

DEVELOPMENT OF NOVEL COMPOSITE MATERIAL USING RECYCLED POLYETHYLENE TEREPHTHALATE (rPET) REINFORCED WOOD DUST



## BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS



### Faculty of Mechanical and Manufacturing Engineering Technology



### Muhammad Khairul Amin Bin Shamsudin

# Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

#### DEVELOPMENT OF NOVEL COMPOSITE MATERIAL USING RECYCLED POLYETHYLENE TEREPHTHALATE (rPET) REINFORCED WOOD DUST

#### MUHAMMAD KHAIRUL AMIN BIN SHAMSUDIN



Faculty of Mechanical and Manufacturing Engineering Technology

#### UNIVERSITI TEKNIKAL MALAYSIA MELAKA

#### DECLARATION

I declare that this thesis entitled "Development Of Novel Composite Using Recycled Polyethylene Terephthalate (rPET) Reinforced Wood Dust" is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



#### 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 (Process and Technology) with Honours.

	$\hat{\mathcal{N}}$
Signature	·
Supervisor N	Name : Dr Nuzaimah bte Mustafa
	AT MAN
Date	: 18 January 2022 DR. NUZAIMAH BINTI MUSTAFA Pensyarah Jabatan Teknologi Kejuruteraan Pembuatan Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan Universiti Teknikal Malaysia Melaka
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#### **DEDICATION**

I dedicate my dissertation work to my family and many friends. I owe a particular debt of appreciation to my devoted parents, Encik Shamsudin and Puan Hapsah, whose words of encouragement and push for tenacity ring in my ears. My sisters Irsyada and Syifa have never left my side and are extremely dear to me. This dissertation is also dedicated to my closest friend, Nina who helped me here and there throughout the process. This work is also dedicated to my closest laboratory buddy Arief and Azrin, who have been there with me from the beginning of this PSM, doing all the projects and tests. All of them are my

biggest supporters.

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#### ABSTRACT

There have been many developments in additive manufacturing technology in recent years. Still, only a few attempts have been made to use composite natural materials such as wood dust and recycled polyethylene terephthalate (rPET) for 3D printing. The initial findings of this research project aim to development of novel composite material using rPET reinforced wood dust. The objectives include characterizing the wood dust and rPET for physical and thermal properties, assessing the effect of sodium hydroxide treatment on the physical and morphological properties of wood dust-rPET composite, and evaluating the effect of fiber loading in the composite. This study was conducted in several laboratories owned by Universiti Teknikal Malaysia Melaka (UTeM). Furthermore, the method used to complete this project is by selecting raw materials such as rPET from matrix material and wood dust from natural fiber material. Wood dust have been identified in terms of properties and then treated using a chemical liquid sodium hydroxide (NaOH) at a value of 6%. In addition, it also has been identified that the effect of treatment given to wood dust can make the composite more rigid. The finding in general shows that wood dust and rPET can be used as filament materials on 3D printing machines. Past studies have also shown that composites between wood dust and other polymers can produce filaments for 3D printing. In conclusion, if rPET and wood dust is recycled and transformed into filament materials for 3D printing, it can contribute to environmental sustainability.

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#### ABSTRAK

Terdapat banyak perkembangan dalam teknologi pembuatan aditif dalam beberapa tahun kebelakangan ini. Namun, hanya beberapa percubaan telah dibuat dengan menggunakan bahan semula jadi komposit seperti habuk kayu dan polietilena tereftalat (rPET) kitar semula untuk cetakan 3D. Penemuan awal projek penyelidikan ini bertujuan untuk membangunkan komposit menggunakan rPET diperkukuh dengan habuk kayu. Objektif termasuk mencirikan habuk kayu dan rPET untuk sifat fizikal dan haba, menilai kesan rawatan natrium hidroksida ke atas sifat fizikal dan morfologi komposit habuk kayu-rPET dan menilai kesan pemuatan gentian dalam komposit. Kajian ini dijalankan di beberapa makmal milik Universiti Teknikal Malaysia Melaka (UTeM). Tambahan pula, kaedah yang digunakan untuk menyiapkan projek ini ialah dengan memilih bahan mentah seperti rPET daripada bahan matriks dan habuk kayu daripada bahan gentian asli. Debu kayu hendaklah dikenal pasti dari segi sifat dan kemudian dirawat menggunakan cecair kimia natrium hidroksida (NaOH) pada nilai 6%. Selain itu, ia juga telah dikenal pasti bahawa kesan rawatan yang diberikan kepada habuk kayu boleh menjadikan komposit lebih tegar. Dapatan secara umum menunjukkan habuk kayu dan rPET boleh digunakan sebagai bahan filamen pada mesin pencetak 3D. Kajian lepas juga menunjukkan bahawa komposit antara habuk kayu dan polimer lain boleh menghasilkan filamen untuk percetakan 3D. Kesimpulannya, jika rPET dan habuk kayu dikitar semula dan diubah menjadi bahan filamen untuk percetakan 3D, ia boleh menyumbang kepada kelestarian alam sekitar.

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### LIST OF SYMBOLS AND ABBREVIATIONS

rPET	-	Recycled Polyethylene Terephthalate
FDM	-	Fused deposition modeling
3D	-	Three-dimensional
FFF	-	Fused filament fabrication
°C	-	Degree celsius
F&B	-	Food & beverage
FDA	-	Food and drug administration
NaOH	-	Sodium hydroxide
%	-	Percentage
CO2	J.	Carbon dioxide
SEM	No.	Scanning electron microscopy
cm	E	Centimeter
MPa	-923	Megapascal
kg/m3	- 1	Kilogram per cubic metre
DSC	此	Differential scanning calorimetry
TGA	-	Thermogravimetric
μm	UNIV	Micron TI TEKNIKAL MALAYSIA MELAKA
dl/g	-	Deciliters per gram
PPM	-	Parts per million
Mm	-	Millimeter
g	-	Gram

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#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Background

In this new age of modern production, production and process industries have to face a significant challenge to eradicate as many defects as possible in the business term. Along with that, the environment-friendly period remains in focus. After seeing the challenge facing the modern manufacturing sector, most people understand the value of manufacturing industries.

The growth of the manufacturing industries can generate national growth through either the sales of their products or the service they provide. It would also impact their great job opportunities by providing a broad sector of local manufacturing industries to employees.

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3D printing produces physical objects from a geometrical representation by successive materials. Nowadays, 3D printing technology has developed very rapidly worldwide, widely used for the production of any open source designs in agriculture, mass customization, automotive industry, healthcare, aviation industries and locomotive industry (Madhav et al., 2016).

Various 3D printing technologies have been developed with their functions. There is no debate about which technology or machine works better because each has a targeted application. Like any manufacturing process, 3D printing needs a mixture of high-quality

materials to produce a device according to the specifications and quality to be used to the maximum (Nwogu et al., 2019).

Composites or functionally graded materials, metallic, ceramic, polymer and their combinations in the hybrid form can be used and produced in 3D printing technology. In terms of the production of polymer components, 3D printing technology is widely used, from prototypes to functional structures with complex geometries. Due to their low cost, low weight and processing flexibility, 3D printing polymer materials in conditions of a low melting point are widely used in the 3D printing industry (Shahrubudin et al., 2019).

Many types of wastes such as plastic waste derived from a petroleum-based polymer such as recycled PET (rPET) become a major threat to the environment due to their non-degradable property. Also, waste from natural sources such as natural fiber waste was also commonly dumped and burnt illegally leading to air pollution. rPET waste of post-consumer plastic is among the least recycled plastics. Meanwhile, wood dust is abundant in woodworking industries such as furniture factories (Kariz et al., 2015).

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Therefore, recycling waste materials is one of the promising solutions to minimize the environmental impacts of this waste while minimizing the use of natural resources. This research will later investigate the effect of wood dust incorporation in the rPET on the thermal and morphological properties of the fabricated composites to be applied as 3D printer filament.

#### **1.2** Problem statement

As already mentioned, among the problems faced now is the uncontrolled excess of plastic waste. So, it is important for the industrial sector that uses 3D printing to develop

and expand 3D printing technology using plastic materials. PET is also widely used for advertising displays, packaging (retail and medical), and electronic insulation. PET has a wide range of applications that are often used in industry because of its resistance to heat, solvents and impacts (Sinicki, 2020).

