DEVELOPING COMPOSITE FILAMENT FROM RECYCLED POLYPROPYLENE AND AGRICULTURE WASTE FOR FUSED DEPOSITION MODELING

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DEVELOPING COMPOSITE FILAMENT FROM RECYCLED POLYPROPYLENE AND AGRICULTURE WASTE FOR FUSED DEPOSITION MODELING

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled "DEVELOPING COMPOSITE FILAMENT FROM RECYCLED POLYPROPYLENE AND AGRICULTURE WASTE FOR FUSED DEPOSITION MODELING" was prepared by LIM KAR YAP has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Mechanical Engineering with Honours at Universiti Tunku Abdul Rahman.

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ABSTRACT

Fused Deposition Modelling (FDM) is a widely used and cost-effective additive manufacturing process. However, most of the materials commonly used contribute to environmental waste. Additionally, agricultural waste like corn husks also contributes to environmental waste. Therefore, this research focused on developing a composite filament from recycled polypropylene and corn husk fiber. The corn husk fibers were extracted via the water retting method and further ground into a fine powder. The recycled polypropylene pellet was produced from post-used food containers. The composite filaments were prepared with various fiber content ranging from 0 to 7.5 wt% using a single screw extruder. The filaments with various fiber content were tested for their melt flow index values. Next, the filaments were printed into tensile specimens at different printing parameters and tested for their mechanical properties. The results showed that increasing fiber content reduced the melt flow index, tensile strength, and modulus. However, increasing the printing temperature significantly increased the tensile strength and modulus. It was also found that specimens printed with a filament containing 2.5 wt% fiber content had the highest tensile strength compared to others. Overall, the printed parts using this filament exhibited better mechanical properties compared to those printed with commercial wood filament. However, the inconsistency and incompatibility of the fiber caused some drawbacks in the performance of the composite filament. In conclusion, this study highlights the potential of using recycled materials in FDM and provides insights for optimizing material properties for 3D printing applications.

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LIST OF SYMBOLS / ABBREVIATIONS

MPa	pressure, Megapascal
wt.%	Weight percentage
AM	Additive manufacturing
ABS	Acrylonitrile butadiene styrene
BF	Banana fiber
CH	Corn husk
CHF	Corn husk fiber
FDM	Fused deposition modelling
PA6	Polyamide 6
PC	Polycarbonate
PETG	Polyethylene terephthalate glycol
PLA	Polylactic acid
PP	Polypropylene
RH	Rice husk
rPP	Recycled polypropylene
rPS	Recycled polystyrene

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Additive manufacturing (AM) is a manufacturing technique where the addition of material is formed layer by layer in a predefined route with a 3D printing machine. It provides minimal to almost no material waste, unlike traditional subtractive manufacturing produces waste materials in the form of chips (Shah, 2022). According to Krishna & Srikanth (2021), it has been found that additive manufacturing uses about 75 to 85% lesser material than subtractive manufacturing, while the energy used is 75% lesser compared to subtractive manufacturing. It is widely used in its application in producing prototypes and even products in industries and universities due to its affordability and capability (Ngo et al., 2018). There are several types of AM methods, such as material extrusion, powder-bed fusion, direct energy deposition, binder jetting, vat photopolymerization, and sheet lamination (Adekanye et al., 2017). Furthermore, the 3D printing industry is estimated to achieve 180-490 billion US dollars by 2025 (Nikitakos et al., 2020). Hence, the market of 3D printing will highly likely be popularised in the next few decades due to its versatility.

Fused Deposition Modelling (FDM) is a type of additive manufacturing technique. In 1989, the FDM technique was patented by Scott Crump, co-founder of Stratasys. Later in 1990, it was made commercially available (Jaisingh Sheoran and Kumar, 2020; Khan and Kumar, 2020). Fused deposition methods are widely used in the recent market due to its simplicity, cost-effectiveness and shorter lead time in contrast to traditional manufacturing methods (Adekanye et al., 2017; Ngo et al., 2018; Shahrubudin, Lee and Ramlan, 2019). FDM has been a vital industry manufacturing part of producing prototypes and products. For example, Signify 3D printed light fixtures (Singal, 2021) and WertelOberfell boots (Dobrosielski, 2022) are manufactured with FDM technology. With the FDM method, the use of a mould to produce parts has been gradually eliminated, resulting in lower costs and a shorter time in manufacturing. Following this, the material selectivity of FDM is broader. Other than typical commercial plastic, FDM can manufacture parts with engineering plastic, biodegradable plastic and composite plastic (Mazzanti, Malagutti and Mollica, 2019).

The most common type of thermoplastic filament used as the raw materials for FDM is polylactic acid (PLA) and Acrylonitrile butadiene styrene (ABS), which is widely used due to their cost-effectiveness and commercially availability (Ngo et al., 2018; Wankhede et al., 2019; William et al., 2021). However, PLA is biodegradable (Pakkanen et al., 2017), thus, it is not suitable for long-term application because of its degradation of mechanical properties. Nevertheless, ABS is a petroleum-based plastic, it will not be a sustainable solution for the environment. According to Gu et al. (2020), the relation between the oil price return and plastic stock return in 2020 was the highest in China. This study has shown that the increase in petroleum prices is directly related to the rise in plastic prices. Besides that, since petroleum is a consumable product, the petroleum reserve will eventually be depleted in 50-plus years, as Laherrère, Hall and Bentley (2022) suggested in the research. Therefore, research on sustainable plastic should be more focused on at present as unsustainable oil-based plastic is strongly based on the market price and the number of oil reserves.

Besides the commercially available type of filament, recycled material as the raw material for 3D printing is also a good alternative compared to PLA and ABS. Recycled materials used as 3D printing feedstock provide a range of advantages such as sustainability, lower cost and reduced global plastic waste issues (Kreiger et al., 2014; Cunico et al., 2019). Some notable successful projects that used plastic waste in 3D printing are the Olympic podiums made from plastic bottles during the 2020 Summer Olympics in Tokyo, Japan (Hahn, 2021) and furniture from recycled plastic waste by R3direct (Kleczinski, 2022). Nevertheless, currently, there are only a few choices for wood filament which are PLA and PETG based in the market whereas options for recycled plastic with natural fiber unfound. Thus, this research will focus on filament made from recycled plastic with natural fiber.

Single-use plastic is a consumable item which is intended to be used only once. Items including plastic cutlery, plastic bags, plastic coffee cups, plastic bottle, and plastic coffee pods are considered single-use plastic. PP is one of the most used single-use plastics in everyday life (Chen et al., 2021). It is mainly used in food packaging, food container, cutlery, and water bottles.

According to Alsabri, Tahir and Al-Ghamdi (2022), PP has occupied up to 16% of the global plastic market as food packaging. On that account, PP will contribute a large amount of plastic waste after the end-user disposes of it. However, PP that is not adequately treated after disposal can cause severe environmental pollution. This includes PP that is ended up in landfill or the ocean. It is known that the plastic will degrade over time, thus, with improper disposal of PP, it will decompose naturally and abrade into microplastic (Sarker et al., 2020). Therefore, the microplastic created will adversely affect the ecosystem and eventually affect humans health (Hwang et al., 2019; Sarker et al., 2020; Chen et al., 2021).

