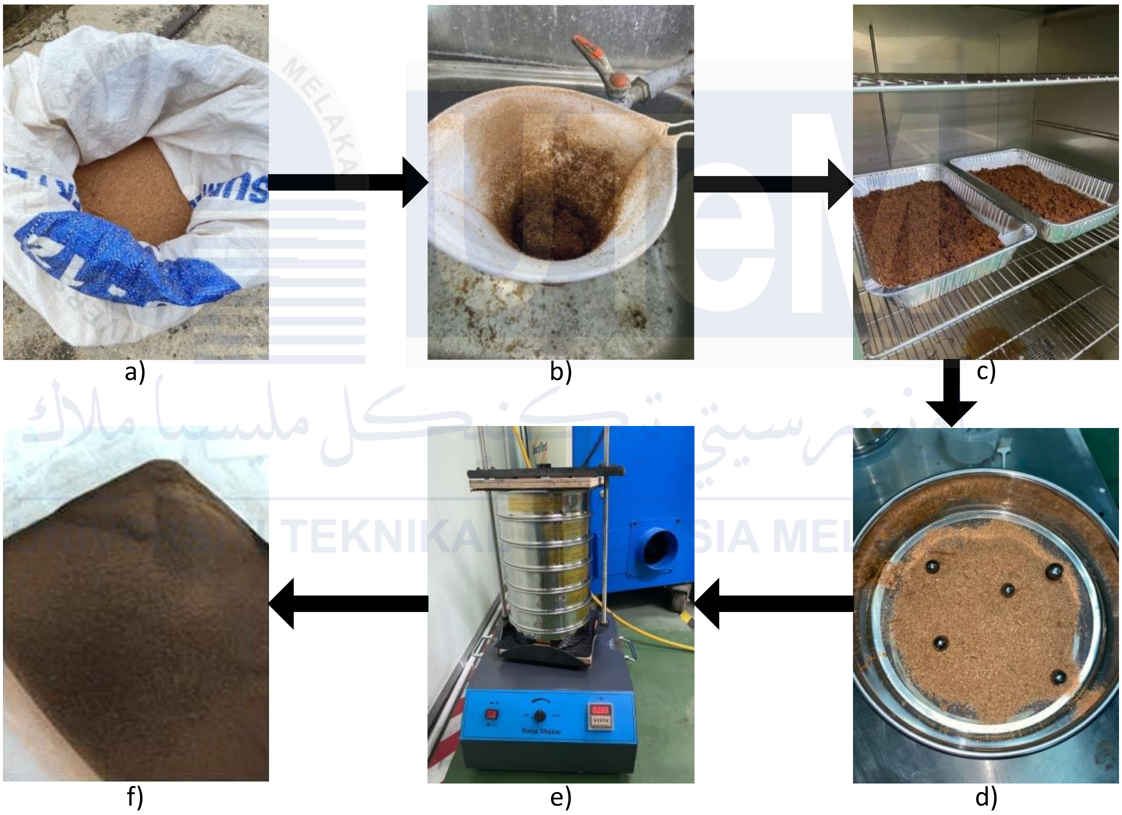


Figure 3.4 Sieving process (a) Raw wood dust from workshop, (b) wash using distilled water, (c) dry using oven for 24 hours, (d) staggered wood dust, (e) siever machine, and (f) 125µm of wood dust

3.3.2 Preparation of recycled polypropylene

Referring to Figure 3.5, recycled polypropylene is obtained from lab and it was already come in pellet form. The total that we used is refer by the composite loading which is 400g per sample. The total amount that we used is depending on percentage of wood dust. The condition of recycled polypropylene was good and ready to use it.

Figure 3.5 Recycle Polypropylene (rPP)

3.4 Wood fiber treatment

In this study, NaOH solution in form of pallet, as shown in Figure 3.6 was used for the alkaline treatment. The material specification for NaOH was shown in Table 3.2.

Table 3.2 Specification of Sodium Hydroxide

Item	**Specifications**
Physical Form	Pellets
Color	White
NaOH Content	More than 99 %
Water Solubility	100 %
Molecular Weight	40 g/mol

Figure 3.6 NaOH in pallet form

Alkaline treatment using NaOH is a chemical analysis which is it commonly used to improve the fiber properties such as thermal properties to improve the addition between fiber-matrix and it used to remove impurities on the fiber interface (Radzi et al., 2019). In this study, preparation of NaOH solution consist of 6% the concentration of NaOH at room temperature for 2 hours and 94% of distilled water will be add together to fulfill the 100% of mixture for NaOH solution. Meanwhile, the weight ratio for wateris shown in Table 3.3. Both NaOH and distilled water will be stirred together until the solution is dissolved. Referring to Figure 3.7, NaOH solution were dissolved with 6% of NaOH and 94% of H2O mixture. After that, the wood was washed several times thoroughly with running distilled water and dried in an oven at a temperature of 60 °C for 24 hours (Nafis et al., 2023a).

Table 3.3 Amount ratio of water

Material	Amount (ml)	Amount (%)
NaOH	60	6%
Water	940	94%
Total	1000	100%

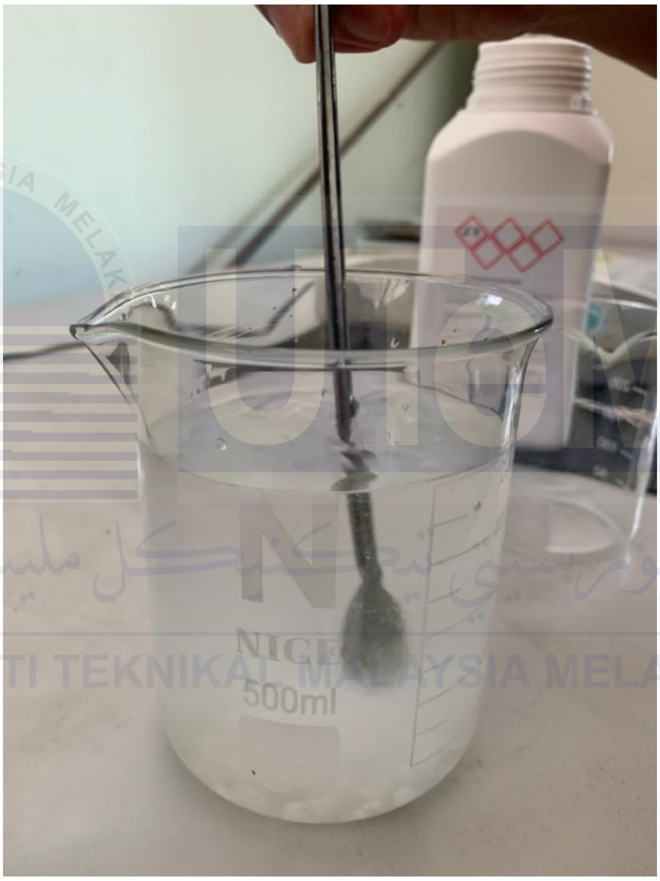
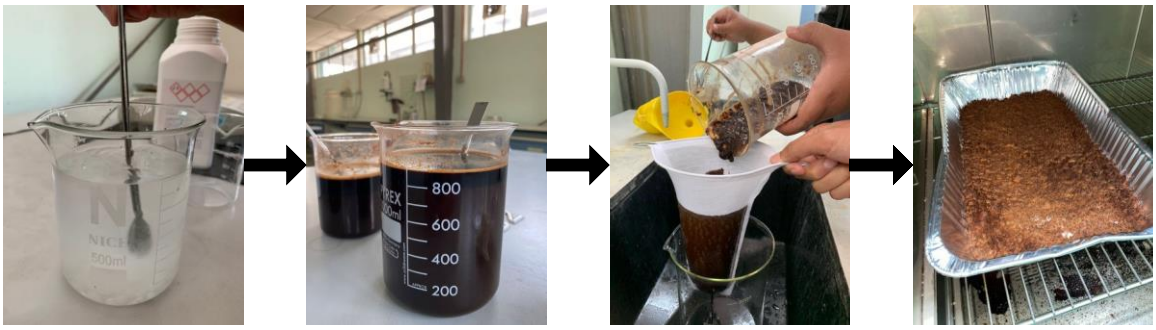


Figure 3.7 NaOH solution.



a) b) c) d)

Figure 3.8 Treatment process (a) preparation of NaOH, (b) soak wood fiber with NaOH, (c) filter using distilled water, and (d) dry treated wood fiber using oven

3.5 Preparation of filaments

3.5.1 Preparation of Recycle Polypropylene/Wood Dust

For each sample, the processed wood fiber represents about 1% to 5% (by weight) of the composite. The recycled polypropylene in pellet form is now prepared for mixing with treated wood dust. For each specimen, the amount of recycled polypropylene is calculated using Table 3.4. Each specimen weighs 600 g in total.

Table 3.4 The sum of wood fiber and recycle polypropylene

Sample	Wood Fiber	Recycle polypropylene
1	1% = 4g	596g
2	3% = 12g	588g
3	5% = 20g	580g

Figure 3.9 The mixed of wood dust and recycled polypropylene.

3.5.2 Hot press process

The recycled polypropylene was fully pressed with wood dust fiber in varying ratios. In order to ensure that the composite mixes properly. The recycled polypropylene was added first, followed by the fiber from wood dust. This process will be the hot process to make the composite mix well. After finishing the first process, the next process will be continue which is cooling press. Figure 3.10 show the type of hot press machine and Figure 3.11 show the output that will produce from the hot press process. Table 3.5 below shows parameters process for the hot press machine.

Table 3.5 The hot press processing parameters

Categories	**Value**
Upper and Lower Mold Temp (˚C)	185
Time (minute)	20 - 30
Pressure (psi)	1 - 2

Figure 3.10 Hot press machine

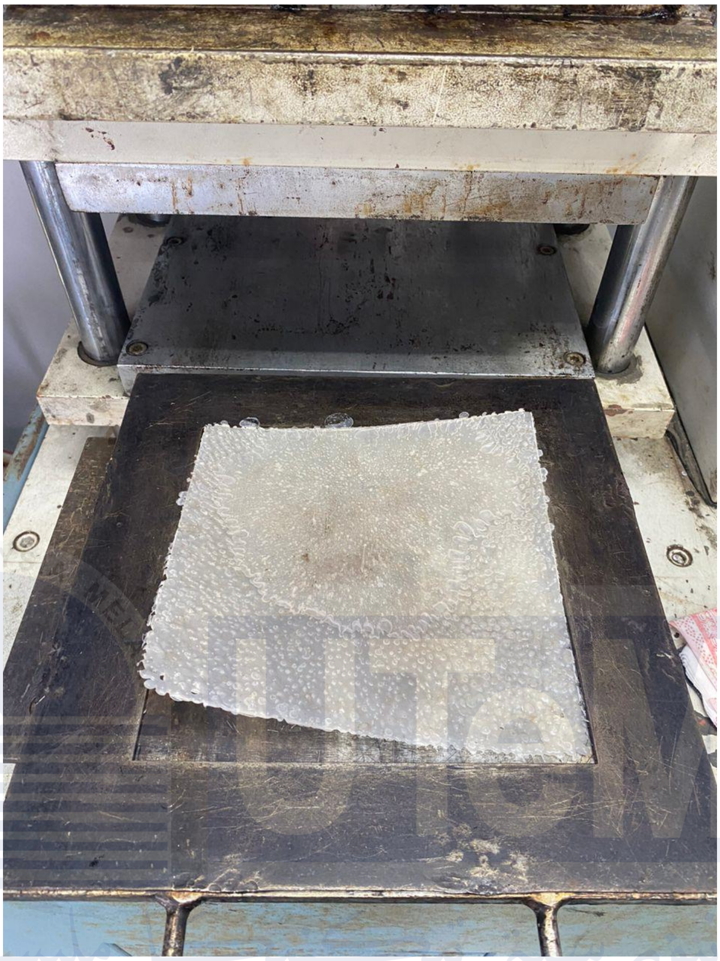
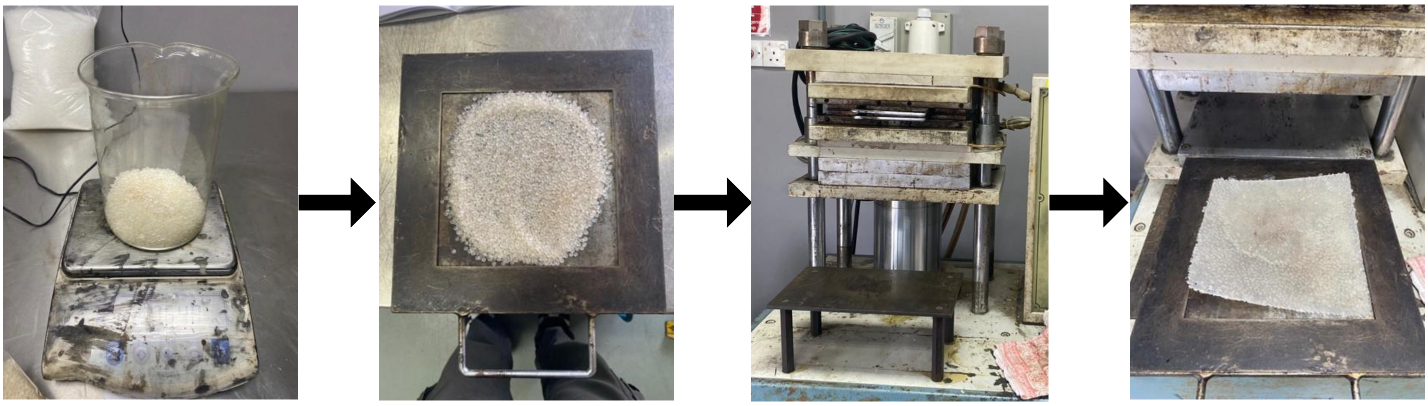