3D printing technology has opened up new possibilities for sectors, including quicker product creation, customization, cost reduction, and tangible product testing. For example, its ideas are gaining traction in the medical and dentistry sectors, where personalization is essential. However, a few problems may affect 3D printing manufacturing, including plastic waste is often non-biodegradable, which means it can take hundreds of years to disintegrate. This is because plastics are composed of intermolecular connections and their structure protects them from rusting or dissolving. Plastics that are improperly disposed of becoming water reservoirs. They block rivers and float on the surface of lakes, contaminating and impeding their flow (Jason Lehrer, 2017).

Every creation has its shortcomings, so the problems that often occur to 3D printing machines include quality problems on the products produced. For example, there are many quality-related problems with 3D printing such as brittle FDM (unified deposition modeling) parts, low-resolution output and materials (Kowalski, 2015).

Due to the issue of increased waste production as a result of the usage of PET, it is necessary to seek other solutions. Chemical recycling is a viable process for converting non-renewable raw materials into a material with potential use in concrete additives, such as polyester resins with the following improvements, and conserving non-renewable raw materials may help decrease the environmental effects (Mendivil-escalante et al., 2014). The cost of printed items is affected by the costs of materials used and the time it takes to be printed. Compared with other filaments, some filaments are costly, and the process of printing may place restrictions on their use. Filament costs can be decreased by using affordable filler materials that are natural fiber to be combined with polymer matrix, which can also improve their flexural rigidity, mechanical characteristics, and stability when solidified (Ahmed et al., 2020).

#### **1.3** Research Objective

The aim of this research is to development of novel composite material using recycled polyethylene terephthalte (rPET) reinforced wood dust. Hence, the objectives are as follows:

- a) To characterize the wood dust and rPET for physical and thermal properties.
- b) To assess the effect of sodium hydroxide treatment on the physical and morphological properties of wood dust-rPET composite.
- c) To evaluate the effect of fiber loading in the composite.

#### 1.4 Scope of Research TI TEKNIKAL MALAYSIA MELAKA

To ensure that all project objectives are achieved, the following are few important elements that must be followed. The scopes of this research are as follows:

- a) Material that used in this research was wood dust and rPET.
- b) Treatment of wood dust using NaOH.
- c) To test and analyse physical and thermal properties of wood dust.
- d) To test thermal properties of rPET.
- e) To study physical and morphological of the composite wood dust and rPET.

f) Material that used in this study was rPET and wood dust with fiber loading 0 %, 1 %, 3 % and 5 %.



#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

This chapter highlights the theory, knowledge, and findings of previous researches about the development of 3D printing filament by using recyclable waste mixed with wood dust by some analysis to compare whether the materials can become a filament to use in 3D printing machine.

#### 2.2 3D printing

Nowadays, 3D printing technology has expanded very quickly and is expected to expand more in the global market in the next few years. Additive manufacturing techniques are rapidly grown in industrial and household environments because they have various exciting features that can be used. For example, suppose production is required on a small scale. In that case, parts can easily be obtained with limited scrap production and energy consumption without expensive tools or complicated installation. 3D printing techniques allow the manufacturer to create objects with complex shapes and suitable thicknesses, which is usually not achievable through standard polymer manufacturing methods (Mazzanti et al., 2019). Figure 2.1 shows the differences between traditional and additive manufacturing methods.



Figure 2.1 Traditional and additive manufacturing concepts are compared (Wasti &



Characteristics of 3D printing filament for FDM (Fused Deposition Modeling) includes the need to choose the suitable filament because using filaments with the wrong diameter or setting will cause printing failure and damage the 3D printer itself. All 3D printers have certain specifications based on the design's speed, temperature, and function that requires the user to study and understand the machine before selecting the filaments. Each filament material has specific characteristics in terms of physical attributes and appearance (Madhav et al., 2016).

#### 2.2.2 Importance of 3D printing filament

2.2.1

3D industrial printing is important because of its reliability and simplicity to produce very complex parts accurately. Hence, it has a lot of advantages over the conventional approach, where one of the most important factors is time. For example, 3D printing has significant applications in the fields of the Aerospace Industry and mechanical engineering. 3D printing has the advantage that makes the process easier to produce any component because it only has three parts for its output, which are printing, design and final component analysis using a 3D printer (Madhav et al., 2016).

#### 2.2.3 Advantages of using 3D printing

3D printing provides a much better advantage over traditional methods where components are made as soon as the design is modeled and analyzed, even with less knowledge and time, it can be made easier with the simplicity 3D printing provides in making components. Moreover, 3D printing allows to physically and visually inspect the product, dimensions and shape aspects of finding out if any design changes need to be made. A coordinate Measuring Machine can be used to check the dimensions and shape, while a profile projector being used to check the profile of the component and it can be used to inspect the product as part of the machine to check if it is suitable and so on (Madhav et al., 2016).

#### 2.2.4 Example of filament using 3D printing

Thermoplastics are used in 3D printing as filament material. Mikula et al. (2021) mentioned that a study has been conducted by (Anderson 2017), polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are the most popular materials used in 3D printing. Figure 2.2 illustrate the overview of the 3D printing. Surgical instruments, automotive components, small garden architecture, prototypes, toys, various types of packaging and many other products are often used as 3D printing materials (Mikula et al., 2021).



Figure 2.2 An overview of the 3D printing process (Mikula et al., 2021)

3D printing is suitable for many materials although the availability of polymers has become very limited. It is not a barrier when compared to injection moulding polymers for suitability on 3D printing. FDM materials have some similarities in properties including adhesion to the previous layer under low pressure imposed by the extrusion mechanism and the material should have a low melting point and a reduced viscosity to flow out of the nozzle for deposition (Manfredi & Minetola, 2017).

#### 2.2.5 Temperature of 3D printing nozzle

The effects of nozzle temperature, ambient temperature, and heat treatment procedures on the mechanical characteristics of FFF 3D printed prototypes were investigated using a heat-control 3D printing system. According to their findings, in FFF, tensile strength has a direct link with nozzle temperature and ambient temperature. They discovered that, among other process variables, extruded temperature and raster width had

the most significant impact on the precision of 3D printed components (Tlegenov et al., 2018).

PET needs very high temperatures, with the nozzle temperature ranging from 220 to 250 °C. PET, on the other hand, does not need a heated bed, unlike ABS. With blue painter's tape on the bed, PET prints best. Without it, the bed should be heated to between 50 and 75 °C to guarantee the extruded filament sticks. Cooling fans may be used while printing since this material does not warp like ABS. PET is not quite as simple to work with as PLA, but it's significantly less demanding than ABS, and it's become one of the most popular filaments on the market today (Paper & Vesel, 2019).

#### 2.3 **Polyethylene terephthalate (PET)**

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PET is one of the most widely available thermoplastic polymers on the market. PET relies on the polyester circle of relatives, a massive class of polymers characterized by esters functionalities inside the major macromolecular chains. PET is broadly used in packages as numerous as films, bottles, fabric fibers and other moulded products. An earlier report stated that PET is classified as the third most used plastic in the packaging industry with increasing demand. These polymers are mainly used to produce containers / bottles for beverages, such as water and carbonated soft drinks in sheets / films, industrial food, and nonfood uses. Firstly, PET is a thermoplastic polymer that can quickly be processed at high temperatures. Moreover, materials from PET can be recycled easily because almost the entire bottle production industry uses this type of polymer extensively (Nisticò, 2020).

Even though PET is generally derived from fossil assets and stays not biodegradable within the surroundings, novel advancements in the discipline pointed out the opportunity of producing PET in a more excellent sustainable way or the possibility of biodegrading this polyester through the enzymatic motion of isolated bacteria, enzymes and specific genetically modified. Using considering the excessive recyclability of PET and the opportunity of potentially indefinitely re-using this material can still anticipate that the destiny of PET continues to be written. In other words, PET has a specialized role in the packaging industry (Nisticò, 2020).

However, many PET products are significant contributors to severe environmental pollution. There are several ways to recycle beverage bottles, including chemical recycling methods such as aminolysis, glycolysis, hydrolysis and others or recycling in physical form with the diluting process. Therefore, plastic recycling is essential for environmental wellbeing. It is important to reduce the amount of plastic waste and produce value-added materials from low-cost sources by turning them into valuable materials. They are a very high demand for recycled plastics, and it has led to the research of alternative processing methods to produce higher-value products (Jankauskaite et al., 2008).