So far, some researchers have studied recycled PP to be turned into composite filament for FDM. For example, Milosevic, Stoof and Pickering (2017) blended rPP with hemp and harakeke fiber. The result was a better mechanical property with the rPP/harakeke composite as compared to the unfilled PP filament. Next, Morales et al. (2021) used rPP/rice husk blend to develop composite filaments. It concluded that although the mechanical properties fall behind neat rPP, it is sufficient for other light-intensive applications and with the use of recycled materials, it uses relatively lower cost to produce. The above example shows the use of rPP as a raw material in their composite filament, nonetheless, the rPP pellet used is directly from the factory. The use of rPP plastics from food container waste to turn into composite filament has not yet been done. Hence, in this research, rPP from single-use plastic food containers will be taken as the matrix for the composite material.

Corn is the most produced crop in the world. It has been used for human consumption and is an important food source for livestock (García-Lara and Serna-Saldivar, 2019). According to Paul Guin, Bhardwaj and Varshney (2018), 45 million tonnes of corn husks are produced for every 640 million tonnes of corn. As such, numerous tons of corn husk will be put to good use in other industrial and commercial aspects such as biofuels and fertilizer. In this research, corn husk was the key research material. Corn husk is the green outer leafy layer protecting the corn cob, consisting of inedible fibres Ariel Leong et al. (2021). One of the uses of the corn husk is to extract the fibres from husk. The vast amount of corn husk produced annually is able to extract corn husk fiber from it. Thus, in this study, the corn husk fiber was used in different approaches to integrating it into a composite filament as a filler.

This research used corn husk as the filler with recycled polypropylene to investigate the composite filaments' printability, mechanical, and melt flow properties. This study is conducted since no study is related to the combination of recycled polypropylene with corn husk fiber.

1.2 Importance of the Study

At present, single-use plastic waste has caused significant damage to the environment. Therefore, in this study, single-used plastic was used as the raw material for 3D printing in order to reduce the environmental issues caused by single-used plastic waste. Currently, there are only a few wood filament types in the market, mostly PLA-wood filament and PETG-wood filament. In addition, the research in thermoplastic-natural fiber composite filament does not have much either. Hence, this research used corn husk fibre as the natural fiber to blend with rPP. Consequently, it also helps the environment because the raw materials are derived from recycled waste. Also, it can supply some new filament materials choices to the market. Thus, this study is essential since there is a gap in the study.

1.3 Problem Statement

It is known that not every plastic material can be developed into a feedstock in FDM applications. The most common problems when developing filament for 3D printing are material properties such as melt flow and mechanical properties. Notably, it is found that the materials with a high melt flow index of around 10g/10min are suitable for 3D printing (Wang et al., 2018), while melt flow index of around 20g/10min is not suitable for this application (Ariel Leong et al., 2021). For this reason, the correlationship between composite material's fiber content and melt flow behaviour is highly important.

In summary, the existing studies on the composite filament of rPP/CHF used in FDM are limited, leaving uncertainties about its natural properties. Important aspects such as the behaviour of rPP from single-used PP containers, the impact of printing parameters on the composite filament, and the melt flow properties with varying fiber content are still unknown. Although previous research by other scholars has explored composite filaments blending rPP with natural fibers, the question of which natural fibers are most effective for reinforcing rPP filament remains unanswered. Thus, there is a need to conduct tests and studies on the rPP/CHF composite filament to address these gaps in knowledge.

1.4 Aim and Objectives

This study aimed to develop a new feedstock for FDM 3D printers by creating a composite filament using recycled polypropylene (rPP) and corn husk fiber (CHF). The objectives of the study were as follows:

- To develop rPP/CHF composite filament from single used PP and corn husk waste.
- To determine the filler content and loading on the melt flow index of the rPP/CHF composite filaments.
- To evaluate the mechanical properties of printed parts from rPP/CHF composite filaments.

1.5 Scope and Limitation of the Study

The main goal of this study is to develop rPP/CHF composite filament for FDM 3D printer. This includes a study of the rheological properties such as the melt flow index of the composite filament, the mechanical properties such as tensile strength and visual inspection and lastly comparison of rPP/CHF with commercial wood filament. The printing parameter was focused on the temperature of the print head. However, more parameters, such as the effect of raster angle, bed temperature, ambient temperature and extrusion rate, are not included due to the project's time constraints and limitations. The other limitation is the availability of testing machines on campus. Hence, an in-depth study of this project can hardly be achieved.

1.6 Contribution of the Study

The study's findings would significantly benefit society in terms of environmental sustainability, especially in fields FDM printing, plastics and agricultural waste. This study provides a comprehensive understanding of the composite filament for FDM 3D printing, which contains polypropylene as the matrix with natural fibers. As a result, other researchers could benefit from this knowledge to be more confidence in continuing further research on the related topic. The study reveals that the use of recycled polypropylene could be an excellent material for commercial FDM printing, which can be marketed to a wider audience of researchers and hobbyists due to its superior properties compared to many of the materials currently in use. Moreover, this study is also able to increase the interest and attention among the public towards 3D printing by highlighting the potential benefits of this study. Consequently, this study can accelerate the advancement of composite materials in this field.

1.7 Outline of the Report

This report consists of five main parts: introduction, literature review, methodology and work plan, results and discussion and conclusion and recommendations. The “Introduction” discussed the title, the importance, problem statement, objectives, scope and limitations, and the contribution of this study. The purpose of the introduction is to provide context, including the motivation for the study, the desired outcome, and any underlying assumptions, which enables the reader to better understand and engage with the main focus of the research.

The literature review presents comprehensive studies from other researchers, such as journals, articles, and textbooks. The readers are expected to gain an understanding of fundamental knowledge, such as the working principle and issues found in FDM machines, current trends in recycled composite filament with natural fibers, the properties of polypropylene, and the nature and extraction of corn husk fiber from corn husks. Readers can easily follow the subsequent chapters with the knowledge gained from the literature review.

Next, is the “Methodology and work plan” section provides details on how the study was conducted. This includes the raw material used, detailed preparation procedures of the experiment and the method of the data collected and the work plan Gantt chart of this study. By reading this section thoroughly, it is expected that readers will gain a clearly understanding on how the experiment is conducted.

"Result and discussion" section provides the actual results and figures along with a brief discussion that includes interpretation of data, explanation and data comparison. After reading this chapter, readers will gain a deeper understanding of the facts, differences between the data in this report and other sources, and the reasons behind the data obtained.

Finally, "Conclusion and recommendations" summarises the entire report and suggestions for future work. It enables readers to determine whether the objectives and aims of the study have been achieved, the properties and the best ratio blend of the composite filament and some recommendations for improving future research.

CHAPTER 2

LITERATURE REVIEW

Introduction

This chapter discusses the literature review for this research in subsections 2.2 to 2.5. This includes the background of FDM, basic principles and the issue and solution for the FDM process. Next, is the development process of composite filament by various researchers. The following subsection 2.4 discusses the process to recycle polypropylene from waste. Finally, subsection 2.5 discusses the corn husk fiber extraction method based on finding from journals.

2.1 Fused Deposition Modelling (FDM)

In recent years, FDM 3D printing has been developing unprecedentedly. The fast-growing communities and the wide accessibility of FDM 3D printing machines have accelerated the development of this industry. Stratasys Inc. commercialized it in early 1990 (Mohamed, Masood and Bhowmik, 2015). Up to now, FDM has been applied to various fields of the industry due to its versatilities, producing parts with complex geometries that were not possible or hard to manufacture with traditional techniques such as CNC. These industries include biomedical field, aerospace and aircraft industry, engineering firm, dentistry, and automotive industry (Mohamed, Masood and Bhowmik, 2015; Dey and Yodo, 2019).