Figure 3.11 Hot press result



a) b) c) d)

Figure 3.12 Hot press process (a) weigh r-WoPPC, (b) put in the mold, (c) Hot press machine, and (d) r-WoPPC in pallet form

3.5.3 Pellet fabrication

Once the composite has been cooled, the crush process will be start so that the composite can be made into pallets. To make sure the size of the pellet is in the range that we needed, the process will be repeated 2 or 3 times. Figure 3.13 show the type of crusher machine and Figure 3.14 show the example of pellet that will produce.

Figure 3.13 Crusher machine

Figure 3.14 Crushing result

3.5.4 Extrusion process

Once the composite has been crushed and become pallets form, the filament was being extruded by single extruder. Figure 3.15 shows the machine that is being used for extrusion process. Before being inserted into the hopper, the composite material must be heated. Table 3.6 below shows parameters process for the filament extrusion and Figure 3.16 show the output filament that will produce from extrusion process.

Table 3.6 The filament extrusion processing parameters

Categories	**Value**
Barrel Temp °	180
Host Current (A)	12 - 17
Host Speed (rpm)	170 - 200
Traction speed (rpm)	15 - 17

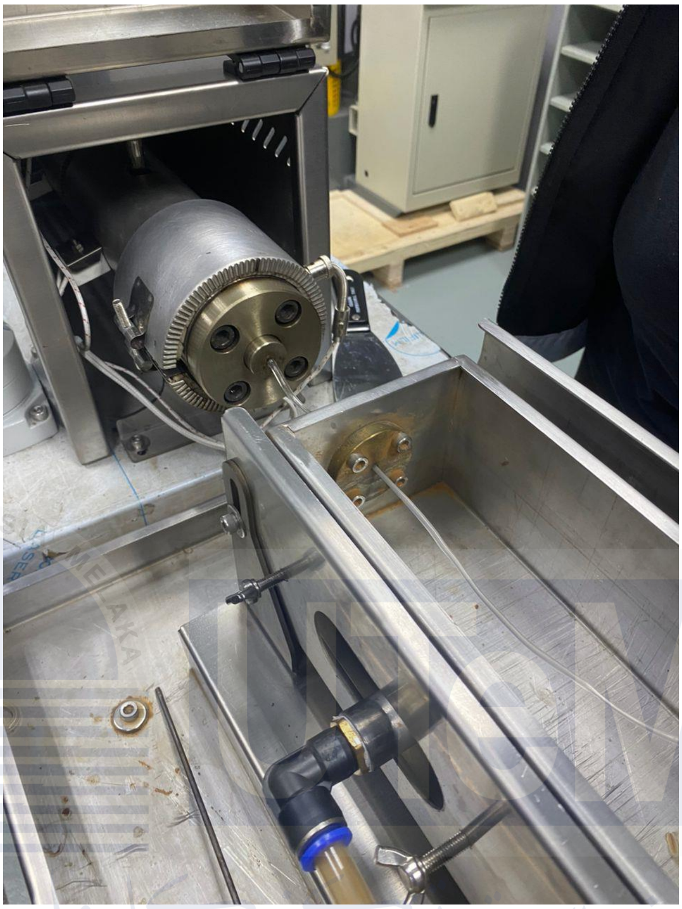


Figure 3.15 Single extruder machine

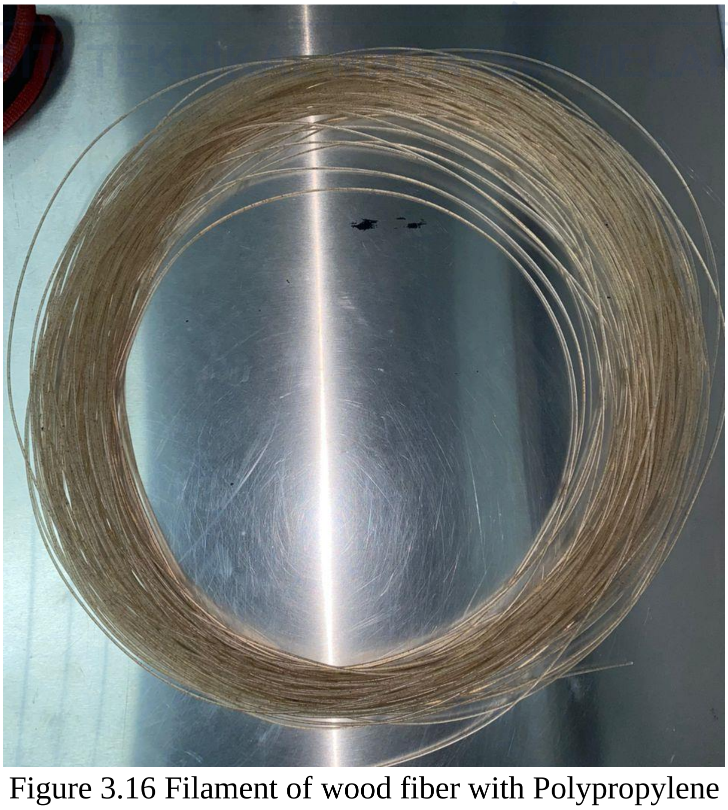


Figure 3.16 Filament of wood fiber with Polypropylene

3.6 3D Printing Process

3.6.1 Preparation of 3D Printing

SolidWork Software were used to made the 3D printing model. The dumbbell-shaped specimen was tested for tensile strength using an Instron universal tester in accordance with ISO 527 and the flexural use standard ASTM D790. The 3D model sample were designed by using SolidWorks software as shows in Figure 3.19 were converted into STL files and those files are common type of file when using Ultimaker Cure software in Figure 3.20. Table 3.7 shown the printing setting in Ultimaker Cure software and Figure 3.21 shown the 3D printed used the 3D filament of wood fiber/recycled polypropylene to produce tensile and flexural specimens.

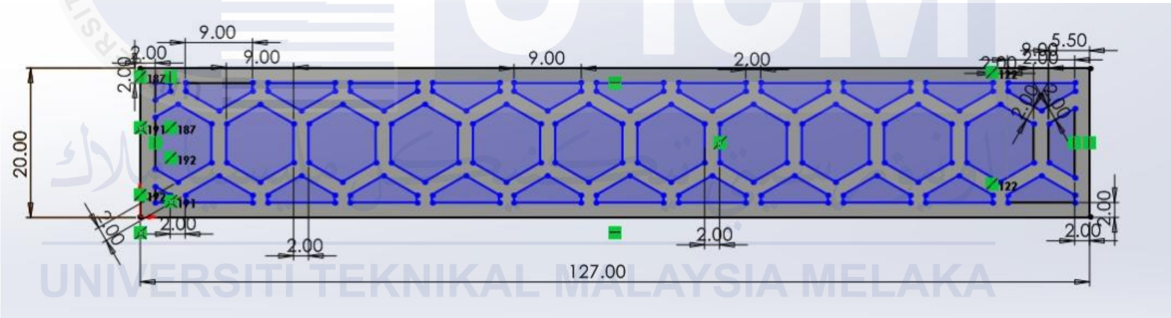


Figure 3.17 Sketch of flexural sample (honeycomb structure)

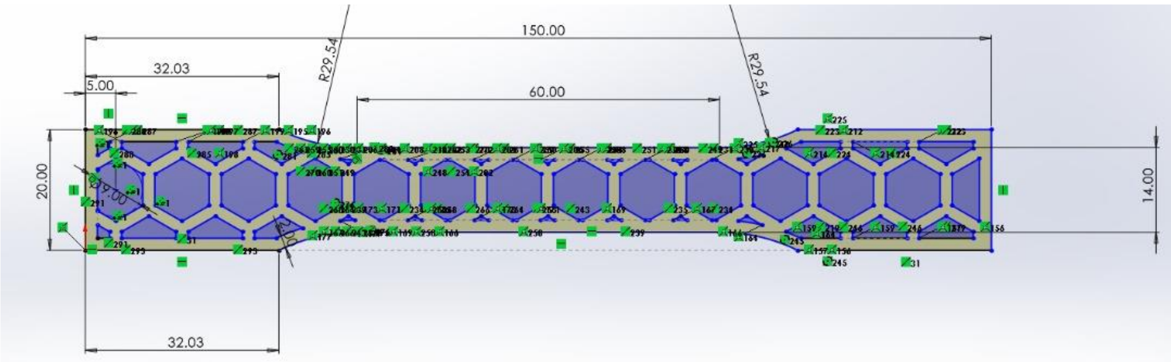


Figure 3.18 Sketch of tensile sample (honeycomb structure)