### 2.3.1 Characteristic of polyethylene terephthalate YSIA MELAKA

There are many characteristics of PET, including the safety of PET. PET is a very safe material to use in the F&B industry because the FDA, Health have approved it Canada, EFSA and other health agencies. Also, PET has high strength and stiffness compared to polybutylene terephthalate (PBT), but as compared to PBT, it also has higher heat distortion temperature (HDT). Moreover, the nature of PET is not easily broken and makes it suitable to be a glass replacement in some applications. Again, PET is simple, environmentally friendly, inexpensive and provides bottle selection, washing and grinding

operations. Furthermore, the PET bottle can be turned into small fragments and quickly dried to be stored for a specific purpose (Albini et al., 2019).

#### 2.3.2 Importance of polyethylene terephthalate

Plastic is a relatively light material compared to other materials. With lower weight and relatively high strength, it is considered one of the most economical, efficient, and powerful packaging systems. PET is a suitable plastic for 3D printing. It also has the strength and flexibility to produce 3D printed prototypes. For example, it is ideal for combining mechanical parts or cases for electronic equipment. PET also emits a slight odour compared to ABS or PLA, although many stores use it as 3D printing material (Chowdhury et al., 2018).

One of the main reasons PET is widely used is that it can produce several different grades in various molecular weights in a single multiproduct polymerization plant. Therefore, plastic recycling is very important for environmental well-being. It is important to reduce the amount of plastic waste and produce value-added materials from low-cost sources by turning them into valuable materials. The demand for recycled plastics is very high and it has led to the research of alternative processing methods to produce higher-value products (Jankauskaite et al., 2008).

Furthermore, PET is also important because it has the highest scrap value among plastic waste due to its low cost and being environmentally friendly. In addition, PET plastics can be easily recycled by crushing into small fragments before decontamination and purification processes are performed (Zulkifley et al., 2014).

#### 2.3.3 Advantages of polyethylene terephthalate

The most trusted plastic consumer goods are materials from PET. Many benefits can be obtained by using plastics as the materials for 3D printing. 3D printing considers more unpredictable plans to be made than when contrasted with more ordinary assembling. Plastics are biocompatible and lightweight, reasonable and require little energy to fabricate. This makes it ideal for disposable devices, which currently cover 85 % of medical equipment.

Plastic waste can be processed into the extrusion and the waste has the potential to be used as other alternative materials that are more sustainable for 3D printing. Likewise, it will set out the opportunity for future examination concerning other recyclable plastics as source material for 3D printers. Therefore, to meet the demand of the plastic market in 3D printing, this work should be developed in a more cost-effective and sustainable conscious method (Jason Lehrer, 2017).

### 2.3.4 Application of PET as 3D filament materials

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The study has shown that the virgin low-density polyethylene (LDPE) and rPET are optimal materials as an alternative filament among other options such as virgin high-density polyethylene (HDPE), virgin PET, virgin polypropylene (PP) and recycled HDPE (Exconde et al., 2019).

Moreover, the outcome showed that rPET is better contrasted with virgin PET. The recycling of PET likewise showed potential as an elective filament for 3D printing (Exconde et al., 2019).

The most progressive 3D printers are those that utilize materials from powder. At that point, this powder will be heated by using the laser. This technique permits it to work with practically any material transformed into powder. Toughness, hardness and high tensile and mechanical strength are the benefits of PET which can be changed over into powder and used to print machine parts. To create pieces as indicated by specific principles, the properties of PET powder should initially be tried to guarantee its reasonableness for 3D printing. In addition, comparisons were also made on 3D printing plastic materials such as HDPE, Nylon, PVA, PLA and ABS, showing that PET powder is very suitable to use as 3D printing materials (Nwogu et al., 2019).

Several materials are accessible for 3D printing filament, which are polymers (polyamide, PVA, PLA, ABS to even ceramic, gypsum, metals (stainless steel, gold and silver, titanium) or even concrete. In any case, the material properties, like strength, electrical and thermal conductivity, and optical straightforwardness, usually are contrasted with their routinely fabricated partners because of the anisotropy brought about by the layer-by-layer approach. The outcomes showed that it is feasible to utilize wood fiber in blends that contain cement for 3D printing (Kariz et al., 2015).

#### 2.4 Wood dust

Wood dust is a tiny object that results from cutting wood using a sharp tool such as a saw. In particular, wood dust is a small waste product found in various sectors such as the furniture industries, paper and pulp plant industries and sawmilling industries. Initially, wood dust was considered as an industrial waste that pollutes the environment but can be reused with three methods, including manufacturing, energy and agricultural utilization. For example, wood dust can produce something valuable as raw material for wood boards, light construction material such as cupboards, notice boards, wall and roof sheeting for mobile houses as an insulator in refrigeration systems and as low temperature storage of fuel in the energy industry, direct or indirect combustion produces wood gas, briquettes and particles.

However, there is also some weakness of wood dust, including burning wood dust in the open air which can cause atmospheric pollution leading to the problem of acidic rain and the emission of carbon oxide. Wood dust can also affect soil and water and is also a threat to the environment if not disposed of properly. There are three main negative effects on soil including reduction of the hydrogen content of the soil when used as mulch and reduced soil phosphorous when incorporated. Soil acidity will increase therefore the soil is not suitable to be used as a crop and contaminated soils will produce phenol compounds. All these effects can reduce soil productivity (Rominiyi et al., 2017).

#### 2.4.1 Characteristic of wood dust

Regarding wood dust, the size of wood dust particles depends on the type of wood from which the wood dust is obtained and the size of the saw teeth. Besides, wood dust is also a degradable lignocellulosic material but relatively stable in recalcitrant environments and rarely produces a bad smell during the long-term biodegradation process. Wood dust is also wood biomass in manufacturing compost as it has low density, high porosity and bacteria tolerance and the biodegradability rate is at an acceptable rate, so in this way, the wood dust-composting process can then be enhanced (Maharani et al., 2010).

#### 2.4.2 Importance of wood dust

Wood dust does not have much importance due to its low burning efficiency. However, pressing the wood dust into pellets becomes a kind of high-quality biofuel product wood pellets or wood dust pellets. Wood dust is a type of biomass that is easy to find and obtain because the furniture factory and timber factory sector is a major producer of wood dust. Wood dust is also a renewable material and can be used as a solid biomass fuel such as pellets or briquette. The briquettes can be used in industrial boilers while the pellet is mainly used in home heating stoves. Anyone who wants to optimize heating cost and increase comfort can use wood pellets because it is suitable for use in industrial and domestic (Kasangana et al., 2017).

#### 2.4.3 Advantages of using wood dust

Studies show that using materials from wood elements such as wood dust has unique features. Wood dust which is wood-based material is biomass and a low-cost the alternative that has shown great promise. Next, good tensile strength and stiffness are also demonstrated on wood materials and wood types tested for 3D printing, including softwood and hardwood types (Lamm et al., 2020).

#### 2.5 Sodium hydroxide (NaOH)

NaOH is an inorganic compound that is known as sodium hydroxide. It also has **UNIVERSITITEKNIKAL MALAYSIAMELAKA** other names namely caustic soda and Iye. The product of the chlorine-alkali formed a NaOH compound. The combination of sodium cation ions + ions and hydroxide anion OH– will create a white solid ionic compound. The highly alkaline caustic and basic NaOH is capable of causing severe chemical burns and breaking down proteins at average ambient temperatures.

In industry, a very popular base material used is NaOH. On average, two sectors use NaOH including 25 % used in the paper industry while around 56 % is used by industry. Next, in the manufacture of sodium and salt detergents, organic synthesis and pH regulation also uses NaOH. Bayer's aluminium production process also uses this

compound. NaOH properties that neutralize acids or increase the alkalinity of the mixture are desirable to use in many scenarios (Ahmadi & Seyedin, 2019). Figure 2.3 shows the caustic soda flakes and chemical structure of NaOH. The caustic soda flakes are white.



Figure 2.3 Chemical structure of NaOH (Ahmadi & Seyedin, 2019)

#### 2.5.1 Properties of sodium hydroxide (NaOH)

NaOH solution is a strong base and highly soluble in water. 60 million tons are the gross amount of NaOH for annual production. NaOH is a wide papermaking industry and a neutralizing agent in the chemical industry. 30 % by weight of NaOH generally contains Soda Iye. A colourless crystalline solid that melts at 318 °C without decomposition is pure NaOH. The surface of the materials becomes soft and smooth as the effect of NaOH usage (Ahmadi & Seyedin, 2019).