2.1.1 Working Principle

Figure 2.1 shows the basic components of an FDM 3D printer. The machine includes an extrusion nozzle, heating element, and printing platform. The feedstock used to print the part is called the filament. The filament material is usually made of thermoplastic such as PLA, PETG, ABS, PC, Nylon, etc.

Before printing, the 3D model should be converted to the stereolithography file format (stl.) which encodes the surfaces of the model as "triangles". After that, the file will be imported into a slicer such as Ultimaker Cura, Simplify3D and Repetier. The main function of the slicer is to "slice" the 3D model into layers through preset print setting and translate the model into gcode. Hence, the machine will be able to read and gcode to proceed with the printing.

During printing, the thermoplastic filament is heated to a semi-molten state by the heating element pushing through the nozzle head. The typical nozzle size of the extrusion nozzle is 0.4 mm. Next, the extruded semi-molten filament is extruded and deposited onto the printing platform. When the filament is extruded, it does not immediately solidify, allowing the semi-molten filament to be paved on the preset path in x and y directions according to gcode. The printing platform will move down to the next layer in the Z direction when the current layer is printed. This process continues until the 3D model is printed.

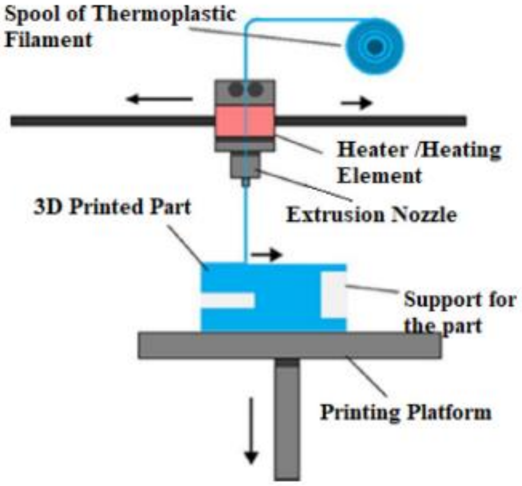

Figure 2.1: The Basic Components of an FDM 3D Printer (Jaisingh Sheoran and Kumar, 2020).

2.1.2 Issue and Solution

Although FDM 3D printing benefits manufacturing and prototyping, there are issues with the printed parts during printing. The below paragraphs state issues and provide a solution to the problem.

The following paragraphs discuss the delamination issues in FDM and the solution.

According to (Ariel Leong et al., 2021) the printed part from the rPS/CHF filament appears to be delaminated between the printed layer due to the reduced coalescence. The delamination has caused a larger void, eventually affecting the print quality and the mechanical strength of the part. The solution to these issues is to increase the filament's extrusion percentage to fill up the void between the layers.

Mosleh, Rezadoust and Dariushi (2021) reported that reducing the printing speed can effectively increase the fusion between the layers. The result successfully increased the bond between the layers and eventually increased the interlaminar shear strength of the printed part.

Wickramasinghe, Do and Tran (2020) stated that reducing the layer thickness can reduce the formation of voids in the printed part. With a lower layer thickness, the formation of airgap could reduce the delamination.

The following paragraphs discuss different types of issues in FDM and the solution.

Rahim, Abdullah and Md Akil (2019) suggested that adhesion between the deposited material with the print bed condition must be optimal to reduce warpage. The solution to the warping issue is to use a heated printing bed and to use a 3D printer enclosure. These solutions provide that the temperature of the deposited material is constant along the printed part. A minor temperature variance between the lowest layer to the higher layer of the print can effectively control the warping due to the evenness of the internal stress.

Carneiro, Silva and Gomes (2015) found that PP is vulnerable to shrinking during cooling, leading to decoupling the printed parts from the printer bed, especially on common printing surfaces such as glass and blue tape. The solution observed to reduce the issue is to use a PP plate as the bed of adhesion. The adhesion between the PP and the PP plate has achieved chemical compatibility to attain optimal conditions.

Bachhar et al. (2020) observed that printed parts with sharp corners are susceptible to warpage due to uneven cooling. Applying adhesive like the commercial polyvinyl acetate-based adhesive on the glass bed provides sufficient adhesion between the printed parts and the printing bed to reduce the warpage of semi-crystalline material like PP. Besides that, "Brim" is a thin 3D printed layer that radiates out from the base of the print and can also reduce warping. This is due to the large surface area in contact with the printing bed, adhering the printing parts tightly to the printing surface.

The following paragraphs discuss the clogging issues in FDM and the solution.

Kariz et al. (2018), Ariel Leong et al. (2021 and Lee et al. (2021) found that clogging occurs in the nozzle. The inhomogeneous distribution of the fiber matrix and the high concentration of the filler resulted in clogging in the nozzle. Milosevic, Stoof and Pickering (2017) observed that simply increasing the diameter of the nozzle can eliminate clogging in the nozzle and increase the surface finish.

Table 2.1 shows a summary of the issues in FDM and the solution associated with it. The most frequent issues face during FDM 3D printing is delamination and warpage. To reduce delamination, the methods are increasing the filament's extrusion rate, reducing printing speed and reducing layer height. Furthermore, PP is a semicrystalline polymer, so it is prone to warpage. To reduce the warpage issues, the solution is working with a heated printing bed and controlling the temperature around the 3D printer. Next is by using a chemical compatibility bed, applying adhesive to the printing bed and implementing "Brim" in the printing part. Last but not least, increasing the nozzle's diameter can address the clogging problem. Solving the above issues, the printed part should be of good quality, and the mechanical properties should be optimal.

2.2 Recycled Composite Filament with Natural Fiber

Composite material is made up of two or more constituent materials with vastly different properties (Egbo, 2021). For example, plastic with wood particles filled is a kind of composite material. Currently, there are plenty of studies and development of composite filament with natural fiber. This review will consider composite filament of recycled plastic with natural fiber. In the following paragraph, the process of the composite filament developed in various literature will be analyzed.

Morales et al. (2021) have researched recycled polypropylene with rice husk (RH). The rPP pellet is obtained from a local plastic resin manufacturer and the rice husk is taken from a local source. Next, the RH is ground into a smaller particle before mixing. Moreover, the RH is weighted to obtain 0, 5 and 10 wt% fiber content. A filament extruder is then used to extrude the filament into a diameter of 1.75 mm at around 195 °C. After that, the extruded filament was granulated and repeated the above process to achieve homogeneity. The

Table 2.1: Issue and Solution in FDM According to Different Studies.