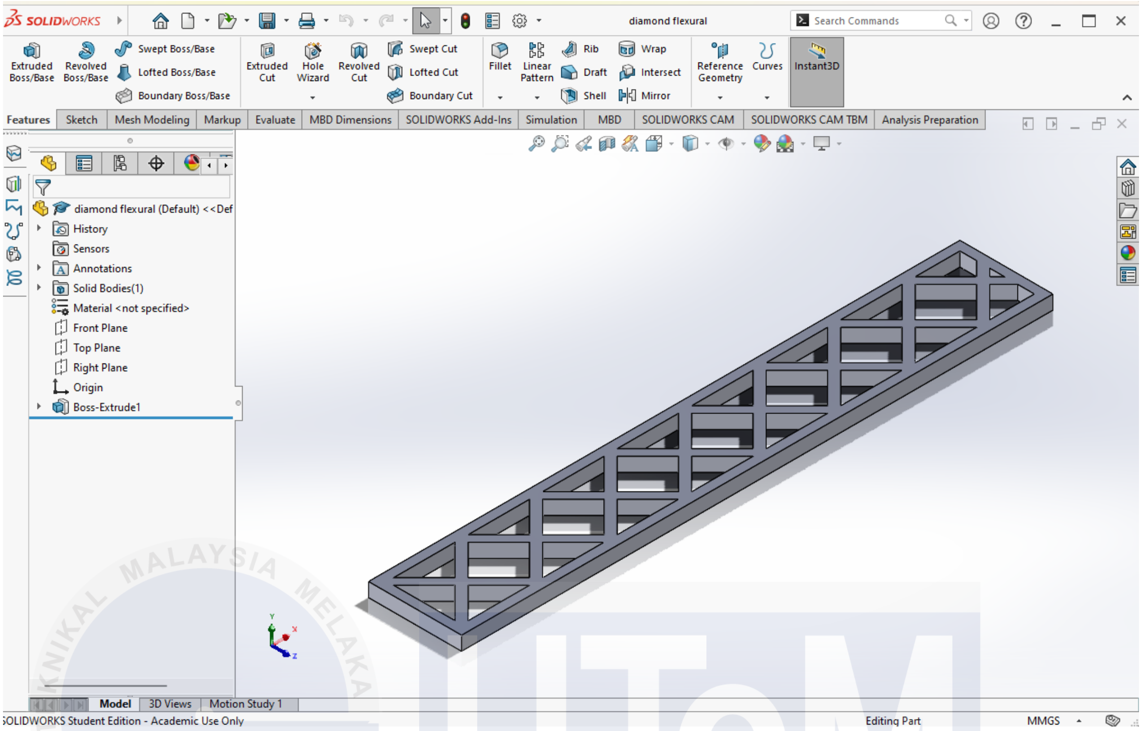


Figure 3.19 3D modelling using SolidWorks

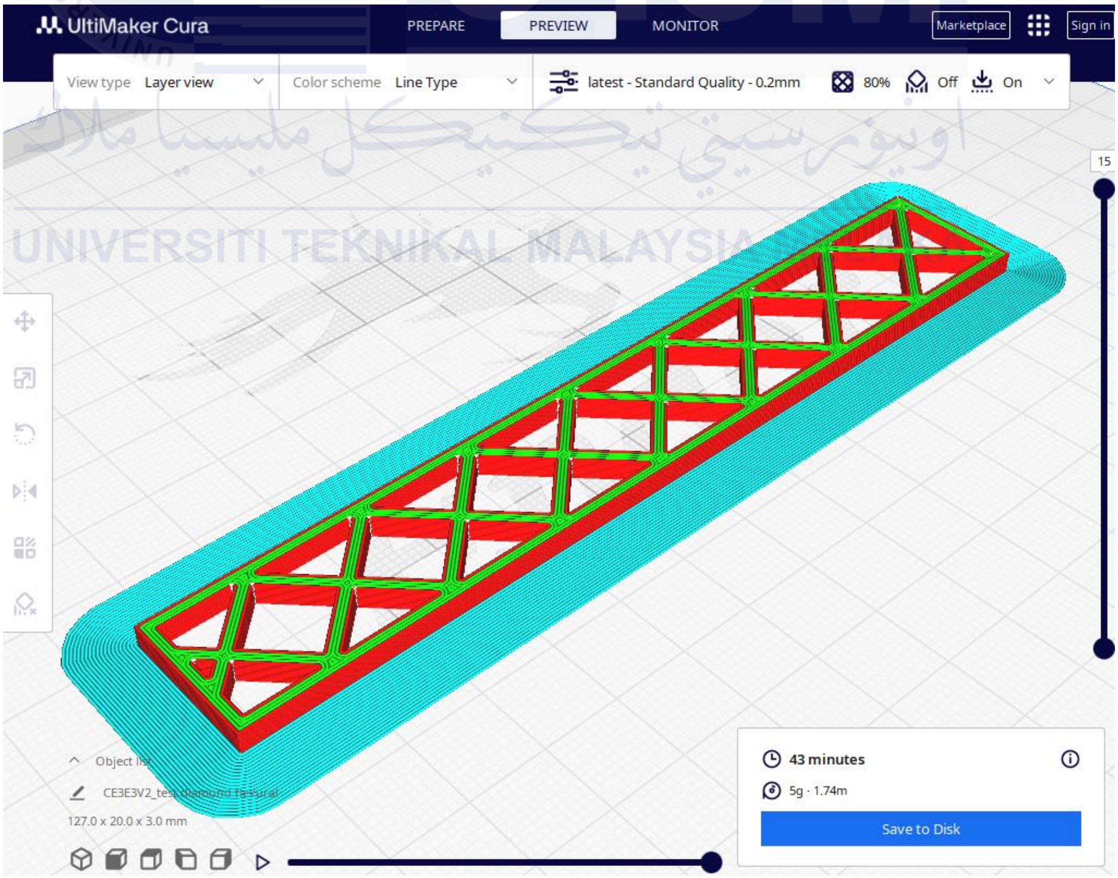


Figure 3.20 3D rhombus sample using Ultimaker Cure software

Table 3.7 Printing settings

Parameters	Value
Temperature of printing (˚C)	195
Initial layer temperature (˚C)	195
Build plate temperature (˚C)	98
Build plate temperature, initial layer (˚C)	98
Infill pattern	Lines
Infill flow (%)	80
The height of the layer (mm)	0.2
Wall thickness (mm)	1.6
Top and bottom layers (layers)	4
The print speed (mm/s)	70
The speed of initial layer (mm/s)	15
Build plate adhesion type	Brim

Figure 3.21 3D printing machine

3.6.2 Sandwich Structure

Three type of sandwich structure has been selected as the sandwich structure to be produced. Solidworks STL files are used for printing, and Ultimaker Cura is used to modify the STL files for the comparison between honeycomb structure, diamond structure and square structure. After the filaments have been inserted through the 3D printer's extruder and the hotbed has been calibrated for printing calibrations as well, printing will start. The duration of time waits depends on the size (%) required for printing. This procedure is repeated multiple times using various weight percentages of wood fiber/recycled polypropylene.

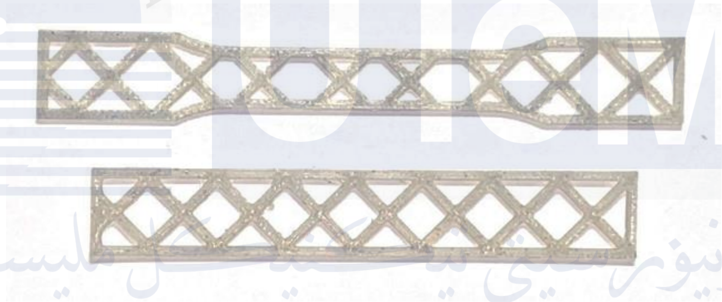


Figure 3.22 Rhombus structure of 3D printing

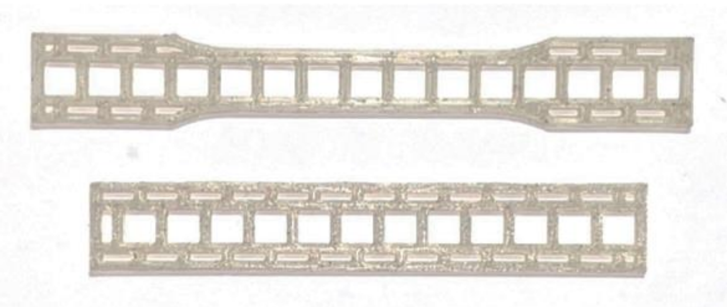


Figure 3.23 Square structure of 3D printing

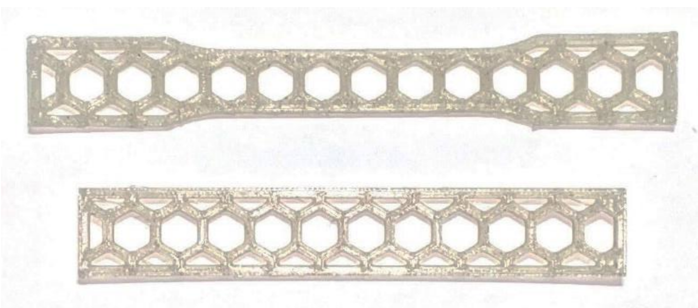


Figure 3.24 Honeycomb structure of 3D printing

3.7 Mechanical Properties

3.7.1 Tensile test

The filament was cut with an overall length of 200 mm for the tensile test. Tensile test can be done by using SHIMADZU Testing Machine as shown in Figure 3.25. The test took 10 – 20 seconds to obtain the result. According to (Lomelí Ramírez et al., 2011a), the tensile sample of Cassava starch-green coir composite were tested at ambient temperature and relative humidity (RH) of 75% at a testing speed of 5 mm/min. Every sample of specimen is printed using 3D printer in ISO 527 standard. Figure 3.25 shown specimens after tensile strength and Figure 3.26 shows the tensile test result.

Figure 3.25 Tensile strength test

Figure 3.26 Specimen after tensile strength

3.7.2 Flexural test

Flexural test can be done by using SHIMADZU Testing Machine. To obtain the result, the test must took 10 to 20 minutes. The most critical components are fretting wear at the outer loading points and compression stress concentration at the centre loading point. Three-point bending test were conducted with speed of 2 mm/min according to ASTM D790. The Figure 3.27 shown flexural strength test using three-point bend and Figure 3.28 shown on specimens after flexural strength test.

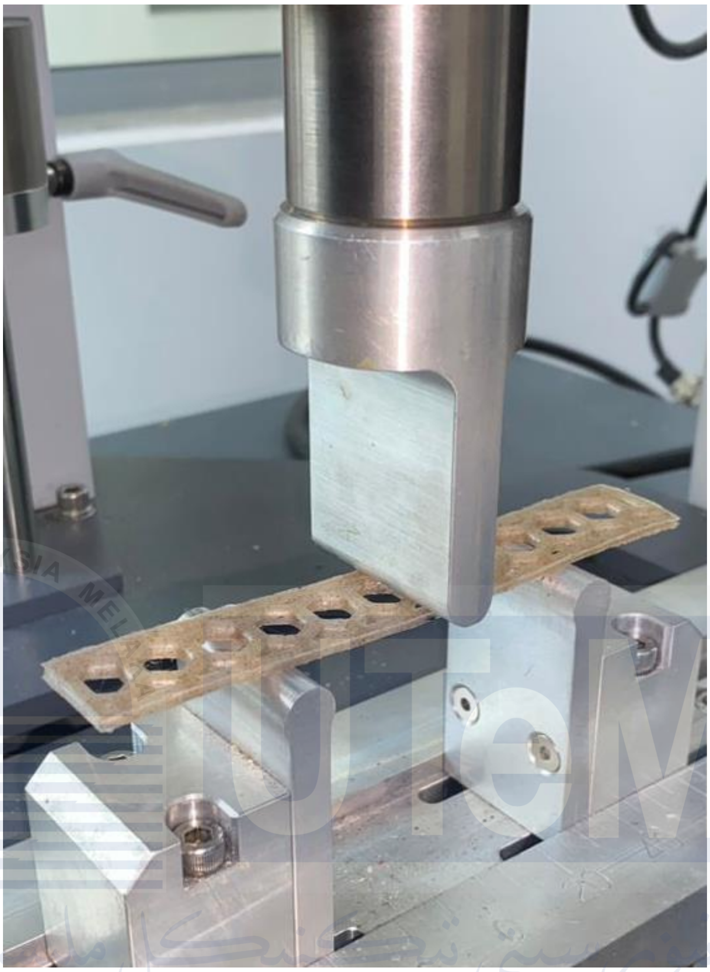


Figure 3.27 Flexural strength test

Figure 3.28 Specimens after flexural strength test

3.8 Physical Properties

3.8.1 Water absorption test

Treated PP/wood fiber composites filament of approxiamate dimension (25.4mm x 1.75 ± 0.55mm) were used for the measurement of water absorption. The samples were dried at 110 °C for 24 hours, and immersed in distilled water at room temperature until a constant weight was reached (Nafis et al., 2023b). The filamenst were periodically taken out of the water. After that, wiped the filament using tissue paper remove the surface water and weighed. The specimens that were used at least three for each filament. The percentage of water absorption, $M_{t,}$ was computed according to the following formula:

$$Water\ Absorption\ (\%) = \frac{W_1 - W_0}{W_0}\ X\ 100\%$$

Where;

W_1 (g) = Weight after immersed and W_0 (g) = Original dry weigh

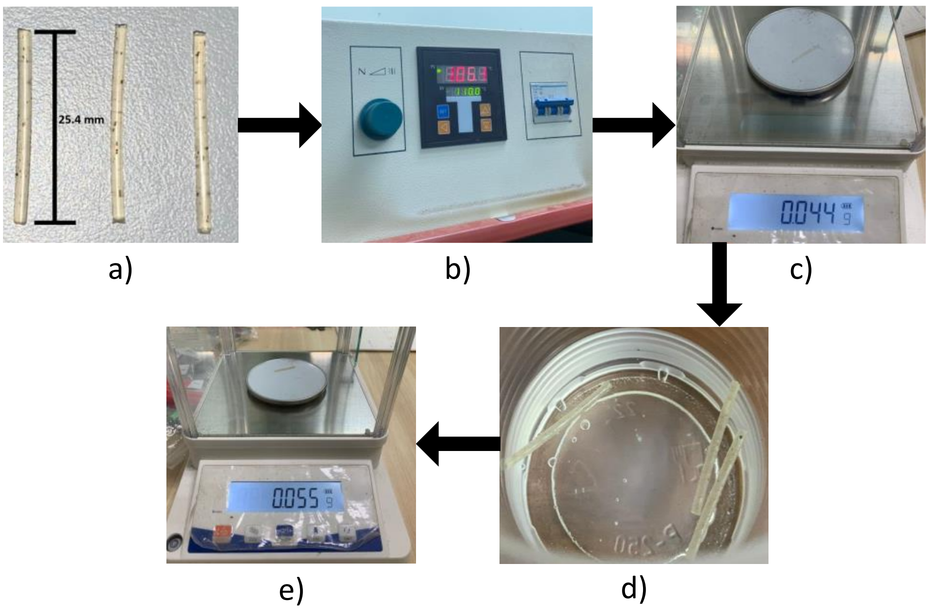


Figure 3.29 Water absorption process (a) cutting sample,(b) stored in oven for 1 day (c) record the initial weight of each sample, (d) immersed completely in distilled water, and (e) record the final weight of each sample

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the recycled polypropylene reinforced with wood fiber by using tensile and flexural strength. The same apparatus was used to measure both the tensile and flexural strengths. The graph's results have been analysed and discussed in relation to the mechanical and morphological testing of the samples. The outcome is relevant to the purpose of this paper.