#### 2.5.2 Sodium hydroxide (NaOH) treatment on natural fiber

Products from clothing to roofs have used natural fibers from grown crops such as cotton, coconut fiber, sisal and flax. Furthermore, biodegradability and renewable properties are evaluated as environmentally friendly materials. In the field of many composites, fibers have great potential. The outer skin of the coconut and the husk will produce fiber (Karthikeyan et al., 2014).

The way to improve the properties of natural fibers is with alkaline NaOH treatment. Increased cellulose content, waterproof properties of fibers and mechanical properties are the effects of the use of alkaline NaOH. High specific modulus, lightweight, non-toxic, absorbs CO2 during its growth, and easy to process are the advantages of fiber. The use of NaOH makes the fiber surface cleaner and is able to change the molecular structure of cellulose. On the other hand, NaOH is also able to increase the aspect ratio diameter or length by reducing the fiber diameter and good adhesion to the matrix can increase the surface area of the fibers (Kabir et al., 2012).

#### 2.5.3 Sodium hydroxide (NaOH) treatment on wood dust

Mechanical properties and adhesion contribute to the increased positive feedback of the filler-matrix interface when subjected to the chemical treatment of wood dust. Chemical treatment for wood dust has become popular because it achieves the adhesion of the filler matrix and the mechanical properties of the composite. Dust on the surface will be removed by washing and drying at a temperature of 65 °C after being processed in alkali treatment.

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1 %, 3 %, 5 % and 7 % are concentrations to be immersed in NaOH solution with a dry substrate at room temperature for 2 hours. The NaOH solution sticking to the filler surface will be removed with distilled water. The acetic acid solution is diluted for a few minutes and washed again with distilled water to neutralize the filler by being soaked and stirred together. Before manufacturing the composite, the wood dust filler is dried up in the oven at 70 °C for 72 hours. 5 % NaOH solution gave the best effect on the composite properties of the treated wood dust (Jaya et al., 2016).
Type of wood dust either softwood or hardwood will influence the effect of alkali treatment and the concentration. As for the softwood, no significant changes can be seen through alkali treatment, and 5 to 6 g of NaOH per 100 g of wood is needed to produce a maximum effect on digestibility in vitro Baker et al. (1975). On the other hand, Rexen et al. (1976) found that treating wood dust or straw with up to 7 % of NaOH will produce the best result (Omole & Onwudike, 1981).

#### 2.6 **Properties of materials**

To create a new filament combination, the mechanical properties of wood dust are an important factor. The purpose is to ensure that mixing rPET with wood dust will produce suitable filaments for the 3D printing process. The mechanical properties of wood dust have high value and benefits due to its high specific strength, small density, lightweight, low cost, recyclability and biodegradability and has acquireparticularcial category of green (Paper et al., 2014).

# 2.6.1 Physical properties of wood dust

#### UNIVERSITI TEKNIKAL MALAYSIA MELAKA Physical characteristics are analyzed, and scanning electron microscopy (SEM) is

used to see them. Raw and residual wood dust was tested for porosity, water retention, and water drainage. SEM was used to examine the morphology of raw and residual wood dust's surface to detect changes in the structure and other characteristics of wood dust after usage (Sunagawa, 1999). Various measurements in the physical properties of wood dust can be modified by combining wood dust particles (Rizki, 2016).

#### 2.6.2 Thermal properties of wood dust

The thermal test shows that low-cost, efficient unfired brick can be developed by using wood dust. Wood dust has a positive effect on the thermal insulation quality of building materials and the thermal transport properties after the experiments are carried out. Thermal conductivity around 20.1 % thermal diffusion, 30 % earth building blocks, and 22.7 % density can be reduced by adding 10 % wood dust (Charai et al., 2020).

The reason for the enhanced thermal conductivity of wood dust reinforced polyester based composites are that the filler material includes thermal releasing elements that are thermally conductive, whilst the utilized wood is thermally conductive when compared to polyester (Hossain et al., 2014).

#### 2.7 Soil burial test

The biodegradability of the polypropylene (PP) and cassava starch blends was tested on a laboratory scale using a soil burial test. Each of the mixes was sliced into dumbbell-shaped specimens of various sizes. The 90-day soil burial test was conducted. To enhance air and water circulation, wet alluvial soil was put in plastic containers with small holes drilled at the bottom and on the side of the container. The soil was maintained moist with water throughout the test and stored outside the room,

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Dumbbell-shaped specimens were buried at a depth of 10 cm below the surface in the soil, exposing them to the activity of soil microorganisms. The blend samples were removed after the test, rinsed with distilled water, dried in an oven at 70 °C for 24 hours, and then stored in a desiccators (Obasi et al., 2013).

#### 2.8 Hot pressing

Hot pressing is a densification technique in which pressure and temperature are applied simultaneously to a mattress made of fibers and resin to form the final product. Hot plate pressing is ideal for densifying materials that are difficult to densify using other methods. Panyakaew and Fotios (2011) studied the impacts of pressing temperature on the physical qualities of insulation boards made from coconut husk and bagasse while using the hot pressing technique.

A pressure of 14.7 MPa was used to create the boards. To study the effects of temperature and time, three temperature settings and three duration settings were used: 180  $^{\circ}$ C , 200  $^{\circ}$ C , and 220  $^{\circ}$ C and 7, 10, and 13 minutes, respectively. Except for swelling thickness, the bagasse insulation boards manufactured with a density of 350 kg/m3, at a temperature of 200  $^{\circ}$ C, and a pressing period of 13 minutes met all of the criteria (Gaspar et al., 2020).

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The application of heat and uniaxial pressure simultaneously is known as hot pressing. Because of the uniaxial nature of the process, this approach can only produce basic forms. Furthermore, the use is much more common in ceramic processing, perhaps due to the greater variety of processing choices available to metals or the specialized applications, such as transparent polycrystalline ceramics, that demand high density and tiny grain size.

Mechanical loading from a basic die and punch system is combined with heating from a furnace surrounding the die and punches in hot pressing equipment, as shown in Figure 2.4. Graphite is often used for dies and punches because it has the correct thermal and mechanical qualities and can be machined. Some ceramic oxides lose their stoichiometry after hot pressing and must be re-annealed in oxygen to restore it. Aluminium oxide and silicon carbide are two alternatives to graphite. A regulated sequence of pressure and temperature is used for hot pressing. Because applying pressure at lower temperatures might affect the component and tools, pressure is often applied after some heating has occurred. The hot pressing temperature is several hundred degrees lower than that of normal sintering. The speed of the operation naturally limits the quantity of grain growth and the lower temperature needed (Figure, 2016).



Figure 2.4 A standard hot press with a furnace containing resistive components or coils for inductive heating is shown schematically (Figure, 2016)

#### 2.8.1 Advantages and disadvantages of hot pressing

In part developed for demanding applications or manufactured from materials that are difficult to densify by other ways. Because pressure accelerates the rate of densification at a given temperature, sintering may be performed in less time and at lower temperatures than traditional sintering. Because pressure does not affect the rate of grain development, the improved densification kinetics result in final materials with smaller grain sizes. Unfortunately, the equipment and tools are more complicated. The operation is batch rather than continuous. The procedures are more costly than the sequential compaction followed by the traditional sintering technique. Next, heat transmission from the surface to the core takes a long time, particularly when the composite is thick. The heat is transmitted from the plate to the core of the panel mostly by conduction and convection (Figure, 2016).

#### 2.9 Summary

The possibility of recycling waste material to become a commercial product that can be utilized in different sectors as a component of their production materials maybe described in the conclusion of this literature study. According to the findings of this literature review, waste material such as wood dust may be developed as natural fibers that can be reinforced with other recycled plastic materials like polymers.

Due to its physical and mechanical properties, reinforcing this recyclable material can enhance its strength. The research found that, despite minor weaknesses in the reinforced waste material, adding this recycled waste material can improve mechanical characteristics when wood dust interacts with polymer in the correct formula and ratio during the mixing process. The ability of wood dust when combined with other polymers to produce a new filament that will be used as materials for 3D printing may be successful.

#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Introduction

This chapter is explaining about the appropriate experimental planning method that will be used in this research. Generally, this chapter describes in detail about the process and presents a new and integrated analytical approach to study the capabilities of development of composite using rPET reinforced wood dust.