Issue	Solution	Remark	Reference
Delamination	Increase the extrusion percentage of the filament	The void between the layers is reduced and increased coalescence between the layer	(Ariel Leong et al., 2021)
	Reduce the printing speed	Interlaminar shear strength increased due to partial impregnation made good fusion between the layers	(Mosleh, Rezadoust and Dariushi, 2021)
	Reduce layer thickness	With a smaller layer thickness, the formation of the void will be lower and hence reduce delamination between the layer	(Wickramasinghe, Do and Tran, 2020)
Warpage	Heated printing bed and use a 3D printer enclosure	The temperature of the deposited material is constant along the printed part resulting in reduced warping	(Rahim, Abdullah and Md Akil, 2019)
	Use a chemical compatibility printing bed	Chemically compatibility improved the adhesion between the printed part and the printing bed	(Carneiro, Silva and Gomes, 2015)
	Applying adhesive to the printing bed and implementing "Brim" in the printing part	Adhesive provides sufficient adhesion between printed part and printed bed	(Bachhar et al., 2020)
Clogging	Increase the nozzle size	Eliminate clogging and increase the surface finishing	(Milosevic, Stoof and Pickering, 2017)

nozzle size used to print the specimen was 0.8 mm. Other than that, the composite's tensile strength was found to decrease with the increase of fiber content due to weak interlayer bonding.

Milosevic, Stoof and Pickering (2017) worked on recycled polypropylene and hemp/harakeke fiber. Both the rPP and hemp/harakeke are sourced from local manufacturers and farms. The study was conducted with 10-30 wt% fiber content of hemp/harakeke fiber blended in the rPP. The hemp and Harakeke fibres were granulated at an average length of 10mm. The rPP, Maleic anhydride grafted polypropylene (MAPP) and natural fiber were extruded using a twin screw extruder at an average temperature of 190 °C and extruded with a 10 mm die. The authors found no problem with extruding 10 wt% of the natural fiber. However, congestion occurred in the extruder for 20 and 30 wt% of fiber content. After the first extrusion, the composite is granulated again and re-extruded to improve the homogeneity. The nozzle size used to print the dog bone specimen is 1 mm. From the study, it was observed that the tensile strength increases with the increase of the fiber content.

Next, Ariel Leong et al. (2021) studied recycled polystyrene (rPS) and corn husks fiber (CHF). The polystyrene was prepared with expanded polystyrene from electrical appliance packaging and CH was collected from the local wet market. The CHF content studied is from 2.5 to 10 wt%. A 30 wt% masterbatch was prepared first in the study. To obtain fiber content of 2.5, 7.5 and 10 wt%, additional rPS were added into the extruder to dilute the masterbatch while preparing the composite filament. The temperature set for extrusion was 200 °C and the extruded filament diameter was controlled at between 1.5 to 1.7 mm. The specimen was printed using a 0.8 mm nozzle. This research also concluded that the fibre increase decreases the tensile and modulus strength. Other than that, it was also observed that the melt flow index also reduced with increased fiber content.

Singh, Kumar and Ranjan (2019) conducted an investigation on using recycled ABS with banana fiber and recycled polyamide 6 (PA 6) with banana fiber (BF). The source of plastic is obtained from local manufacturers and the BF were prepared in the lab. Both of the recycled plastics were blended with 5 wt% of BF. The temperature for extrusion was 230 °C and the extruded filament width was 1.5 mm. 0.3 mm nozzle was used to print the specimen. The tensile test results from this research found that the tensile strength increases with the addition of fiber in the matrix. In short, Table 2.2 shows a summary of the recycled composite filament by various authors. Most of the literature have a filler ranging below 10 wt %. However, for Milosevic, Stoof and Pickering (2017), more than 10 wt % of fiber content was used but it appeared to have congestion and difficulty during the extrusion. To solve the issue, Milosevic, Stoof and Pickering (2017) used a larger diameter of the nozzle in order to allow smooth extrusion of the composite filament. As discussed earlier, the source of recycled plastic used in the literature was mostly from the local manufacturer. In contrast, developing filament form rPP made from single used containers was not done in any study. Also, the combination of rPP and CHF has also never been studied in any literature. The results of the tensile test are mixed, with some studies (Morales et al., 2021; Ariel Leong et al., 2021) showing a decrease in strength and others (Milosevic, Stoof and Pickering, 2017; Singh, Kumar and Ranjan, 2019) showing an increase. Therefore, further research is needed to provide a conclusive answer.

2.3 Polypropylene

Polypropylene (PP) is one of the numerous types of petroleum-based thermoplastics. It was discovered in 1954 and due to its attractive properties, such as low density, chemical resistance, high temperature resistance, good mechanical properties, and can be easily processed (Maddah and Maddah, 2016; Bachhar et al., 2020). The typical type of PP commercially used is isotactic polypropylene (iPP). Since PP have long chains and can never fully crystallize, as a result, when molecularly regular polymers crystallize, amorphous and crystallized states constantly coexist. Consequently, such polymers are called semicrystalline (Bachhar et al., 2020). Nonetheless, semicrystalline polymer has some challenges in FDM 3D printing such as not adhering to the printing bed and serious shrinkage resulting in warpage (Bachhar et al., 2020).

According to a study of Chandara (2015), it shows the recycling process of commercial plastic waste in Indonesia, and this includes the recycling of PP. According to his study, the process of recycling plastic involves several

Table 2.2: Recycled Composite Filament by Various Author.

Type of Recycle Plastic	Source	Filler	Filler content	Nozzle size (mm)	Fiber content effect on tensile strength	Reference
PP	Local Manufacturer	Rice Husk	0-10 wt%	0.8	Decreased	(Morales et al., 2021)
PP	Local Manufacturer	Hemps/Harakeke	10-30 wt%	1.0	Increased	(Milosevic, Stoof and Pickering, 2017)
PS	Used electrical appliances packaging	Corn husk Fiber	2.5-10 wt%	0.8	Decreased	(Ariel Leong et al., 2021)
ABS, PA6	Procured from Local Manufacturer	Banana Fiber	5%	0.3	Increased	(Singh, Kumar and Ranjan, 2019)

steps, which is shredding, washing and drying, extrusion and pelletizing. The steps to recycle every type of plastic are the same at the beginning except for the extrusion step. During the shredding steps, the plastic should be shredded to the size of 0.5 - 2 cm to ensure that the plastic can be fed into the extruding machine (Chandara, 2015). Next, at the extrusion step, each type of plastic requires a different temperature to extrude. For polypropylene, the temperature of the extruder at 4 of the heating zones is different. The temperature required at Zone 1, 2, 3 and 4 is 140-160, 160-180, 180-200 and 170-180 °C respectively. After the PP is extruded, the plastic strands are cooled before entering the pelletizer. Lastly, the PP strands will be cut into pellets and stored.

2.4 Corn Husk

Corn husk refers to the outer leafy layer covering the corn. It is a flexible, low density, high elongation, high cellulose content, and low ash and lignin concentration natural lignocellulosic fiber (Ibrahim et al., 2020). Hence, there is plenty of fiber content that can be further extracted. Corn husk fiber is a lignocellulosic fiber with a cellulose content between 80 and 87%.

According to Herlina Sari et al. (2018), CHF treated with NaOH demonstrates lower moisture content and better mechanical properties than raw CHF. The NaOH-treated CHF reduced the hemicellulose content in the fibers. Hence, the water absorption ability decreased. Next, the treated CHF with NaOH (0.5%-8%) has a tensile strength ranging from 224.05 ± 22.14 to 368.25 ± 78.97 MPa compared with Raw CHF with a tensile strength is 160.49 ± 17.12.

On the other hand, according to Yilmaz (2013), CHF treated with enzyme displayed an increase in initial modulus. However, it shows a significant decrease in the breaking tenacity, breaking force and elongation, and the same goes for no significant increase in the mechanical properties of CHF. In short, alkaline-treated CHF offers better properties than enzymatic-treated CHF.