4.2 Fabrication of r-WoPPC filament

Thermoplastic and wood-based dust fillers are the matrix and reinforcing materials used in this study, respectively. The wood dust was bought from an online platform called Shopee. The wood dust needs to be washed using distilled water for the cleaning process and let it dry using oven at temperatures below 80°C for 1 day as shown in Figure 4.1(a).. The wood dust was sieved using a Siever machine to get the needed size particle of wood dust which is 125 µm at the FTKIP composite lab at the University Technical Malaysia Melaka as shown in Figure 4.1(b).

NaOH solution in form of pallet was used for the alkaline treatment. The ratio for the alkaline treatment is 6% sodium hydroxide to 94% distilled water (Radzi et al., 2019). The temperature range of 20 – 180 °C and the amount of time spent soaking in the solution to treat the wood fiber are respectively for 3 hours as shown in Figure 4.1(c), NaOH Treatment. After the treatment, rinse the solution using the distilled water in several times and prepare the container to dry the treated wood fiber in the oven at 80°C for 24 hours (Nafis et al., 2023b).

The processed wood fiber represents about 1% to 5% (by weight) of the composite. The clear white recycled polypropylene was used and mix well with treated wood fiber in this study is seen in Figure 4.1(d) so that the wood particles are evenly distributed throughout the polypropylene. To aid the melting and flow of the polypropylene, the combined material is subsequently warmed to a particular temperature. The temperature used is 185℃ with a little pressure that is 1 - 2 psi for 20 to 30 minutes to get better results as shown in Figure 4.1(e) and then to create pallets out of the composite as shown in Figure 4.1(f), the crushing process will begin.

The filament was made using a single extruder, as depicted in the Figure 4.1(g) displayed below. A single screw extruder equipped with a die nozzle with a diameter of 1.75 mm was used to extrude the filament of the composite material, and the material was then fed into three different heating zones. It was discovered that 180°C were the appropriate starting preheating temperatures for the barrel and die nozzle zones, respectively. The molten material was being forced upwards into its die nozzle at a forward barrel screw rotation speed of 170 - 200 revolutions per minute (rpm). The rollers of the filament reducer were set to a speed of 15 - 17 revolutions per minute, and they were responsible for forcing the hot extruded filament. Figure 4.1(h) show the output filament that will produce from extrusion process.

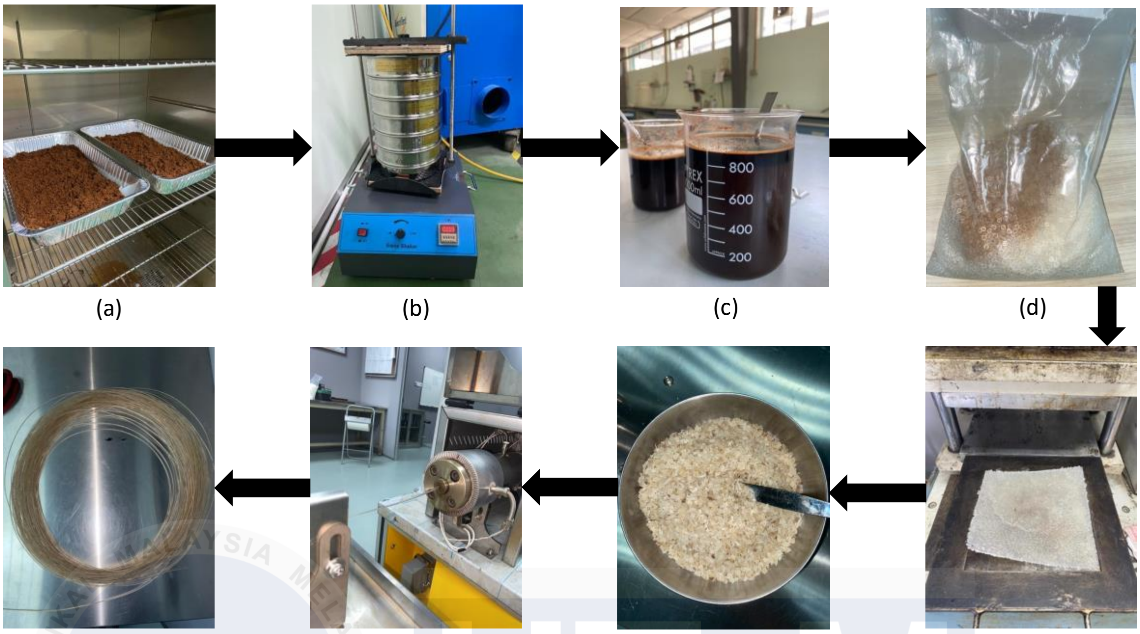
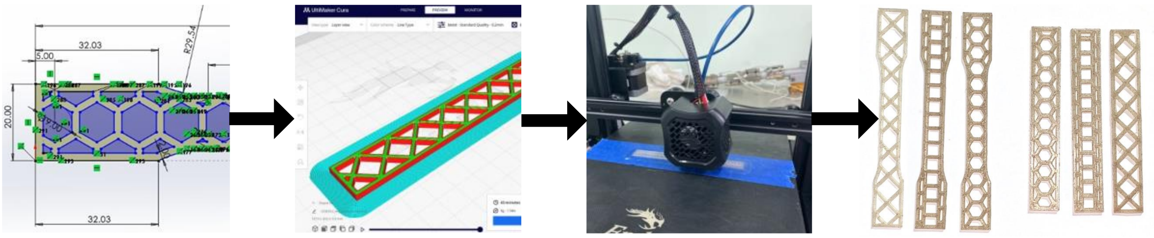


Figure 4.1 (a) dry process, (b) sieve process, (c) treatment process, (d) mix r-WoPPC, (e) hot press process, (f) crush into pallet form, (g) extrude process, and (h) r-WoPPC filament

4.3 Fabrication of r-WoPPC 3D printed sandwich structure

Figure 4.2(a) displays how the 3D model sample was created using SolidWorks software. The parameter and printing setting was adjusted and converted into STL files, which are a typical file type when using Ultimaker Cure software in Figure 4.2(b). There are three different types of r-WoPPC sandwich structures which is honeycomb structure, rhombus structure and square structure that will be created using 3D printer machine as shown in Figure 4.2(c). The filaments have been inserted through the 3D printer's extruder and the hotbed has been calibrated for printing calibrations as well, printing will start. The temperature of novel was set up to 195°C and the build plate temperature is 98°C with speed 70 mm/s to ensure that the 3D printing results are not easily detached and curved from the build plate. Figure 4.2(d) show the final result of r-WoPPC 3D printed sandwich structure that will produce from 3D printing machine.



a) b) c) d)

Figure 4.2 (a) sketching 3D sample, (b) slice into STL file, (c) 3D printing process, and (d) r-WoPPC samples

4.4 Characterization of filament

A single extrusion from composite lab was used to fabricate r-WoPPC filament. The development of filaments using a single extruder is shown in Figure 4.3. Each filament is shown with a different wood fiber loading (1%, 3%, and 5%) mix using a hot press machine and successfully extruded recycled polypropylene. Research by (Nafis et al., 2023a) showed that 1.75 mm filament could be generated at temperatures between 180 and 190 °C for nozzle extrusion and between 15 and 17 rpm for pulley speed. Every filament was extruded at a temperature of 180 °C with filament pulley speeds ranging from 15 to 17 revolutions per minute. A filament diameter of 1.75 mm was achieved by adjusting the nozzle temperature and pulley speed, as indicated by the label dimensions in Figure 4.4.

a) b) c)

Figure 4.3 Filament r-WoPPC (a) 1% wood fiber loading, (b) 3% wood fiber loading, and (c) 5% wood fiber loading

Figure 4.4 Filament diameter, 1.75 mm.

Figure 4.5 shows 3 types of r-WoPPC filament with different wood fiber loading taken using a Dino-Lite AM4113 digital microscope. It is commonly known that the polymer matrix, reinforcing filler, surface chemistry between components, and processing factors can affect the mechanical properties of polymer composites (Ramesh et al., 2022). The morphology and surface condition of the r-WoPPC filament with different wood fiber loading was obtained using Dino-Lite AM4113 at 170x optical magnification.

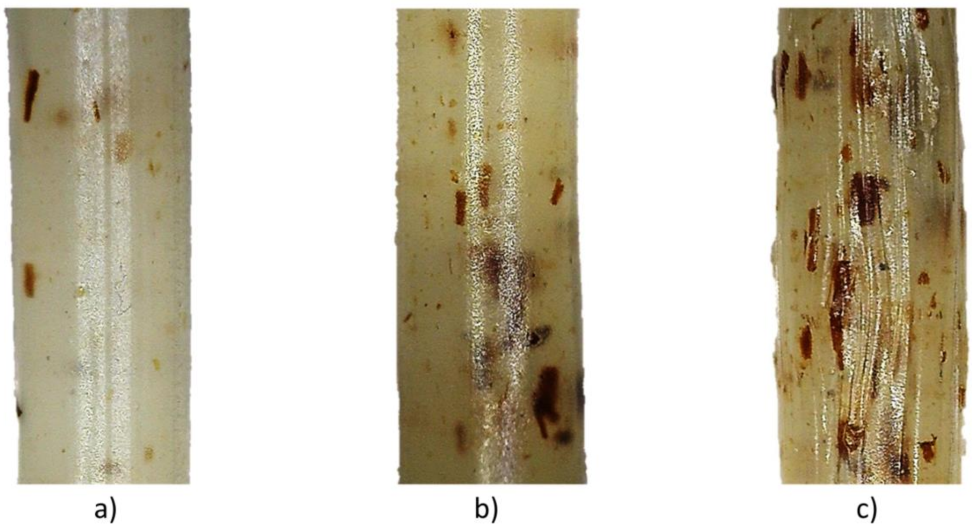


Figure 4.5 Microscopic image of r-WoPPC filament with different wood fiber loading (a) 1%, (b) 3%, and (c) 5%

4.5 Characterization of sandwich structure

As seen in Figure 4.6, the flexural test specimens have dimensions of 127 mm, 20 mm, and 3 mm for length, width, and height, with 2 mm representing the thickness of the skin. The tensile test specimens have dimensions of 165 mm, 20 mm, and 3 mm. The core geometry of the sandwich structure is shown in magnification in Figures 4.7, 4.8, and 4.9. To obtain an average of the results, three identical specimens were 3D printed for each test condition. A sufficiently thick cell wall is necessary for the FDM machine to print the object easily because an excessively thin cell wall could complicate printing and cause deformation of the object (Faidallah et al., 2023) . In order to make the cell wall thickness thick enough to be easily printed, the appropriate cell size was selected. The cell sizes that were selected were 8 mm for the square structure, 11.31 mm for the rhombus structure, and 9 mm for the honeycomb structure. In addition, as Figures 4.7, 4.8, and 4.9 demonstrate that the cell wall sizes for the square, rhombus, and honeycomb were 2 mm. But it's important to remember that because of the technology's anisotropic nature and the range of its printers and materials, it can be challenging to determine the precise or ideal 3D printing settings (Ficzere et al., 2021). The sample will be easier to print using 3D printer if the sketch of sandwich structure has large cell sizes.