This chapter shows the steps from the sample preparation for the composite process until the final test is carried out. Started by studying the past research similar to this experiment and then began drafting in the literature review chapter. After that, selecting the appropriate methodology for this study by initiating materials preparation and then proceed with the mixing composite rPET and wood dust. When the test is done, the result will be analyzed and mentioned in this thesis. This chapter will cover the flowchart, material preparation, material treatment and all thermal, morphological, and particle size tests. For the treatment process, the formula and ratio will also be described. Figure 3.1 shows the overall structure of methodology performed in this research.



Figure 3.1 Process flowchart

#### 3.2 Raw materials

The raw materials needed in this experiment include fiber material from wood dust, matrix material from rPET and finally the chemical substance from NaOH.

#### 3.2.1 Recycled polyethylene terephthalate (rPET) pellet

rPET is the matrix chosen to develop a 3D printing filament as a thermoplastic material. rPET in the form of a pellet were obtained from the Glowmore Express Sdn. Bhd. located at Port Klang. Table 3.1 shows the product specification of the rPET pellet.

wet WA	Table 3.1 Specification of the rPET pellet						
No	Specifications	Unit / type					
1	Pellet size	3 mm					
2	Intricist velocity	0.65-0.70 dl/g					
3	Moisture	≤ 1.0 % PPM					
-4	Melting point	250 250					
UN5VE	Structure EKNIKAL M	Crystalline MELAKA					
6	Transparency	Clear					
7	Strength	Rigid stable					
8	Specific gravity	1.33 to 1.45					

#### 3.2.2 Wood dust

The wood dust was obtained and collected from Kilang Papan RT (Melaka) Sdn. Bhd. Malacca with a total of one medium-size sack. Table 3.2 shows the content of raw wood dust while Figure 3.2 shows the picture of raw wood dust and the picture of excess wood dust at the Kilang Papan RT (Melaka) Sdn. Bhd, Malacca.

No	Received Wood dust	Specifications
1	Size range	250 - 125 μm
2	Received form	Agglomerate
3	Colour	Brown

Table 3.2 Wood dust from furniture making specification



Figure 3.2 Raw wood dust: (a) wood dust chip, (b) excess wood dust at the Kilang Papan

RT (Melaka) Sdn. Bhd, Malacca.

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#### 3.2.3 Sodium hydroxide (NaOH)

During this research, NaOH will be applied as a fiber treatment agent to assist and improve fiber surface characteristics and increase the adhesion between fiber and matrix. In this investigation, NaOH was utilized in the form of pellets and it is called pellets EMPLURA® from Merck. Table 3.3 shows the content specifications of NaOH. Figure 3.3 shows NaOH that has been used for this project.

No	NaOH contents	Specifications
1	Physical form	Pellets
2	Colour	White
3	Density	2.13 g/cm3
4	Water solubility	100 %
5	Molecular weight	40 g/mol
6	Boiling point	1390 °C
7	Melting point	323 °C

Table 3.3 NaOH specification



Figure 3.3 Pellets EMPLURA® (Merck)

#### **3.3** Preparation of materials

This topic will explain the preparation of materials for this project. The raw material needs to be prepared are wood dust and rPET to produce the composite.

#### 3.3.1 Preparation of recycled polyethylene terephthalate (rPET)

For the preparation of rPET, it was purchased from Glowmore Express Sdn. Bhd. located at Port Klang. The pellet is 3mm in size and can be seen in the Figure 3.4. rPET were prepared to be used as fiber loading.



Figure 3.4 3 mm rPET obtained from Glowmore Express Sdn. Bhd

#### 3.3.2 Preparation of wood dust

The wood dust was sieved using manual method to obtain a particle size of 125  $\mu$ m and it can be seen in the Figure 3.5. The particle size for wood dust needs to be highlighted because only 125  $\mu$ m wood dust can be used to run this project. As a safety measure, this manual sieve should be done by wearing a face mask to prevent shortness of breath while sieving the wood dust.



Figure 3.5 Manual method of sieving wood dust: (a) wood dust size in the range of 150 to 250 μm, (b) a manual method has been used where the wood dust has been sieved manually using a net siever, (c) the expected wood dust size which is 125 μm is



In this step, two processes were involved which is a preparation of NaOH concentration and process treatment for wood dust. Figure 3.6 shows the preparations of the mixing process to treat the wood dust.



Figure 3.6 Preparations for the mixing process: (a) wood dust, (b) NaOH pellet, (c)

# 3.4.1 Preparation of sodium hydroxide solution (NaOH)

During this treatment procedure, the exact concentration of NaOH must be created. A solution of 6 % NaOH and 94 % distilled water was utilized to prepare the solution. The NaOH was in the shape of a pellet and had to be weighed before mixing with water. Finally, distilled water and pellet NaOH were mixed until completely dissolved. An example of calculating the amount of NaOH to be used should be based on the formula Equation 3.1.

$$\frac{6}{100}$$
 X 1000 = 60g of NaOH (Equation 3.1)

Figure 3.7 shows the mixing process of distilled water with NaOH pellet solution. The amount of NaOH is needed only for 50 g and during the mixing process, the NaOH reacts and produces a sound and makes the beaker warm.



Figure 3.7 Mixing process of distilled water and NaOH pellet

#### 3.4.2 Treatment of wood dust

Wood dust needs to be cleaned and washed using distilled water and treated using UNIVERSITITEKNIKAL MALAYSIA MELAKA NaOH solution. NaOH will be mixed with wood dust inside a beaker. The chemicals need to be soaked together until completely absorbed into the wood dust for 2 hours at room temperature. Figure 3.8 shows the mixing process for wood dust and NaOH solution.



Figure 3.8 Mixing process of wood dust and NaOH solution

Next, distilled water is used to clean the mixture and should be rinsed at least three times by putting it in a strainer. Figure 3.9 shows the process for cleaning the wood dust by using strainer.



Figure 3.9 Cleaning process of the wood dust: (a) prepared the strainer, glove and aluminium foil (b) straining process of the wood dust

Finally, the moist wood dust were placed inside the oven for 24 hours at a temperature of 100  $^{\circ}$ C by using aluminium foils to dry the wood dust completely. As for

the form, the result of treated and untreated wood dust is in lumps form after going through the drying process. As for the colour, treated wood dust changed to bright brown colour. Meanwhile untreated wood dust remains its original colour. Figure 3.10 shows the drying process.



Figure 3.10 Drying process of moist wood dust for 24 hours: (a) the treated and untreated wood dust has been placed in the oven, (b) the result of untreated, (c) the result of treated

# اونيونرسيني تيڪنيڪل مليسيا ملاك 3.5 Characterization of wood dust KAL MALAYSIA MELAKA

Particle size analysis and the TGA test will be done to identify two specific characteristics which are thermal and physical properties.

#### **3.5.1** Particle size analysis

Particle size analysis is where wood dust will be sieved using manual method. The objective of sieving wood dust is to reduce the size of the raw material from a large to fine mesh size.

#### 3.5.2 Thermogravimetric analysis (TGA)

The thermal properties of the fibers in the treated wood dust were investigated using a TGA analyzer, considering the weight loss of the fiber because of a rise in temperature. To examine the thermal degradation of wood dust, the machine parameter is an important factor that must be monitored. According to previous research, the temperature was set between 25 to 600 °C, with a dynamic nitrogen temperature of 10 °C added (Bhatti et al., 2016). Figure 3.11 shows the TGA analyzer that will be used for this step.



Figure 3.11 TGA analyzer (Q50 V20.13 Build 39)

#### **3.6** Characterization of recycled polyethylene terephthalate (rPET)

Polymers are one of the key components that must be carefully selected in creating 3D printing filament since this material will be the filament's most important component. There are many different polymers, but the most common are elastomer, thermoplastic and thermoset. So, in this research, thermoplastic was chose because it has a low melting point and can be reshaped easily in a viscous condition, if compared to thermoset resin, it cannot

be melted due to molecular bonding that prevents this from happening. rPET was chosen as the filament's matrix based on its fatigue resistance, low cost, lightweight and low moisture absorption.