The following paragraph discusses the methods to extract CHF.

It is known that there are two main treatment methods to extract the fibers from the corn husk: water retting and chemical treatment. The paragraph below states the corn husk fiber extracting process from various authors.

Ariel Leong et al. (2021) firstly water ret the corn husk by submerging it in the tap water for 16 days in airtight condition. Next, the swollen corn husk is then separated from the fibers. The fiber is then dried under direct sunlight until the fiber is fully dried. Furthermore, a solution with 5% v/v hydrogen peroxide (H_2O_2) is used to soak the corn husk fiber with a ratio of 1:10 w/v at a temperature of 70°C and pH 11 (by adding 1mol of NaOH solution) for 60mins. The above process is done twice to ensure that the CH fiber extracted is fine. Next, the CH fiber is rinsed thoroughly with distilled water until the solution is neutral. Lastly, the CH fiber is dried in a force convection oven at 60°C for 6 hours before the fibers are grounded and sieved.

Sari et al. (2020) used fresh water to soak the corn husk for 10 days. Afterwards, the fiber is collected, dried under the sun, and stored in a storage box at 30% humidity. Next, the CHF is chemically treated with 8% NaOH for 120mins. The treated CHF is washed and dried under the sun before storing it in a box at 30% humidity.

Kambli et al. (2016) reported that submerging the corn husk at 120°C, 10% w/w concentration of NaOH solution 5g/l with material-to-liquor ratio of 1:20 gives the best quality of CHF. The CHF is then further bleached with 6% hydrogen peroxide to improve the white appearance of the fiber. The process is undergone at 85°C for 60mins with a 1g/l concentration of NaOH with a material-to-liquor ratio of 1:20 and 1.5g/l of silicate to stabilize the bleaching process reaction.

Lokantara (2020), used water retting method to extract the fiber from the CH. CH is immersed in water for 16 days. Then, the fibre is extracted with a plastic comb, and the fibres are then dried naturally in the air.

Table 2.3 shows the method to extract corn husk fiber according to various literature. From the above literature, it can be concluded that to extract fiber from the corn husk, the methods are water retting or chemically treated with NaOH. To improve the appearance of the CHF bleaching process can be done by treating with H_2O_2. According to Kambli et al. (2016) treating CH at

120°C with a 10% w/w concentration of NaOH can produce good quality CHF. Next, with only water retting is also able to produce quality fiber (Lokantara, 2020). Hence, there are multiple methods to extract corn husk fiber according to the need.

In summary, in this study, water retting method was used to extract CHF. Water retting method is chosen because of the simple process, low cost and ability to produce a relatively good fiber (Lokantara, 2020). Other than that, the water retted CHF will be also dried in a convection oven to produce a better quality of fiber than drying under the sun as ultra-violet (UV) rays from the Sun light will bleach the fiber (Lokantara, 2020). Although some of the literature mentioned above that chemical treatment for CHF improved the properties of CHF, due to the time limitation and knowledge, sole water retting method is sufficient for the study.

Table 2.3: Different Types of Corn Husk Fiber Extraction Method.

Method	Steps	Remark	Reference
Water retting and chemical treatment	1. Submerge CH in tap water for 16 days. 2. Separate the CHF from CH and dry. 3. Soak CHF in a solution with 5% v/v H_2O_2 with a ratio of 1:10 w/v at a temperature of 70°C and pH 11 for 60mins. 4. Wash the CHF with distilled water until the solution is neutral. 5. Dry the CHF in a force convection oven at 60°C for 6 hours.	CHF turned from yellowish to white after treated with chemicals	(Ariel Leong et al., 2021)
	1. Soak the CH in freshwater for 10 days. 2. Collect the CHF and dried under the sun before storing it in a box at 30% humidity. 3. Treat the CHF with 8% NaOH for 120mins 4. Wash the CHF with fresh water and dried before storing it in a storage box.	-	(Sari et al., 2020)
Chemical treatment	1. Submerge CH at 120°C, 10% w/w concentration of NaOH solution 5g/l with material to liquor ratio of 1:20. 2. Bleach the CHF with 6% H_2O_2 at 85°C for 60mins together with 1g/l concentration of NaOH with material to liquor ratio of 1:20 and 1.5g/l of silicate.	Reported that 120 ° C, 10% w/w concentration of NaOH solution provides the optimal quality of CHF and NaOH and silicate is added to the bleaching process in order to bleach effectively and stable	(Kambli et al., 2016)
Water retting	1. CH is soaked in water for 16 days. 2. The fiber is then extracted using a plastic comb 3. The fiber is naturally dried.	-	(Lokantara, 2020)

CHAPTER 3

METHODOLOGY AND WORK PLAN

Introduction

In this chapter, a detailed methodology and work plan was stated to conduct the preparation of raw materials for the rPP/CHF composite filament and the following studies on the visual inspection, melt flow index and the mechanical properties of the printed composite material. Figure 3.1 shows the flowchart of the project.

3.1 Raw Material

The recycled polypropylene (PP) containers were collected from food containers and food boxes from self-collection. The corn husk was collected from the local wet market at Pasar Alam Damai, Cheras. The FlashForge Wood PLA filament is bought from 3D Gadget Sdn Bhd.

3.1.1 Preparation of rPP pellet from PP Container

The recycled PP container was washed thoroughly with dish soap and water to remove oil stains and contaminants. Next, the PP container was dried under ambient air. The cleaned PP container was cut into smaller pieces at around 70mm x 70mm. It was cut to ease the operation of the plastic shredding machine. Then, the rPP pieces were shredded using Pulian's plastic shredding machine, model AA-150. Next, the shredded rPP plastic was dried in Cometech's ageing oven, model QC-607L at 80 °C for two hours to remove any moisture in the plastic.

After that, the shredded rPP was fed into Collin's Teach-Line E20T Single Screw Extruder plastic extrusion machine. The rPP plastic was extruded at 170 °C, 8 rpm screw speed. The extruded filament was passed through a water bath before being pelletized into pellet. Figure 3.2 shows the process of recycling PP containers into rPP pellets.