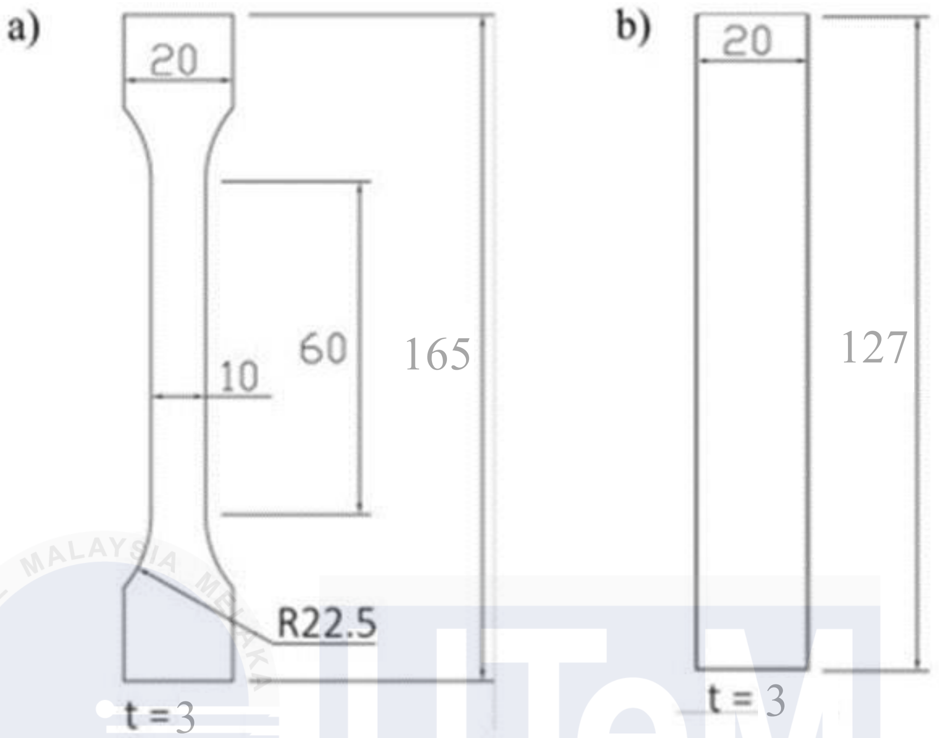
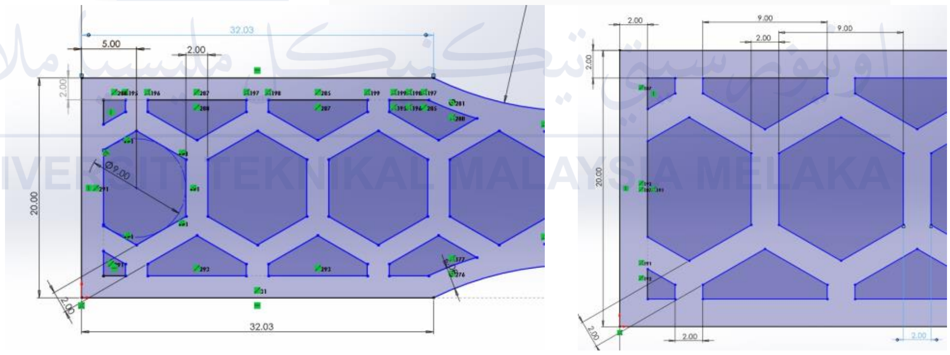
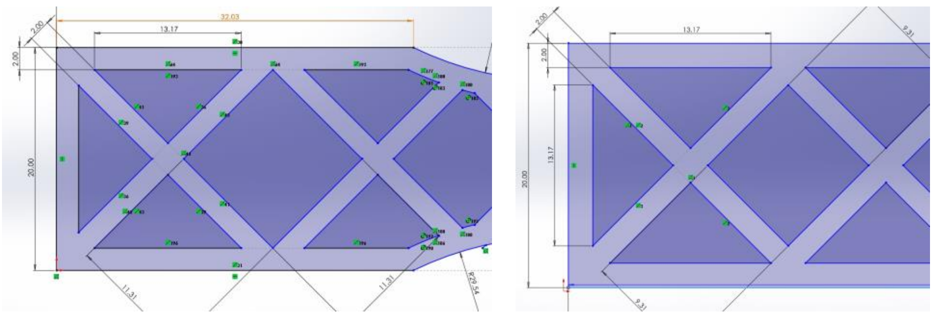


Figure 4.6 Specimens' dimensions of a) tensile test and b) flexural test



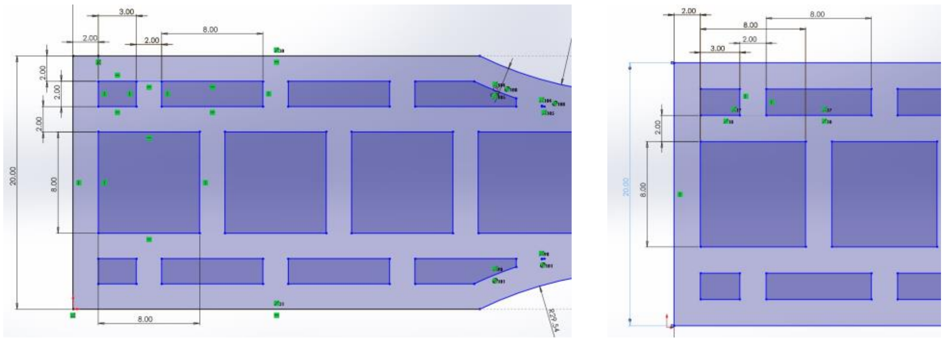
a) b)

Figure 4.7 Dimensions of 2D sketch honeycomb structure for (a) tensile sample and (b) flexural sample



a) b)

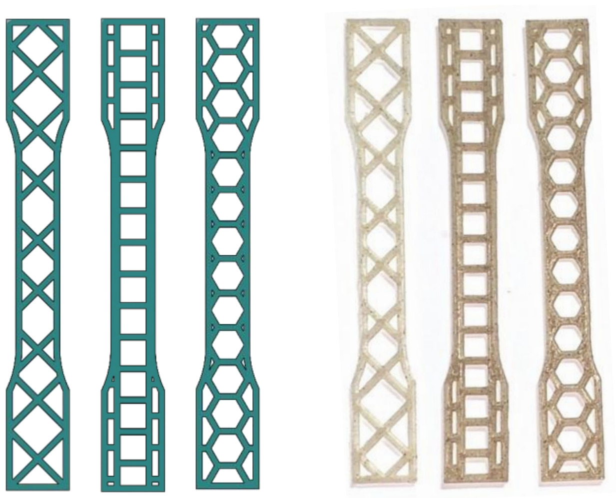
Figure 4.8 Dimensions of 2D sketch rhombus structure for (a) tensile sample and (b) flexural sample



a) b)

Figure 4.9 Dimensions of 2D sketch square structure for (a) tensile sample and (b) flexural sample

There have been three types of sandwich constructions have been used which is square, rhombus and honeycomb. The actual look of a few 3D model samples and r-WoPPC 3D printed sandwich structure samples can be seen in Figures 4.10 and 4.11. The standards ISO 527 -type 1A for tensile samples and ASTM D790 for flexural samples were followed in the design of these structures. As seen in Figures 4.10(a) and 4.11(a), the originally planned specimens with the honeycomb, rhombus, and square sandwich structure were prepared for the tensile and flexural tests.



a) b)

Figure 4.10 Types of sandwich structure for tensile test (a) 3D model using SolidWorks and (b) r-WoPPC 3D printed sandwich structure samples

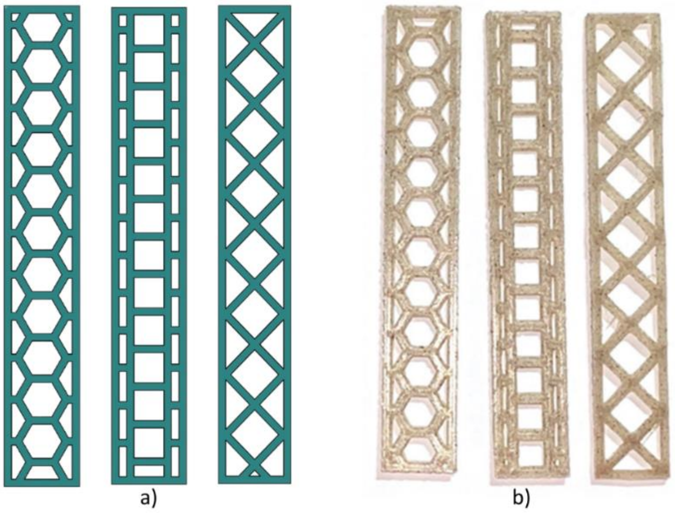


Figure 4.11 Types of sandwich structure for flexural test (a) 3D model using SolidWorks and (b) r-WoPPC 3D printed sandwich structure samples

4.6 Mechanical Properties

4.6.1 Tensile strength

The tensile tests were performed on 3 types of r-WoPPC 3D printed sandwich structure as the polymer matrix and 1 - 5 wt% of wood fiber from the wood dust as reinforcement. The testing using three sample on each specimen. After the composite test sample was investigated, the average tensile strength was measured. Table 4.1 below shows the result of different ratio of wood fiber mixed with recycled polypropylene and different type of sandwich structure on tensile test. From the table, it is observed that 3 wt% of wood fiber in square structure have the highest tensile strength value than 1 and 5 wt% of wood fiber content in recycled polypropylene filament.

Table 4.1 Result of tensile strength

Wood fiber loading (%)	Sandwich structure	Tensile strength (MPa)
1	Honeycomb	5.91
	Rhombus	5.15
	Square	8.39
3	Honeycomb	6.27
	Rhombus	6.19

	Square	8.90
5	Honeycomb	5.66
	Rhombus	5.02
	Square	8.05

The best results from the tensile tests of the square, rhombus, and honeycomb structures with 3% wood fiber loading are displayed in Figure 4.12. With a tensile strength of 8.90 MPa, the square core sandwich samples were clearly the strongest percentage improved by 30.42%. As shown in Figure 4.14, the square sandwich structure that had different wood fiber loading produced the better values. These specimens reliable core structure contributes for their higher tensile strength. As a result, a greater surface was subjected to the imposed load, increasing the resistance to failure (Faidallah et al., 2023). The mechanical characteristics of three different sandwich structures which is honeycomb, diamond-celled, which mimics the rhombus in the current work, and corrugated have been researched by Zaharia et al (2020). They found that the diamond structure had a higher tensile strength and load (needed to shatter) than the honeycomb, which is consistent with the results of the current investigation. However, research by Nath & Nilufar (2022), shows the comparison simulation of honeycomb, re-entrant H, diamond and square sandwich structure and it proved that square is the highest strength compared to other sandwich structures.

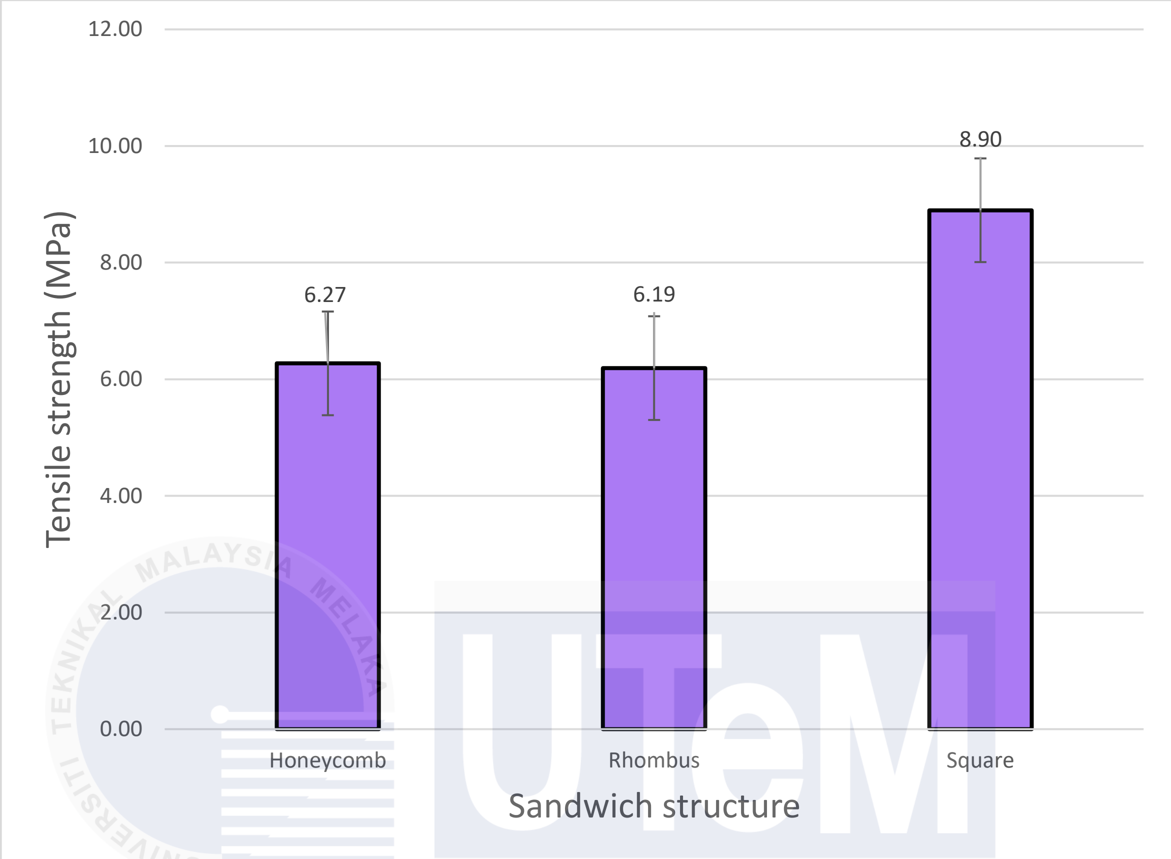


Figure 4.12 Tensile strength of 3% wood fiber loading with different sandwich structure