#### 3.6.1 Thermogravimetric analysis (TGA)

TGA was carried to evaluate thermal degradation of rPET due to weight loss of the hydrocarbon. The machine used to run this test were Q50 V20.13 Build 39 with temperature 0  $^{\circ}$ C until 800  $^{\circ}$ C with additional dynamic nitrogen temperature with 20  $^{\circ}$ C / min heating rate.

#### **3.6.2** Differential Scanning Calorimetry (DSC)

DSC analysis will be done to obtain information on thermal transitions that occur in the sample. The transitions include residual reactivity, solvent evaporation, melting, crystallization, crystal transition, and glass temperature. DSC analysis was performed with a heating rate of 20 °C / min, from 30 to 800 °C. The sample weight that was used for this study was about 11 g.

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#### **3.7** Preparation of composite

Both materials, wood dust and rPET, will be sorted and weighed according to fiber loading content. It will refer to the target of 500 g per 1 mixture composite. Figure 3.12 shows the process of weigh and packed of wood dust and rPET.



Figure 3.12 Preparation of composite: (a) weigh rPET, (b) prepared and packed rPET inside zip lock bag, (c) prepared and packed treated and untreated wood dust inside zip

lock bag

#### 3.7.1 Mixing recycled polyethylene terephthalate (rPET) with wood dust

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The manual process was used to combine wood dust and rPET in zip lock bags by shaking them till appropriately mixed the fiber loading ratio utilized in the composite (0, 1, 3, and 5) wt %. Table 3.4 showed the weightage of the rPET and wood dust according to the fiber loading.

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Table 3.4 Weightage of composite

Fiber loading	0 %	1 %	3 %	5 %
rPET	0 g	5 g	15 g	25 g
Wood dust	500 g	495 g	485 g	475 g

#### 3.7.2 Hot pressing

Hot pressing machine were used to produce plate composite. The first step is to weigh 150 g of the composite for each session. Then the composite was placed on the compartment plate and being flattened evenly. Then set up the machine and the hot press process will automatically occur. The time taken for each session of the test is 15 minutes. During this process, safety factors must be a priority because the machine is set at a temperature of  $260 \,^{\circ}$ C.

The composite of wood dust and rPET were mixed manually with zip lock bags. The thickness of the plate composite was 2 mm. The plate composite will be used for 3 tests including water absorption test, soil burial test and SEM. Figure 3.13 illustrated the process of hot press.



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA** Figure 3.13 Hot press process: (a) placing the composite on the plate, (b) the result of hot

pressing process in plate form

#### 3.8 Characterization of composite

The surface composition of the composite will be investigated using a Scanning Electron Microscope (SEM). Meanwhile, a TGA machine may be used to examine the composite's thermal degradation, thermal stability and thermal properties. It's important to

assess the thermal characteristics of the filaments produced in this study to ensure that it will be thermally resistant.

#### 3.8.1 Morphological

The composite will be investigated by using a SEM to determine the characterization of rPET reinforced with wood dust. For example, a study has been conducted by Taylor (2009) mentioned that morphological investigation surface modification of Hibiscus sabdariffa fibers by silane treatment resulted in the fibers becoming coated and the surface characteristics of the fibers were not apparent. The distinction between Hibiscus sabdariffa and surface-modified fibers was established using SEM. This project will use JEOL JSM-6010PLUS/LV Scanning Electron Microscope with Motorized X-Y Stage to study the surface structure of the plate composite. Figure 3.14 shows the SEM machine used for morphological study.



Figure 3.14 JEOL JSM-6010PLUS/LV machine

#### 3.8.2 Soil burial test

This test requires mesh cloth, soil, distilled water and poly bags. The plates composite that have been hot pressed needs to be planted in the soil inside the poly bags. This testing lasts for a week and needs to be watered once a day at the same time in an amount of 30 ml. Each sample should be weighed and recorded before this test is performed. Then plate composites should be placed in the oven for 30 minutes at a temperature of 100 °C and the samples should be weighed and be re-recorded. An example of calculating the weight reduction (%) to be used should be based on the formula Equation 3.2. Figure 3.15 shows the preparation of equipment for soil burial test. The equipment needed including distilled water, soil, poly bags.



Figure 3.15 Soil burial test: (a) equipment needed for test, (b) the poly bags were placed at the area that can received sun light but protected rain water

Weight reduction (%) = 
$$\frac{Wi - Wf}{Wi} X 100 \%$$
 (Equation 3.2)

#### 3.8.3 Water absorption test

This test will be performed to see how much water will be absorbed under different conditions. Each plate composite with different fiber loading will be weighed 5  $g \pm$  as the preparation material for the water absorption test. The material will be soaked in distilled water for 48 hours for this test. Every 24 hours, the samples will be dried manually by using tissues and will be weigh to see if there is any physical changes occur after being soaked in distilled water. Every weigh of the samples must be recorded. An example of calculating the water absorption (%) to be used should be based on the formula Equation 3.3.



This chapter discussed the preparation, technique, and procedure for the development of novel composite material using rPET reinforced wood dust. The flow chart is used to represent the whole process for the project from the beginning to the end. The objectives are stated in the flow chart to ensure that all tasks and processes were completed in order to meet the objectives.

One of the processes during the project is to treat wood dust fiber by using NaOH. The purpose is to study the effect of the treatment on the properties of the fiber. Then, the equipment used for this project has been determined based on the previous research of surface structure analysis, morphological, and thermal analysis. These steps will be done to get the effective outcomes and to achieve the objectives. Particle size and TGA analysis test were selected to achieve the first objective by sieving the wood dust (125  $\mu$ m).

TGA tests will be conducted on the treated, untreated, and rPET materials to assess material degradation. The thermal behaviour of polymeric and recyclable materials will be investigated using DSC analysis. This TGA and DSC study will be carried out in order to achieve the second objective of the project.

In addition, a few tests will be carried out to achieve the third goal, including soil burial, morphological analysis, and a water absorption test. The outcome will be discussed in the next chapter.



#### **CHAPTER 4**

#### **RESULTS AND DISCUSSION**

#### 4.1 Introduction

The results and analysis of the development of composite using rPET reinforced wood dust are presented in this chapter. The wood dust will be mixed with rPET, as stated in the previous chapter. This composite will be placed in a hot pressing process to perform 3 tests including soil burial, water absorption and SEM.

A few tests and analyses were performed on the sample of plate composite from wood dust and rPET. The thermal degradation of material was recorded. The water absorption test was carried out to evaluate how much water the composite material absorbed under different conditions. A surface morphology study by using SEM was also performed to assess composite surface fractures, flaws, and contaminants. The expected result for this study will be described in the subtopic below.

The data of TGA, soil burial test and water absorption test was analyzed and discussed to study the mechanical, physical, and thermal properties of novel composite material using rPET reinforced wood dust. Three samples were investigated in the thermal analysis, including treated wood dust, untreated wood dust and rPET pellets. Information on thermal behaviour for all samples has been obtained from the study and utilized in process development and analyses.

#### 4.2 Thermogravimetric analysis (TGA)

TGA was analyzed on 3 samples including treated wood dust, untreated wood dust and raw rPET. Figure 4.1 illustrates the result of TGA analysis for treated wood dust and untreated wood dust. It shows that the degradation occurs at 105.45 °C until 186.44 °C at the loss of 80.30 % of fiber content. So that means it is still moist. The second degradation phase started at 186.44 °C and only 40.68 % fiber left after the second phase. The final degradation phase occurs at 520.32 °C – 800 °C, where all the wood dust has transformed into ashes.

The initial decomposition of untreated wood dust occurs at temperature 88  $^{\circ}$ C – 212  $^{\circ}$ C (10 % weight loss), most components that degrade moisture content. The second degradation phase starts at 213  $^{\circ}$ C until 390  $^{\circ}$ C, decomposing lignocelluloses and hemicelluloses content. Final degradation started at 390.32  $^{\circ}$ C until 800  $^{\circ}$ C and only ashes that can be seen.



Figure 4.1 Results of TGA analysis for wood dust: (a) treated wood dust, (b) untreated wood dust

In conclusion, there is little difference between treated and untreated wood dust. The treated fiber has a higher combustion resistance where the degradation value for the treated is 105 °C compared to the untreated with a temperature of 88 °C. So, the treatment of wood dust provides an advantage in combustion resistance which is suitable for extruding at high temperatures according to the rPET temperature. The previous research proved this result by Haque et al. (2020). The obtained result shows that the treated wood dust thermal properties were stable compared with untreated wood dust.