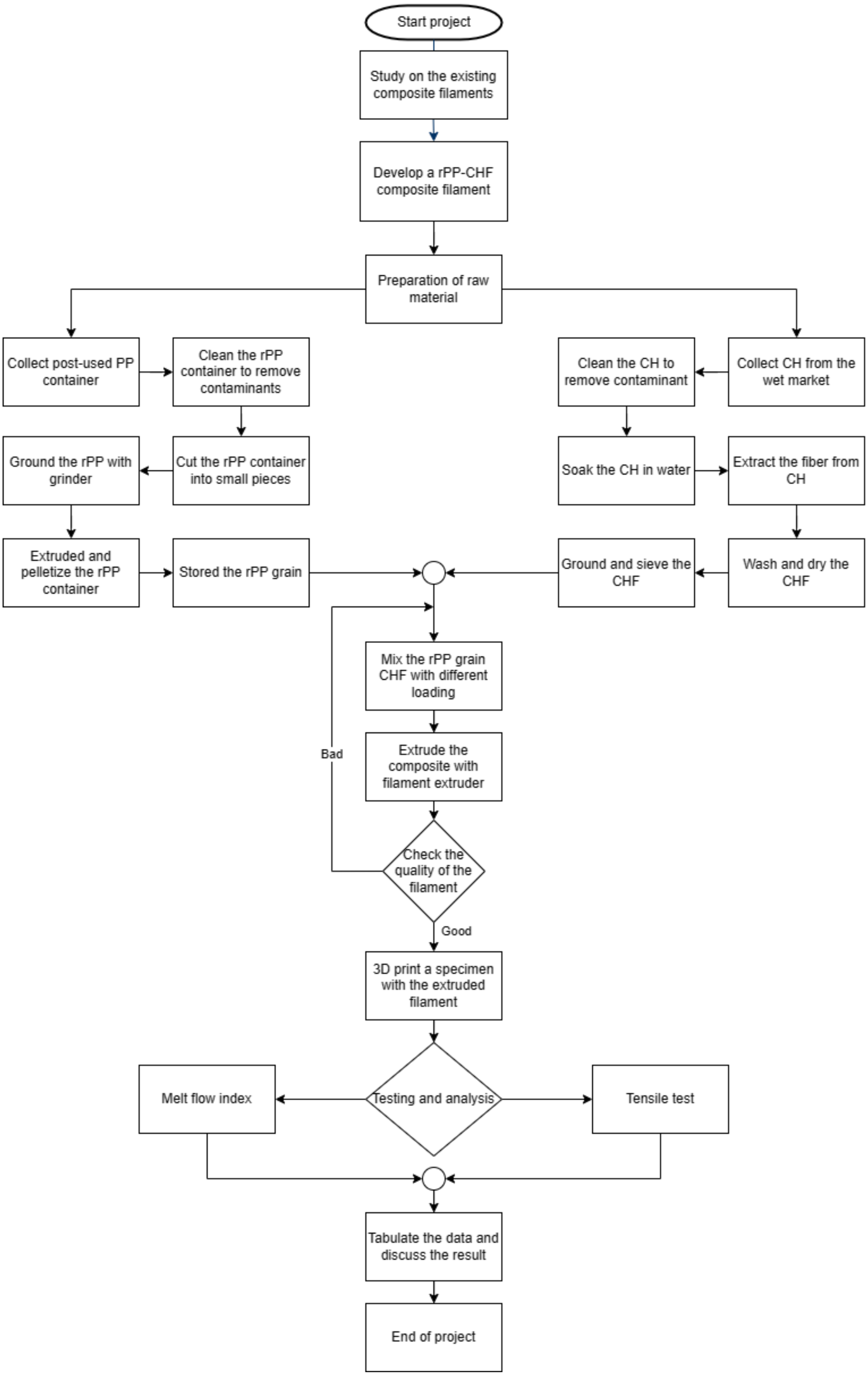

Figure 3.1: Flowchart of the Project.

Figure 3.2: Process of Recycling PP Container into rPP Pellet.

3.1.2 Preparation of Corn husk Fiber

Firstly, the dirt and contaminant were washed from the surface of the CH using tap water. Next, the CH was soaked in a bucket with tap water for 7 days. After 7 days, the fiber separated from the CH with pressure washer. Then, the CHF was dried under sunlight. Next, CHF was cut into around 7 cm lengths using scissors before grinding. After that, the cut CHF were grinded with High-speed grinder, model 800Y until into fine powder. Lastly, the powder was sieved with 250 mesh size sieve to ensure the consistency of the fiber size. The overall preparation of CHF is illustrated in Figure 3.3.

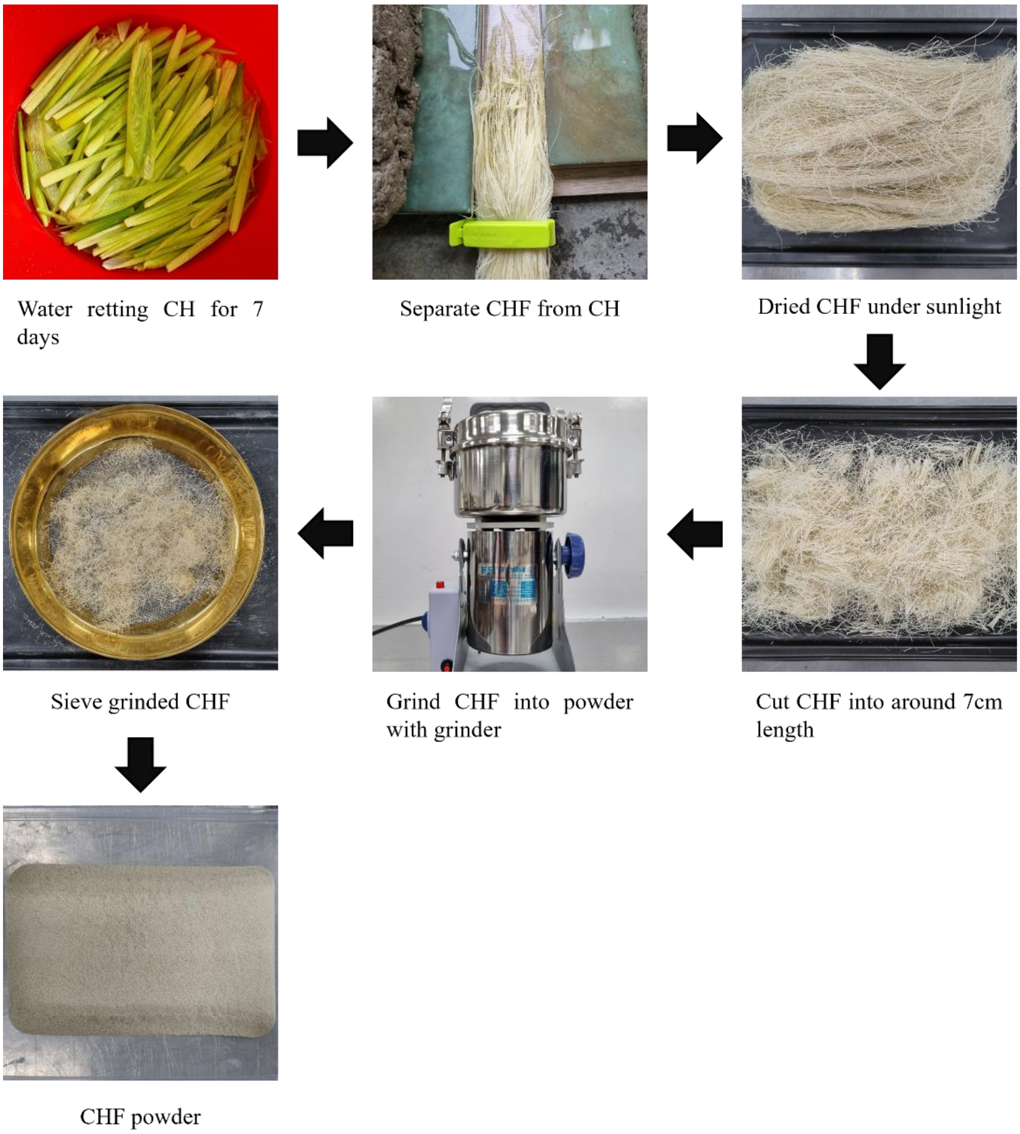

Figure 3.3: Process of Recycling CH into CHF Powder.