Tensile strength results are influenced by the square sandwich structure in different wood fiber loading as Figure 4.13 shows. Tensile strength is best in the specimen with a 3% wood fiber loading. The tensile strength of rPP can be increased to 8.90 MPa by adding 3% of wood fiber loading compared to 1% of wood fiber loading based to this study. According to Larsen & Thorstensen (2020), r-WoPPC generally has higher tensile strength at loadings of 3% and 5% than those at 1%. The 5% wood fiber loading is slightly lower than the 3% wood fiber loading. With a square sandwich structure and r-WoPPC, the composite exhibits the best tensile strength among the results. However, Figure 4.14 shows that square sandwich structure still has the highest tensile strength compared to honeycomb and rhombus structure in different wood fiber loading.

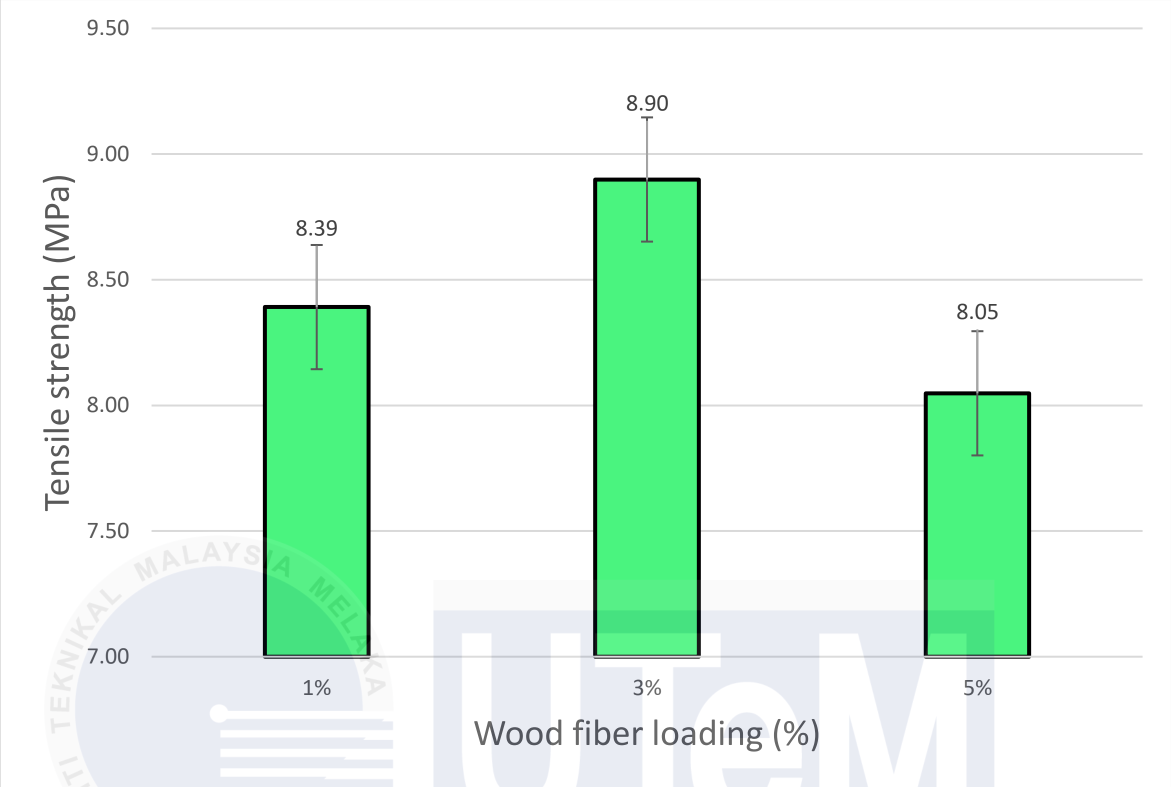


Figure 4.13 Tensile strength of square sandwich structure with different wood fiber loading

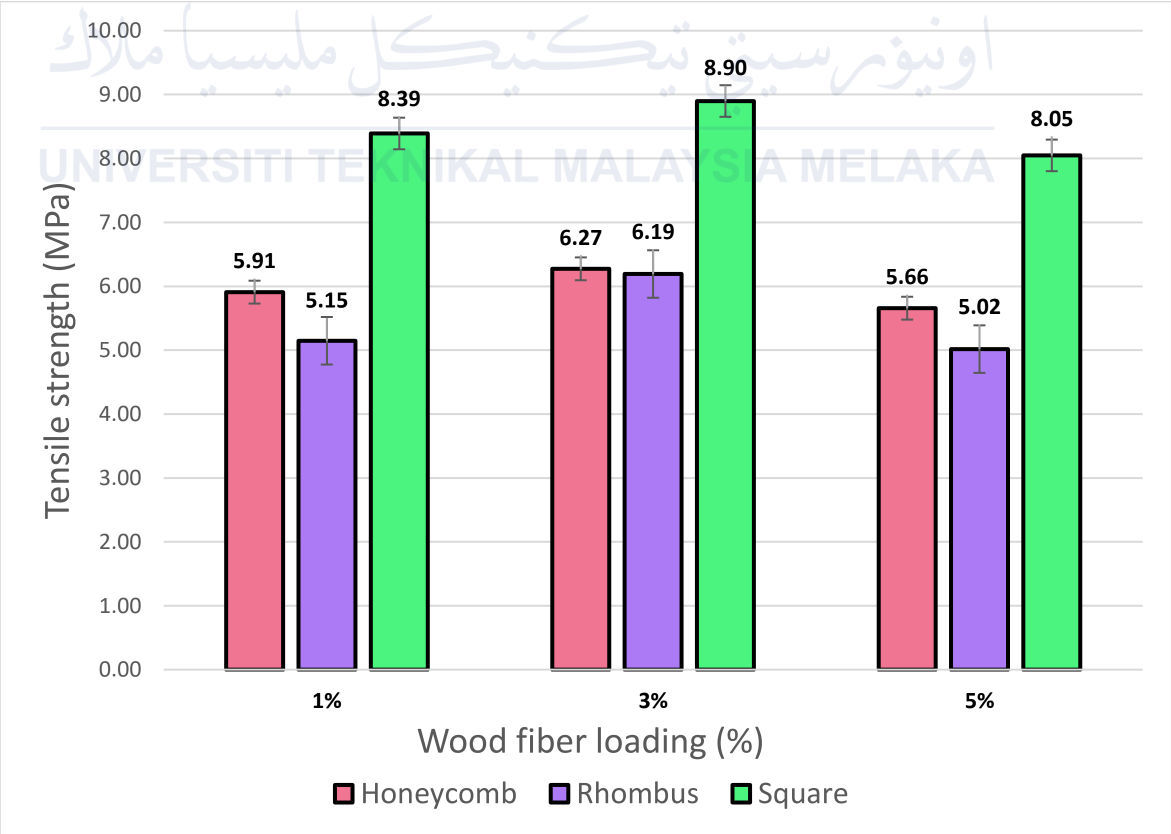


Figure 4.14 Tensile strength of r-WoPPC 3D printed

The result of tensile strength can be related by refer to Figure 4.15. The microscopic result showed that most of the samples from the r-WoPPC filaments were properly blended. There is no uneven and hallow surface for 1% and 3% r-WoPPC filament but there is a bump appear and uneven surface at the filament surface for 5% r-WoPPC filament that will affect the result which causes its strength to be very low. Large hollows are seen in the cross-section area, more fiber is well attached and this is what happened when the amount of fiber loading increased. This could have been the reason for the low flexural and tensile strengths. The r-WoPPC structure is probably damaged by the NaOH treatment, which may have an effect on the mechanical properties of the composites (Radzi et al., 2019).

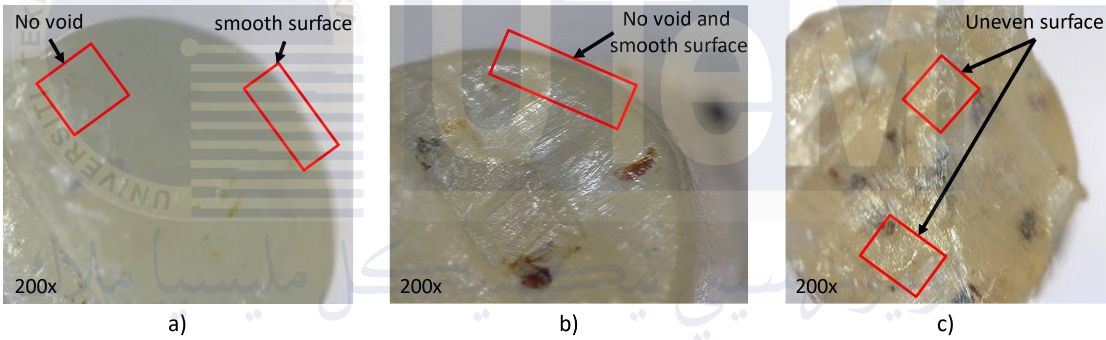


Figure 4.15 surface of r-WoPPC filament with 200x magnification (a) 1% wood fiber loading, 3% wood fiber loading , and (c) 5% wood fiber loading

4.6.2 Flexural strength

The flexural test were use to testing is r-WoPPC 3D printed sandwich structure sample. Flexural test for determining the flexural properties of sandwhich structure, edgewise compression test for determining compression strength along edges and bond strength test for determining interfacial bond strength between core and face sheets (Gohar et al., 2023). From the table shows in Table 4.2 it has been found that 3 wood fiber loading and square sandwich structure has the highest flexural strength value compared to 1 and 5 of wood fiber loading.

Table 4.2 Result of flexural strength

Wood fiber loading (%)	Sandwich structure	Flexural strength (MPa)
1	Honeycomb	6.74
	Rhombus	6.20
	Square	8.94
3	Honeycomb	9.15
	Rhombus	7.86
	Square	9.47
5	Honeycomb	6.42
	Rhombus	4.85
	Square	6.73

Figure 4.16 shows the best results from the flexural tests did on the square, rhombus, and honeycomb structures with a 3% wood fiber loading. The square core sandwich samples had the highest flexural strength which is 9.47 MPa and the percentage improved by 17% followed by the rhombus and honeycomb structures which is 6.27 and 6.19 Mpa. The square sandwich structure containing different wood fiber loading produced better results, as seen in Figure 4.18. The consistent core structure of these specimens provides an explanation for their greater flexural strength. In as compared to the findings of the current study, Zaharia et al (2020) discovered that the diamond structure had a higher flexural strength than the honeycomb. But according to research by Nath & Nilufar (2022), square sandwich structure has the highest strength if compared to other sandwich structure, with comparison simulations of honeycomb, re-entrant H, diamond, and square sandwich structure demonstrated.