TGA for rPET is influenced by both time and temperature at the same time in a single phase. The rPET degradation phase lasts from 398 °C to 494 °C, with all materials entirely degraded. This is because the rPET molecules bonding have completely decomposed at this point. Figure 4.2 illustrates the result of TGA analysis for raw rPET.



Figure 4.2 Results of TGA analysis for raw rPET

Differential scanning calorimetry (DSC) was a method to identify the melting temperature for the rPET. The DSC result in Figure 4.3 shows that the first peak temperature at 253 °C was the melting temperature for the rPET. From the curve, rPET shows glass transition temperature at 62 °C. The second peak point was at the temperature of 445 °C, where it is a value for maximum temperature for the rPET before it is started to degrade. This value will be an indicator for the hot press process. The hot press temperature was set to 250 °C to ensure that the polymer was fully melted and proper distribution heat during the compression process.



Figure 4.3 Results of DSC analysis for raw rPET

#### 4.3 Water absorption test

A water absorption test was performed to see how much water was absorbed under different conditions. The water absorption percentages of the composite may be seen in the table and graph below. The water absorption test showed a slight change in the results obtained. It can be seen when the rate of water absorption was calculated based on the weight of the plate composite after 48 hours of soaking. The water absorption test findings showed that the composite's water absorption capabilities improved as the wood dust content increased from 1 % to 3 % to 5 %. This is because of the hydrophilic character of wood dust. Therefore, with 1 % and 5 % reinforcement, the lowest and highest water absorption rates were obtained, respectively. Table 4.1 and 4.2 illustrates the results for treated plate composite, untreated plate composite and rPET.

Fiber	St. Sala	Treated (g)						
(70)	Before	Average	Day 1	Average	Day 2	Average	Day 1	Day 2
	5.218		5.346		5.280			
1%	5.055	5.113	5.180	5.247	5.230	5.229	2.621	2.269
	5.066	_	5.215		5.176			
	5.168	Wh .	5.330		5.394			
3%	5.211	5.176	5.393	5.319	5.340	5.330	2.763	2.975
	5.148	a hun	5.233	-u-	5.256	ومرسب	190	
	5.080		5.220		5.195			
5%	5.075	5.073	5.210	5.226	5.248	∆ 5.247 ∆	3.016	3.430
	5.065		5.248		5.298			

 Table 4.1 Results for water absorption test (treated composite)

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Fiber	Untreated (g)						Water absorption (%)	
(%)	Before	Average	Day 1	Average	Day 2	Average	Day 1	Day 2
	4.973		5.018		5.030			
1%	5.107	5.067	5.167	5.126	5.160	5.131	1.164	1.263
	5.122	]	5.194		5.202			
	4.981		5.115		5.146		2.397	2.790
3%	5.215	5.090	5.343	5.212	5.365	5.232		
	5.074		5.178		5.186			
	5.176		5.337		5.395		3.123 4	
5%	4.961	5.059	5.115	5.217	5.134	5.262		4.013
	5.040		5.200		5.256			

Table 4.2 Results for water absorption test (untreated composite)

Figure 4.4 illustrates the graph for water absorption test. The water absorption rate of fiber loading after 24 hours of immersion in distilled water is 2.62 % for 1 % fiber loading. The graph shows that water absorption rate for treated plate composite with 5 % fiber loading has a maximum water absorption rate of 3.43 %. The treated plate composite demonstrates a consistent rise in water absorption rate after being immersed for 48 hours. As for 1 % fiber loading day 2, the water absorption rate was lower than 1 % fiber loading day 1. It may due to over tapping during manual drying process by using tissue.

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Figure 4.4 Results for water absorption test for treated composite

After 24 hours of immersion in distilled water, observation on the water absorption test for untreated plate composite has been done. The rate of water absorption can be seen in Figure 4.5. For 1 % fiber loading day 1 displays 1.16 % water absorption. The percentage of water absorption for 3 % fiber loading day 1 has been steadily increasing at 2.4 %, whereas 5 % fiber loading day 1 has been steadily rising at 3.12 %. It showed a consistent rise in water absorption rate after 48 hours of untreated plate composite immersion. The most significant amount of water absorption can be seen in untreated plate composite with 5 % fiber loading, which is 4.01 %.



Figure 4.5 Results for water absorption test for untreated composite

Figure 4.6 shows that the absorption of water increased but was not effective because it did not mix with other fiber. Generally, the more fiber loading combines with polymer, the more space void, so the more water was being absorbed by the plate composite. The absorption graph has shown a similar pattern in water absorption, showing that the treated, untreated and raw rPET plate composite continues to rise. As a result, it may be stated that the water absorption rate was dependent on the quantity of fiber loaded.



Figure 4.6 Results for water absorption test for raw rPET

#### 4.4 Soil burial test

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The soil burial test was used to investigate the biodegradation rate on treated and untreated rPET reinforced wood dust. This test determines the degradability of the composite under specific conditions and time (Pang et al., 2020). Table 4.3, 4.4 and 4.5 illustrated the result for soil burial test for treated, untreated and raw rPET plate composite respectively.

	Treated (g)						
Fiber (%)		One week					
	Before	Average	After	Average	Test (%)		
	4.9		5.6				
1%	5.0	5.0	5.0	5.4	8.0		
	5.1		5.6				
	5.0		5.3				
3%	5.2	5.1	5.3	5.3	3.9		
	5.0		5.2	1			
5%	5.0		5.1	5.2	2.0		
	5.1	5.1	5.2				
	5.2	]	5.3				

Table 4.3 Results for soil burial test (treated composite)

Fiber (%)	Untreated (g)						
		Soil Burial					
	Before	Average	After	Average	Test (%)		
	4.9		5.7				
1%	5.1	5.0	5.9	5.8	16.0		
	5.0		5.6				
	5.0		5.5				
3%	5.1	5.1	5.3	5.4	5.9		
	5.1		5.4				
	5.2		5.3				
5%	4.9	5.0	5.2	5.2	4.0		
	4.9		5.2				

Table 4.4 Results for soil burial test (untreated composite)

Table 4.5 Results for soil burial test (raw rPET)

and a second	R	aw rPET (g)		
TE	One w	veek		Soil Burial
Before	Average	After	Average	1 est (%)
5.1		5.1		
5.1	5.0	5.2	5.1	2.0
4.9	1	5.0	1	1 inter
		a <sup>3</sup>	. S. V	1. C. C.

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Figure 4.7 and Figure 4.8 show the percentage of weight loss for treated and untreated plate composite with 1 %, 3 %, and 5 % fiber loading after testing it for seven days. Both graphs show decreasing data, which is related to the theory information. The sample will degrade under the soil. For treated plated composite, the percentage of weight loss is 8 % for 1 % fiber loading, 3.9 % for 3 % fiber loading and 2 % for 5 % fiber loading. This data shows that percentage of fiber loading affects the degradation process.



Figure 4.7 Results for soil burial test for treated composite

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For untreated plate composite, results show that 1 % fiber loading has the highest weight loss compared to the 3 % and 5 % fiber loading. This result can conclude that the mixture of untreated wood dust and rPET absorbed distilled water more because soil and wood dust is free of impurities. According to Maran et al., 2014, the additional water content in the material will encourage the growth of microorganisms during the degradation process and increase the weight loss of the sample.



Figure 4.8 Results for soil burial test for untreated composite

#### 4.5 Morphological

The surface structure morphology of treated and untreated plate composite was analyzed by using a JEOL JSM-6010PLUS/LV. The examined plate composite surface was sputter-coated with silver before being inspected using a JEOL JEC-3000FC auto fine coater model. This analysis identified whether the fiber was completely mixed and attached properly with the matrix or not. Figure 4.9 illustrated the result for spatter-coating plate composite.



Figure 4.10 illustrates a comparison of surface morphology for treated and untreated plate composite. For treated plate composite with 1 % fiber loading, an observation that can be made from the SEM images is that the fiber content and void cannot be seen clearly because the fiber content was low. Next, for 3 % fiber loading, a few fibers and void has been detected on the fiber surface due to the increased rate of fiber content. Lastly, an observation on 5 % fiber loading shows a lot of void and fiber.
From the micrograph below, for untreated plate composite with 1 % fiber loading, there was no void, and the fiber cannot be observed clearly because it has less fiber content. So, the strength value was low. Next, for untreated plate composite with 3 % fiber loading, it shows that there were a few fibers and void can be observed which can cause the strength of the plate composite to decrease. For untreated plate composite with 5 % fiber loading, an observation was made and there was a lot of void and fiber that can cause the plate composite to also become decrease.