3.1.3 Preparation of Composite Filament

The fiber content prepared for the study is neat rPP, 2.5, 5 and 7.5 wt%. The fiber content of more than 7.5 wt% was not prepared due to the difficulty in the extrusion process. The filaments tend to break before solidified because of the porosity in the matrix. The total mass of each filament was 250 g. Table 3.1 displays each fiber content's formulation with the mass of the rPP pellet. Next, the quantity of the material required was weighed with a digital weighing scale and then thoroughly mixed in a container. After that, the composite mixture was extruded at a constant temperature of 170 °C with different screw and spooling speeds as shown in Table 3.2. The extruded diameter of the filament was measured at around 1.5 to 1.8 mm. Figure 3.4 shows the extruded composite filament with different fiber content. The extruded composite filaments were dried in the air circulated oven after rolled into a spool.

Figure 3.4: Extruded Composite Filaments from 2.5 wt% to 7.5 wt%.

Table 3.1: Formulation of rPP/CHF Composite.

Filament (wt.% CHF loading)	rPP (wt.%)	CHF (wt.%)	CHF (g)	rPP pellet (g)
Neat rPP	100	0	0	250
2.5	97.5	2.5	6.25	243.75
5	95	5.0	12.5	237.5
7.5	92.5	7.5	18.75	231.25

Table 3.2: Screw and Spooling Speed of the Composite Filament.

Filament (wt.% CHF loading)	Spooling speed (rpm)	Screw speed (rpm)
Neat rPP	170	8
2.5	160	8
5	150	8
7.5	140	8

3.2 3D print of the specimen

ASTM D-638 Type V standard tensile test specimen and a test specimen for observation with dimensions of 30 mm × 30 mm × 2 mm were prepared using Solidwork 2020. Next, the 3D model specimen was saved as STL format file and converted into g-code with slicer Ultimate Cura v5.0.0. Next, the fabricated material was fed into a Creality's Ender 3 V2 FDM machine. A 0.8 mm diameter brass nozzle was used in this project. The printing temperature and extrusion rate for observation and tensile are listed in Table 3.4. The bed temperature was set at 100 °C and Ginnva's Biaxially-Oriented Polypropylene (BOPP) tape was taped on the glass bed surface to increase bed adhesion. The layer height of the specimen was printed at 0.2 mm and the layer width is 0.6 mm. The infill density of the specimen was set to 100% to ensure that no void was present in the specimens. Next, the raster angle of the specimen will be set to 0° and 90° between each layer to ensure that the strength is homogenous in all directions. Furthermore, the printing speed was set at 15 mm/s and the wall thickness of the specimen was 1.2 mm. A summary of the printing parameter of the specimen is listed in Table 3.3

3.3 Visual Observation

The printed specimen was captured with a phone camera and microscope with 100x magnification. The visual observation of the printed specimen mainly focused on each specimen's appearance, the printed layers' adhesion, and the bonding between the extrusion strands.

Table 3.3: Printer Parameter of the Specimen.

Printing Parameter	Value
Layer height	0.2mm
Layer width	0.6mm
Wall thickness	1.2mm
Infill density	100%
Raster angle	0°
Printing speed	15mm/s

Table 3.4: Printer Parameter of the Specimen for Observation and Tensile Test.

<table>
<tr><th rowspan="2">Material</th><th colspan="2">Observation</th><th colspan="2">Tensile Test</th></tr>
<tr><th>Temperature (°C)</th><th>Extrusion rate (%)</th><th>Temperature (°C)</th><th>Extrusion rate (%)</th></tr>
<tr><td>rPP</td><td rowspan="4">220</td><td rowspan="4">100,110,120,130</td><td rowspan="4">210,220,230</td><td>100</td></tr>
<tr><td>rPP/CHF 2.5%</td><td>110</td></tr>
<tr><td>rPP/CHF 5%</td><td>120</td></tr>
<tr><td>rPP/CHF 7.5%</td><td>130</td></tr>
<tr><td>Wood PLA</td><td colspan="2">-</td><td>200</td><td>100</td></tr>
</table>

3.4 Tensile Test

The tensile properties of the printed specimens were determined using Shimadzu’s universal tensile testing machine. The ASTM D638 standard was used as the indicator for performing the tensile test. For each fiber content and commercial wood, at least 7 specimens were used to evaluate the tensile properties. The Shimadzu’s universal tensile machine's crosshead speed was adjusted to 5 mm per minute, and a load cell of 100 kN was used.

3.5 Melt Flow Index Analysis

The flow properties of the rPP/CHF composite and commercial wood filaments were examined through melt flow index (MFI) analysis. Dynisco’s melt flow index was used to analyze the MFI of composite and commercial wood filaments in line with the ASTM D1238 standards. The MFI test was carried out at a constant temperature of 230 °C for composite material and 210 °C for wood filament to investigate the quantity of the molten material to be extruded over the course of 10 minutes with 1.2 kg of loads applied.

3.6 Summary

In this chapter, the methodology and work plan for preparing the raw materials for rPP/CHF composite filament was prepared as shown in Figure 3.1. The recycled polypropylene containers were collected from food containers and boxes, while corn husks were obtained from a local wet market. After washing and drying the collected PP containers, it was shredded, extruded, and pelletized to produce rPP pellets. Furthermore, the corn husks collected (CH) were washed, soaked, separated, dried, cut, ground, and sieved to prepare the CHF powder. The composite filaments were prepared with 2.5, 5, and 7.5 wt% fiber content and neat rPP filament with different screw and spooling speeds. The filaments were extruded, dried, and rolled into a spool before being fed into a 3D printer to print tensile test specimens and observation specimens. Visual inspection and tensile tests were performed to evaluate their appearance, layer adhesion, and mechanical properties. Finally, the melt flow index (MFI) analysis was conducted to investigate the flow properties of the rPP/CHF composite filament.

CHAPTER 4

RESULT AND DISCUSSION

Introduction

This section presents the experimental result on the properties of rPP/CHF composite filament for FDM 3D printer The chapter includes a thorough analysis and discussion of the results obtained, including the important data, interpretation of the results, and comparison to other research studies. The chapter is organized into several key sections, which is visual observation, melt flow index, and tensile test.

4.1 Visual Observation

4.1.1 Composite Filament

Figure 4.1 shows the comparison of the surface appearance of extruded rPP/CHF composite filaments and a commercial wood filament. From left to right, are neat rPP, rPP/CHF with 2.5 wt%, 5 wt% and 7.5 wt% fiber content and commercial wood filament respectively. For the appearance, Neat rPP appears as a translucent color, while rPP/CHF blends exhibit a beige color that becomes darker with increasing fiber content. The smoothest surface is observed in neat rPP, and as fiber content increases, the surface becomes rougher.

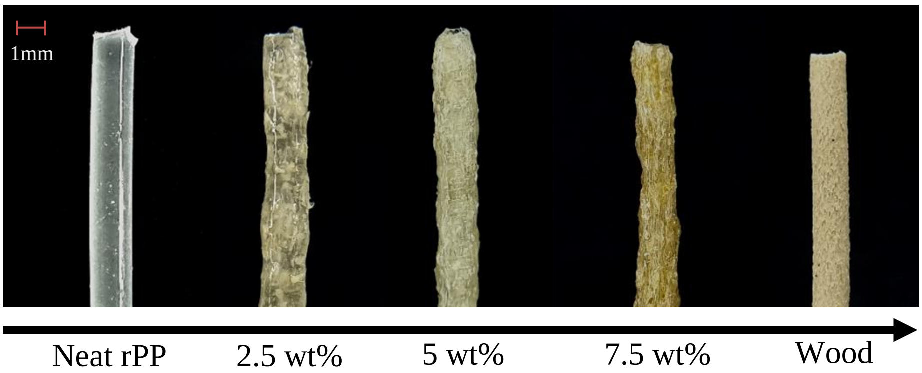

Figure 4.1: High Magnification View of the Filament Surface.