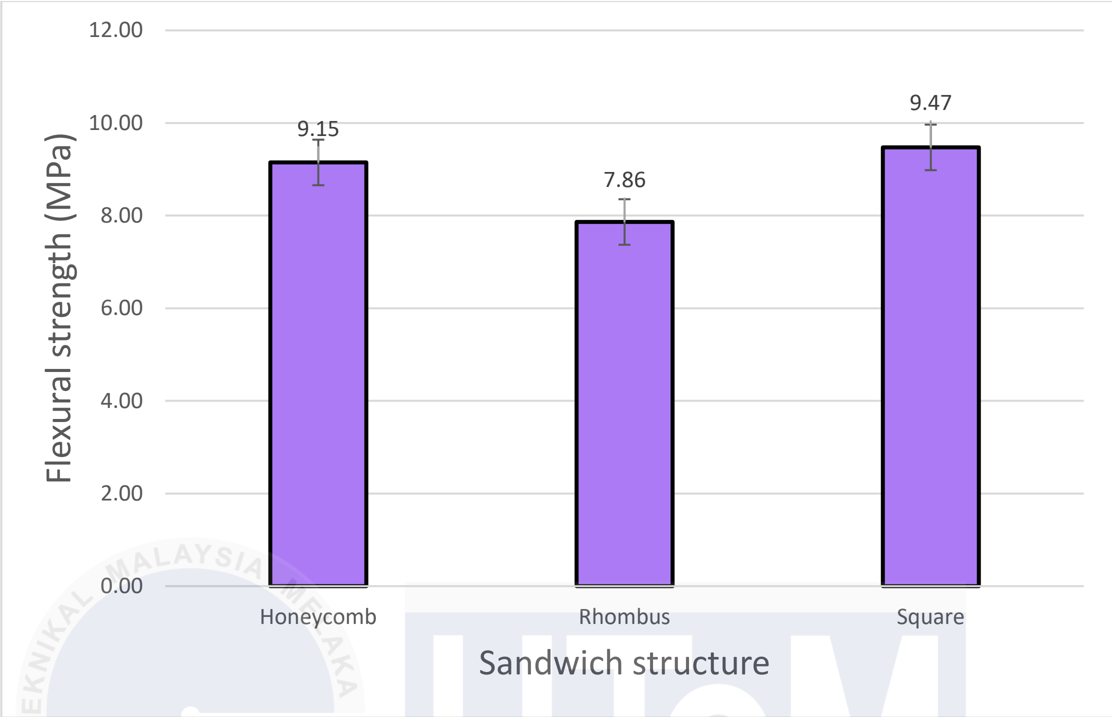


Figure 4.16 Flexural strength of 3% wood fiber loading with different sandwich structure

Table 4.2, Figures 4.17 and 4.18 show how the flexural properties of the r-WoPPc are affected by the loading contents of wood fiber. Three specimen samples were used for each wood fiber loading that was tested in order to determine each wood fiber loading. However, the mechanical characteristics of r-WoPPc may be improved by adding 3% wood fiber loading to the square sandwich structure. The specimen with a 3% wood fiber loading has the highest flexural strength. According to this study, rPP's flexural strength may be enhanced to 9.47 MPa by adding 3% of wood fiber loading as compared to 1% of wood fiber loading. The wood fiber loading of 5% is lower than 3% wood fiber loading. Based of all the results, the composite with a square sandwich structure and r-WoPPC has the highest flexural strength. In contrast to honeycomb and rhombus structures, Figure 4.18 shows that the square sandwich construction maintains its maximum flexural strength with different wood fiber loading conditions.

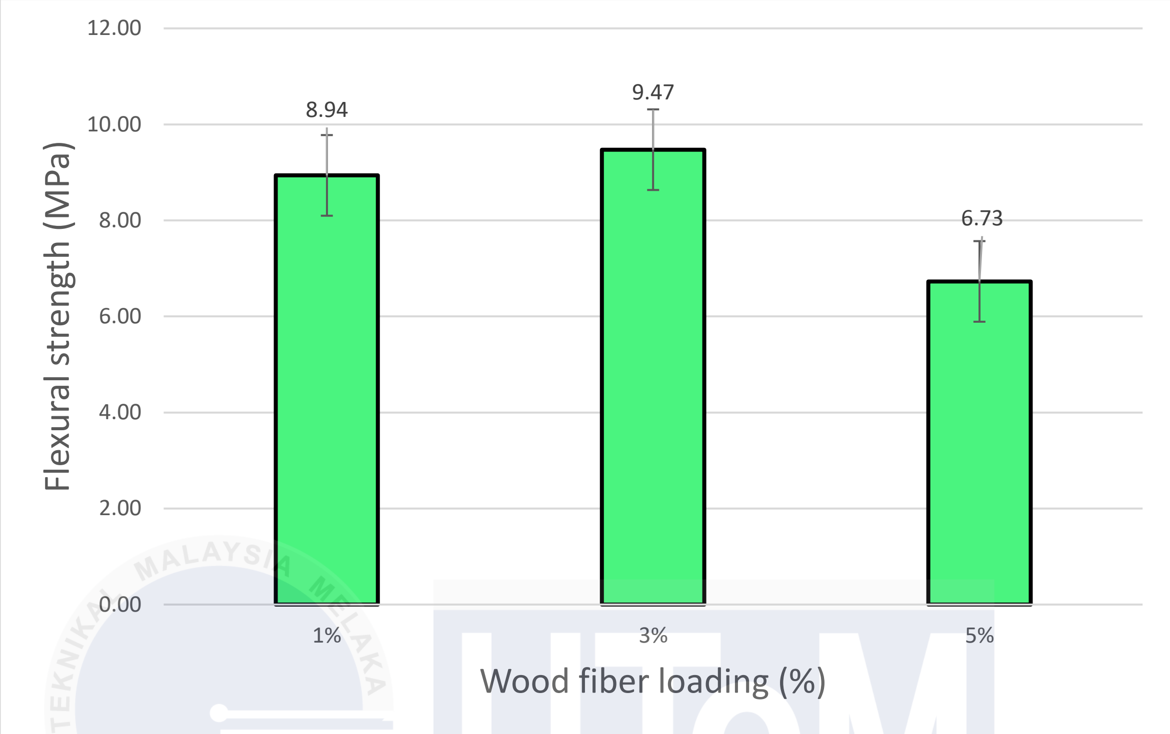


Figure 4.17 Flexural strength of square sandwich structure with different wood fiber loading

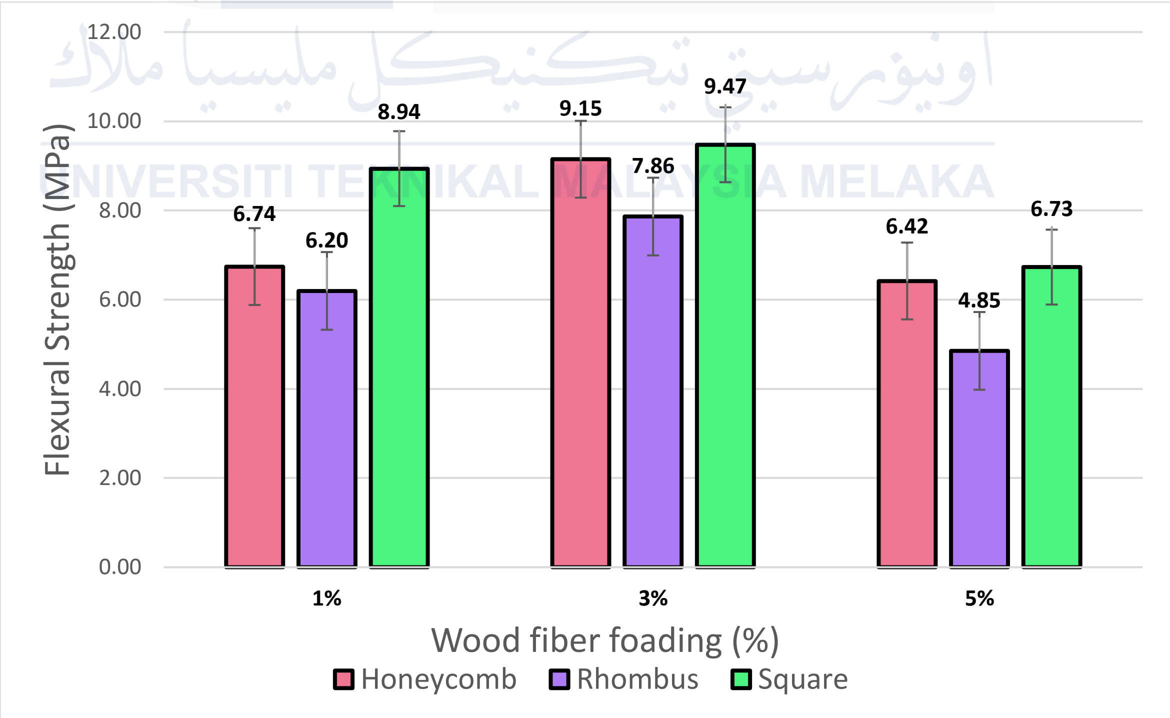


Figure 4.18 Flexural strength of r-WoPPC 3D printed

The result of flexural strength can be related by refer to surface result shown in Figure 4.19. For 1% and 3% of wood fiber loading surface have no uneven and hallow surface but for 5% wood fiber loading has a bump appear and uneven surface It will have an impact on the outcome, making its strength extremely low. When the amount of fiber loading increased, large hollows were observed in the cross-section area showing that more fiber was well attached. The NaOH treatment possibly caused damage to the r-WoPPC structure which could have an impact on the composite's mechanical properties (Radzi et al., 2019).

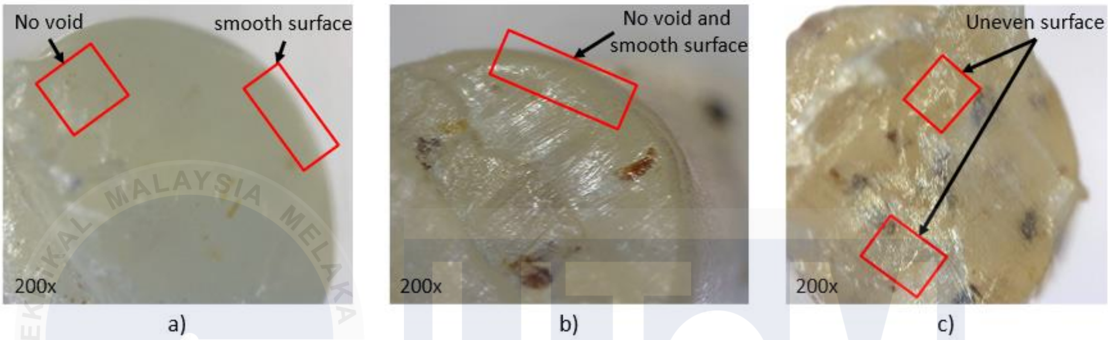


Figure 4.19 surface of r-WoPPC filament with 200x magnification (a) 1% wood fiber loading, 3% wood fiber loading , and (c) 5% wood fiber loading

Additionally, the square sandwich structure has very little damage. When compared to other strengths, the square sandwich panel construction offers better mechanical and weight-saving qualities. The square structure in sandwich panels gives stability and integrity even after the first crack, making it suited for engineering applications that need structural longevity (Nath & Nilufar, 2022). A sandwich panel with a square structure might have a large capacity for energy absorption.

4.7 Physical Properties

4.7.1 Water absorption

The objective of the water absorption test is to identify the quantity of water that absorbs in a specific amount of time. Table 4.3 shows the average water absorption. A percentage can be calculated to determine the average increased weight.

Table 4.3 Result of the water absorption for r-WoPPC with different wood fiber loading

Wood Fiber loading (%)	Initial weight (g)	Final weight (g)	Total water absorb (g)	Percentage of water absorption (%)
1	0.049	0.051	0.002	5.479
3	0.045	0.046	0.001	2.985
5	0.056	0.061	0.005	8.333

Analysing water absorption allows to determine the amount of water absorbed in a given situation. Water absorption is affected by a number of parameters, including filament diameter, fiber content ratio, viscosity of the matrix, weight, and voids/pores. To determine the amount of water absorbed by filament samples exposed to water based on their fiber loading and a water uptake test is conducted. According to Faidallah et al (2023) and Lomelí Ramírez et al (2011), water absorption is essential for thermoplastic starch-based materials since the characterisation of the material can affect its efficiency and contribute to environmental preservation.

Figure 4.20 shows the comparision between final weight and initial weight for each wood fiber loading and Figure 4.21 shows the water absorption percentage for different r-WoPPC filament.