This SEM verified the trend of higher fiber loading has more void, thus the more water absorption. The comparison between treated and untreated can be seen based on the observation on the micrograph image which shows that the untreated surface structure was better than treated. This is because NaOH treatment has damaged the wood dust fiber structure.

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Figure 4.10 Comparison of surface morphology for treated and untreated plate composite: a) treated fiber 1 %, b) treated fiber 3 %, c) treated fiber 5 %, d) untreated fiber 1 %, e) untreated fiber 3 %, f) untreated fiber 5 %

### **CHAPTER 5**

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

As mentioned in the previous chapter, three objectives must be achieved to complete this project. This project is considered successful since all of the objectives have been acquired.

The first objective is to characterize physical and thermal properties of wood dust from furniture waste and rPET. It can be considered successful because of the production of wood dust particles up to 125 µm by using a siever and the wood dust can be used to be combined with rPET to produce composite. 125 µm wood dust samples and rPET pellets were also being analyzed using TGA analysis to study the thermal characteristics of the material. DSC test has also been conducted for rPET to determine the glass transition, melting point and degradation temperature to study the behaviour and compatibility of rPET is a composite material.

The second objective was to evaluate the effect of NaOH treatments on the thermal properties of wood dust fiber. This objective was achieved by obtaining data on fiber degradation for treated and untreated wood dust, which revealed that there is no significant difference in thermal degradation between the treated and untreated wood dust.

For the third objective, the physical, morphological, and mechanical characteristics of rPET enhanced with wood dust were investigated using soil burial tests, SEM, and water absorption tests. The result obtained showed that percentage of fiber loading can affect the result of the tests that has been done.

Meanwhile, the water absorption rate increases as the overall percentage of wood dust mixture increase. The result also showed that untreated plate composite have higher water absorption rate compared to treated plate composite. This is because the composites with high fiber content have more voids, which may degrade the strength of the plate composite. For soil burial test, plate composite with higher fiber loading will decreased the percentage of weight loss. Untreated wood dust have higher water absorption rate because it is free from any impurities. This SEM analyzed that plate composite with higher fiber loading has more void, thus increased water absorption.

However, based on all of the observations made on treated and untreated composites throughout the tests and analyses, NaOH treatment may cause some damage to the wood dust structure or surface which promotes a better surface that results in superior water uptake and degradation for the composite.

# 5.2 Recommendation

Based on the research and all of the findings in developing a composite using rPET reinforced wood dust, a few improvements should be made to improve this project in the future.

To begin with, using NaOH as a bonding agent for the wood dust in this project seems to be ineffective, as shown by the fact that the strength of the plate composite was reduced. Other bonding agents, such as silane, may increase the fiber's quality and characteristics. To guarantee that the fiber was mixed correctly with the rPET, the particle size of the wood dust should be reduced from 125  $\mu$ m to 50 or 70  $\mu$ m. The physical characteristics of the wood dust may improve if the recommendations are taken into consideration.

Next, rPET should be dried in an oven at a suitable temperature. This process should be implemented due to the hygroscopic nature of rPET which contains moisture from the synthesis process. Excess moisture from polymer will cause abundant void and crack on the composite which will influence the thermal and physical properties of composite.

## 5.3 Project potential

The development of novel composite material using rPET reinforced wood dust was a project that can be used for a few suitable applications. However, this project is still in the beginning of the study which has not been able to produce filaments but previous studies have stated that fibers from wood dust and polymers from rPET can be used as filament materials.

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Then, the ability of wood dust when combined with rPET to produce a new filament that will be used as materials for 3D printing may be successful. A future study on the project should be done to gain more data to match the use of this natural fiber material.

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### APPENDICES

### APPENDIX A Gantt Chart of Study for PSM 1

ACTIVITIES	STATUS	WEEK															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SUPERVISOR SELECTION AND REGISTERED TITLE	PLAN	10															
25	ACTUAL	Y	1														
BRIEF AND PROJECT EXPLANATION BY SUPERVISOR	PLAN		19									1					
2	ACTUAL		A														
MODULE #1 RESEARCH DESIGN AND PLANNING	PLAN							1	-								
-	ACTUAL		-														
DISCUSS PROBLEM STATEMENT AND OBJECTIVE FOR	PLAN																
CHAPTER 1	ACTUAL				<u>يەرە</u>	1			-								
MODULE #2 FINAL YEAR PROJECT LITERATURE	PLAN				·	1			-								
REVIEW	ACTUAL																
DRAFTING LITERATURE REVIEW AND WRITING UP	PLAN																
CHAPTER 2	ACTUAL		1	1		/			-			. •	1				
MODULE #3 RESEARCH METHODOLOGY	PLAN	30	. L		2.			13 .	100	: للمل	00	13.6					
	ACTUAL		0		- 44				50	6	1						
RESEARCH ON METHODOLOGY AND WRITING UP	PLAN																
CHAPTER 3	ACTUAL																
WRITING UP PRELIMINARY RESULT	PLAN		ΞK	VIN	AL		AL.	AY:	SIA	M	= []	AK.	4				
	ACTUAL																
SUBMISSION OF FIRST DRAFT PSM 1	PLAN																
	ACTUAL																
SUBMISSION OF SECOND DRAFT PSM 1	PLAN																
	ACTUAL																
PREPARATION AND PRESENTATION PSM 1	PLAN																
	ACTUAL																

APPENDIX B Gantt Chart of Study for PSM 2

ACTIVITIES	STATUS	WEEK															
Activities		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MEETING AND DISCUSSION	PLAN																
	ACTUAL																
PREPARATION OF RAW MATERIAL	PLAN																
N	ACTUAL																
CONDUCTING THE EXPERIMENT	PLAN	N/															
2	ACTUAL																
COLLECT DATA AND MAKE ANALYSIS ON SAMPLE	PLAN		Se .									1					
×	ACTUAL		7						-								
DISCUSS ON RESULT EXPERIMENT	PLAN								~								
	ACTUAL																
START DRAFT REPORT AND WRITING UP CHAPTER 4	PLAN																
e.	ACTUAL								5								
START DRAFT REPORT AND WRITING UP CHAPTER 5	PLAN					1			ľ								
	ACTUAL		_														
SUBMISSION OF FIRST DRAFT PSM 2	PLAN																
6 ml	ACTUAL			1		/		. 6.0									
RECHECK FIRST DRAFT	PLAN	20	. 12		2.			2.	10	زلليت	AC	20					
	ACTUAL		0		- 10			4	2.	6	1	sec-all					
WRITING UP CONCLUSION FOR THIS STUDY	PLAN								÷.								
1.15.115.7	ACTUAL		-12		1.4.1		A 1	43.0	AL A			1.1.1					
SUBMISSION OF FULL REPORT	PLAN		ΞN	MIR	AL	. 141	AL.	AT	SIA	N.	ΞIJ	AN					
	ACTUAL																
FINALIZE THE CORRECTION OF FULL REPORT	PLAN																
	ACTUAL																
PREPARATION AND PRESENTATION OF PSM 2	PLAN																
	ACTUAL																



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### BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

### TAJUK: DEVELOPMENT OF NOVEL COMPOSITE MATERIAL USING RECYCLED POLYETHYLENETEREPHTHALATE (rPET) REINFORCED WOOD DUST

### SESI PENGAJIAN: 2021/2022 Semester 1

### Saya MUHAMMAD KHAIRUL AMIN BIN SHAMSUDIN

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Khairul Amin

Disahkan oleh:

Alamat Tetap:

BLOK D-1-1,

PERUMAHAN POLIS IPD SETIU,

22100, SETIU, TERENGGANU

Cop Rasmi:

DR. NUZAIMAH BINTI MUSTAFA Pensyarah Jabatan Teknologi Kejuruteraan Pembuatan Fakulti Teknologi Kejuruteraan

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Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh LIMA tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

Nama pelajar: Muhammad Khairul Amin bin Shamsudin (B091810184) Tajuk Tesis: Development Of Novel Composite Material Using Recycled Polyethylene Terephthalate(rPET) Reinforced Wood Dust

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAHANNYA ADALAH SULIT. ALAYSIA MELAKA

Sekian, terima kasih.

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