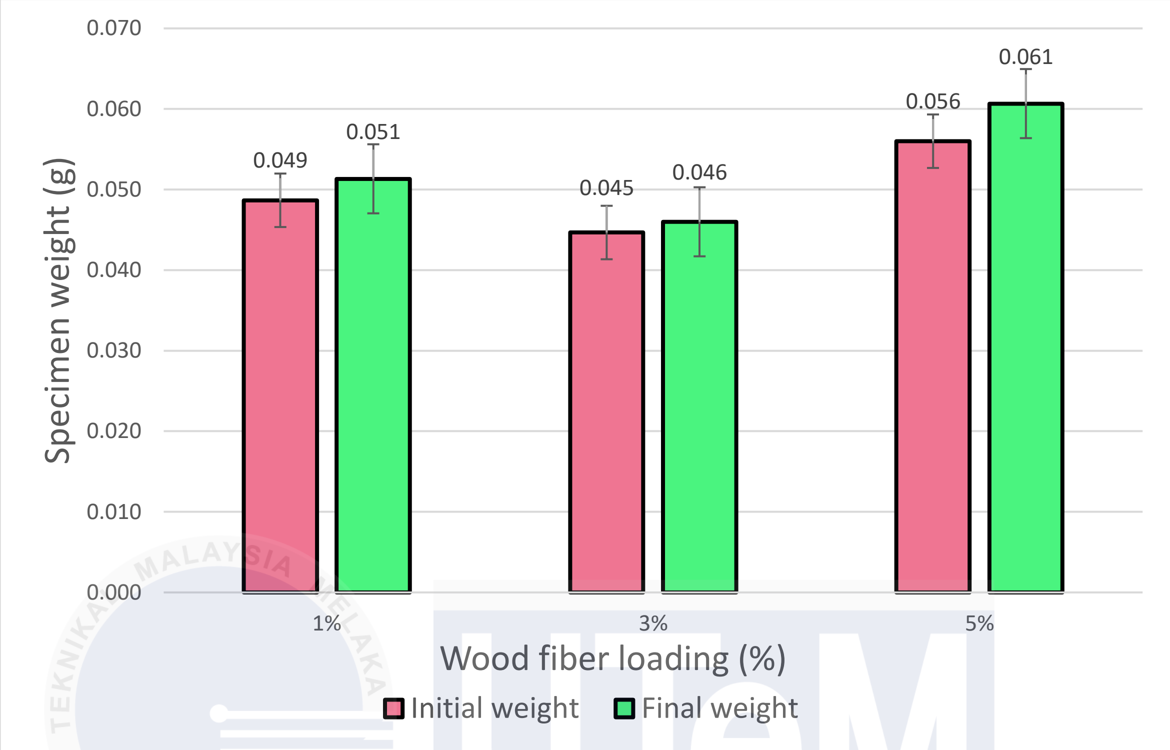


Figure 4.20 Specimen weight with different wood fiber loading

After a 24-hour immersion in distilled water, the wood fiber loading of 5% shows the largest absorption of water, with a following of 5.48% for 1% wood fiber loading and 2.99% for 3% wood fiber loading. According to the study, when more wood fiber loadings were applied with rPP, the water uptake for r-WoPPC increased steadily. The amount of water absorbed increases with the number of fiber loadings applied. In this instance, the percentage result shows that the highest percentage of water absorption can be observed in r-WoPPC filament with a 3% wood fiber loading. This is as a result of a process that the filaments in the r-WoPPC alkaline sample through that enabled the fibers and the polymers to successfully connect (Syahmi A et al., 2022).

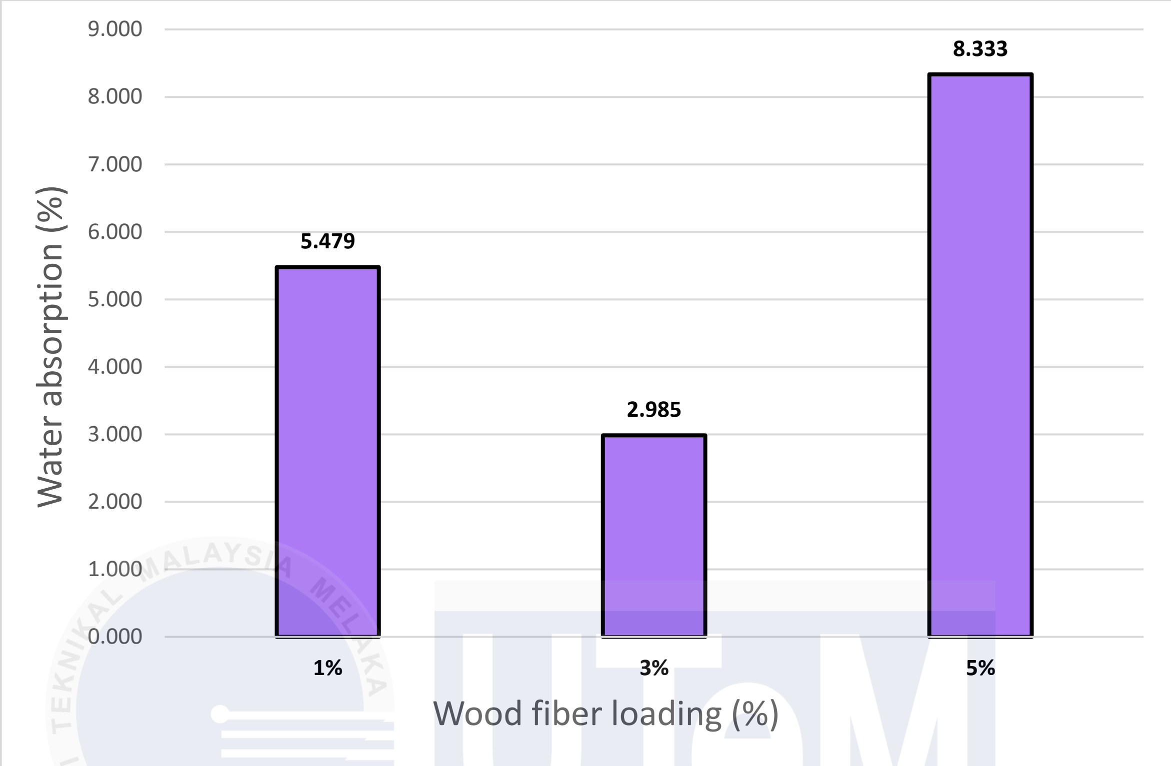


Figure 4.21 Water absorption with different wood fiber loading

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The ability to create complex geometric sandwich structures can be obtained by FDM fabrication. In this study, 3D printed sandwich structures made up of wood fiber and recycled polypropylene (r-WoPPC) filament were investigated. The structures included honeycomb, rhombus, and square designs. Using a single extruder, 1%, 3%, and % of wood fiber were added to a recycled polypropylene (PP) matrix to create the filaments. The sandwich structure model was created using SolidWorks software, before it was then converted into STL files for 3D printing. Tensile and flexural strength of the sandwich, together with the morphological and water absorbing properties of the filament, were all tested in terms of its mechanical performance. The general findings of this study are listed below based on the research objectives outlined in section 1.3:

Objective 1: To produce 3D printing filament with the material made of wood fiber and recycle Polypropylene.

Physical and mechanical properties were used to characterise wood fiber and recycled polypropylene. In this study, wood fiber with a particle size of 125 µm was obtained using a siever, while recycled polypropylene was already available in pellet form. Then, the wood fibers suffered an alkaline treatment using Sodium Hydroxide (NaOH) in order to improve its thermal characteristics and eliminate any impurities from its surface. To create a pallet containing different wood fiber loading, recycled polypropylene was used and thoroughly mixed with treated wood fiber before being heated through a hot press method. The r-WoPPC pallet form went thru the extrusion process, and the r-WoPPC filament was produced using the parameter setup. In summary, there are a lot of issues on the filament surface at the 5% wood fiber loading. It's possible that wood fiber affect the filaments. 1% and 3% r-WoPPC filaments had smoother structural surfaces and no voids were found. This happens as a result of a procedure that the r-WoPPC filaments through that allowed the fibers and polymers form a strong bond. The use of sodium hydroxide at the beginning of this process results in a much stronger filament binding than the filaments that were not treated. Additionally, it makes the fiber and polymer blend better with the surface.

Objective 2: To investigate mechanical properties of 3D printer sandwich structure sample made of wood fiber and recycle Polypropylene.

This study's goal of assessing the strength on different sandwich structure types and wood fiber loading on the mechanical properties of 3D printed r-WoPPc specimens was successfully achieved. Tensile and flexural tests were used to analyse the mechanical characteristics of r-WoPPC. The same machine measurement was used for testing tensile and flexural strength. In comparison to honeycomb and rhombus structures, it can be shown that the square sandwich structure of r-WoPPC has a good tensile strength and flexural strength, which are 8.90 MPa and 9.47 MPa, respectively. For every type of 3D printed sandwich structures, the greatest value for both tensile strength and flexural strength is found to be 3% wood fiber loading. Other test results also show that 3% wood fiber loading has the best tensile strength and consistent flexural strength because the r-WoPPC sample's filaments underwent a process that successfully bonded the fibers to the polymers.

5.2 Recommendation

The strength of a 3D printed sandwich structure as a compatibilizer for wood dust fiber and any kind of polymer is another aspect of this study that can be further upon:

1) Firstly, research additional study on the characteristics of wood fibers to serve as the polymer matrix's reinforcement when creating filament for 3D printing.

2) It is suggested that alternative recycled thermoplastics be tried, such as recycled ABS, recycled polylactic acid, recycled polystyrene, and recycled polyvinyl chloride, as there isn't much research needed to compare them to polypropylene thermoplastic.

3) Additionally, it is suggested that to use alternative alkaline treatments, such as silane, as the results of the water absorption test produce inaccurate percentages of wood fiber loading, suggesting that the NaOH treatment of the wood fiber did not improve its physical qualities.

4) Lastly, add another sandwich structure to be studied because most studies only use honeycomb structure and rhombus structure to compare the strength of the structure.

5.3 Project potential

The study discovered that sandwich structure could be manufactured as a product component and useful for industrial applications such as aerospace components, automotive components and consumer electronics. Due to the qualities of both materials combined, polypropylene mixed with wood fiber, often known as wood-plastic composite (r-WoPPC), offers a variety of uses. A number of potentials uses for polypropylene-wood fiber composites in construction, furniture and packaging.

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APPENDICES

Gantt Chart for PSM 1

No	Activities	Status	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Supervisor selection and registration of PSM title	Plan														
		Actual														
2	Briefing and explaination of PSM by supervisor	Plan														
		Actual														
3	Drafting and planning of Literature Review	Plan														
		Actual														
4	Presentation of chapter 2 with supervisor	Plan														
		Actual														
5	Discuss problem statement and objective for Chapter 1 with supervisor	Plan						M								
		Actual						I								
6	Submission of Chapter 1	Plan						D								
		Actual						S								
7	Research on methodology for Chapter 3	Plan						E								
		Actual						M								
8	Start doing some experiment in the lab	Plan														
		Actual						B								
9	Drafting and present chapter 3 with supervisor	Plan						R								
		Actual						E								
10	Writing up preliminary result of Chapter 4	Plan						A								
		Actual						K								
11	Submission of first draft PSM 1	Plan														
		Actual														
12	Submission of second draft PSM 1	Plan														
		Actual														
13	Submission of report to supervisor and panels	Plan														
		Actual														
14	Preparation and presentation slide PSM 1	Plan														
		Actual														

Gantt Chart for PSM 2																
No	Activities	Status	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	MEETING AND DISCUSSION	Plan														
		Actual														
2	PREPARATION OF RAW MATERIAL	Plan														
		Actual														
3	CONDUCTING THE EXPERIMENT	Plan														
		Actual														
4	COLLECT DATA AND MAKE ANALYSIS ON SAMPLE	Plan														
		Actual						M								
5	DISCUSS ON RESULT EXPERIMENT	Plan						I								
		Actual						D								
6	START DRAFT REPORT AND WRITING UP CHAPTER 4	Plan						S								
		Actual						E								
7	START DRAFT REPORT AND WRITING UP CHAPTER 5	Plan						M								
		Actual														
8	SUBMISSION OF FIRST DRAFT PSM 2	Plan						B								
		Actual						R								
9	MEETING AND DISCUSSION	Plan						E								
		Actual						A								
10	RECHECK FIRST DRAFT	Plan						K								
		Actual														
11	WRITING UP CONCLUSION FOR THIS STUDY	Plan														
		Actual														
12	SUBMISSION OF FULL REPORT	Plan														
		Actual														
13	PRESENTATION FOR PSM 2	Plan														
		Actual														