As the fiber content increased, the amount of CHF per volume unit in the filament increased, significantly affecting the extrusion process of the composite filament. The rPP/CHF filament with 7.5 wt% fiber content had the lowest dimensional accuracy compared to others. In contrast, 10 wt% fiber content resulted in frequent filament breakage during extrusion due to the excessive amount of CHF that obstructed the flowability of the filament. Hence, it does not yield a good roll of filament to conduct further studies. Similar observation can be found in work of other researchers (Milosevic, Stoof and Pickering, 2017; Ariel Leong et al., 2021).

Furthermore, the size of the fibers is also crucial in the matrix of a composite material. In Figure 4.2 is the sample batch of the CHF used in this research. Although 250 mesh size sieve is used, the length of the fibers is not homogenous. It can be observed that some of the fibers were particulated, and some were longer, thus it imposed a significant impact on extruding the composite filament. Short fiber can create more complex flow patterns and require more energy to orient within the matrix during the melting and extrusion process. As a result, the presence of long fiber reduced the melt flow index of the composite. Next, short fiber also causes filament to be easier to break and inconsistent extrusion when printing and extruding. In contrast, particulated fiber does not have the above problems.

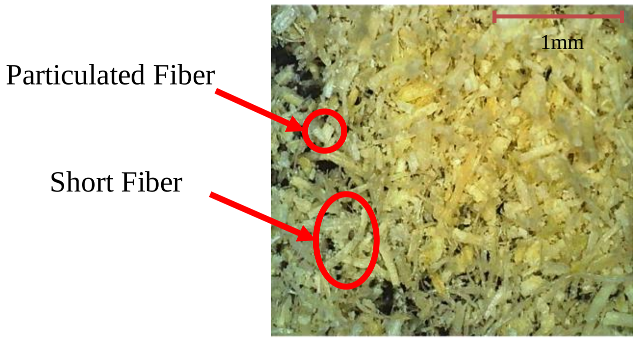

Figure 4.2: Magnification view of the CHF used.

Figure 4.3: Section View of rPP/CHF with 7.5 wt% fiber content.

Next, Figure 4.4 show voids in the filament. The increased in fiber content resulted voids emerged in the filament. This phenomenon led to under-extrusion and voids and pores forming in the printed part result in poor printing. This will be further explained in section 4.2.2.

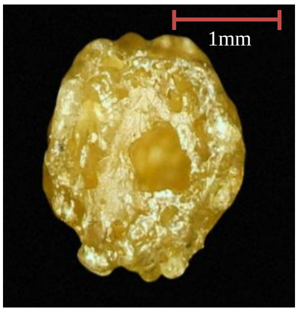

Figure 4.4: Cross-section of rPP/CHF with 7.5 wt% fiber content.

Figure 4.5 presents the orientation of the CHF in the rPP/CHF composite filament. In the section highlighted by the red box, the absence of long grains of CHF resulted in higher flowability and lower viscosity. This allowed the filament has faster flow during filament extrusion, resulting in narrower sections. Conversely, sections with bulges consist of more long grains, some of which were almost perpendicular to the flow extrusion orientation of the filament. This orientation caused flow disruption in the within the matrix, increasing overall resistance and making the overall extrusion inconsistent. The large amount of random orientation and size of the CHF contributed the inferiority of the rPP/CHF with 7.5% compared to the other ratios tested.

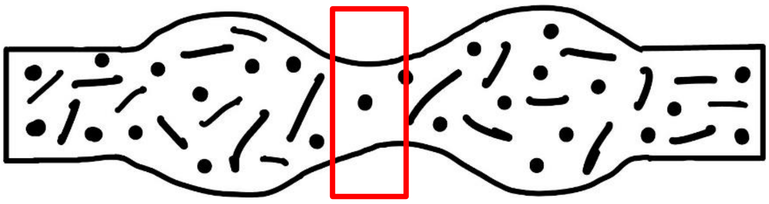

Figure 4.5: Schematic representation of CHF in the Matrix.

In short, the surface appearance of the rPP/CHF composite filament varies with increasing fiber content, it will becoming darker and rougher with the increase of fiber. The amount and size of CHF in the filament significantly affect the extrusion process, with excessive fiber content causing filament breakage and long fibers reducing the melt flow index and causing inconsistency in extrusion. The poor wettability of CHF with PP results in weak interfacial bonding and poor adhesion, leading to the presence of voids in the filament and reducing its printability. The orientation of the CHF also plays a role in the extrusion process, with the presence of long grains has resulted in lower flowability and also the inconsistency in extrusion.

4.1.2 Test Specimen for Observation

Figure 4.6 displays the optimal extrusion percentages needed for stable printing of the composite filament. From figure Figure 4.6, it can be seen that no visible hole was found on the surface of the neat rPP at 100% extrusion percentage. At 100% of composite filament with 2.5 wt% fiber content, small gap was noticeable on the surface. Next, on rPP/CHF with 5 wt% with fiber content, large amount of holes was observable on 100% and fewer on 110% extrusion percentage. Lastly, on rPP/CHF with 7.5 wt% with fiber content, large amounts of gaps and holes were found on the surface of 100% while it reduced with the increase of extrusion percentage until 120%.

Hence, from Figure 4.6, it can be observed that neat PP does not require any extra extrusion percentage for optimal printing, and any further increase of extrusion can cause over-extrusion of the print and extrusion percentage of 110% is optimal. For rPP/CHF with 2.5 wt% fiber content, extrusion percentages lower than 110% may result in under-extrusion, such as voids between layers. For rPP/CHF with 5 wt% and 7.5 wt%, the optimal extrusion percentages are 120 and 130% respectively.

In conclusion, the test specimen showed that the extruded filament contains voids and pores reducing the volume per unit length for printing and resulting in under-extrusion. To compensate for the lost volume, a higher percentage of extrusion is required for the composite filament.

4.2 Tensile Test

Figure 4.7 illustrates the tensile strength and modulus of the neat rPP, rPP/CHF with 2.5, 5 and 7.5 wt% at different temperatures. The tensile test of the commercial wood filament was used as a benchmarking result, in which the tensile and modulus strength was 27 MPa and 2000 MPa, respectively. From the results, it was found that the tensile strength increases about 18% and modulus strength increased around 7% when temperature elevated from 210°C to 230°C for rPP/CHF with 2.5 wt% fiber content. The tensile and modulus strength increased 7% and 5% respectively for 5 wt% fiber content from 210°C to 230°C. Moreover, the tensile and modulus strength for neat rPP increased about 6% and 4% respectively from 210°C to 220°C. However, the tensile and modulus strength decreased around 9% and 0.72% correspondingly when the temperature further increased to 230°C. The result did not show a similar result as in study of (Milosevic, Stoof and Pickering, 2017; Dey and Yodo, 2019) where the tensile strength increases with the temperature. This maybe due to the grade with recycled polypropylene used in this study having different mechanical properties compared with the study used. Next, the results of composite filament

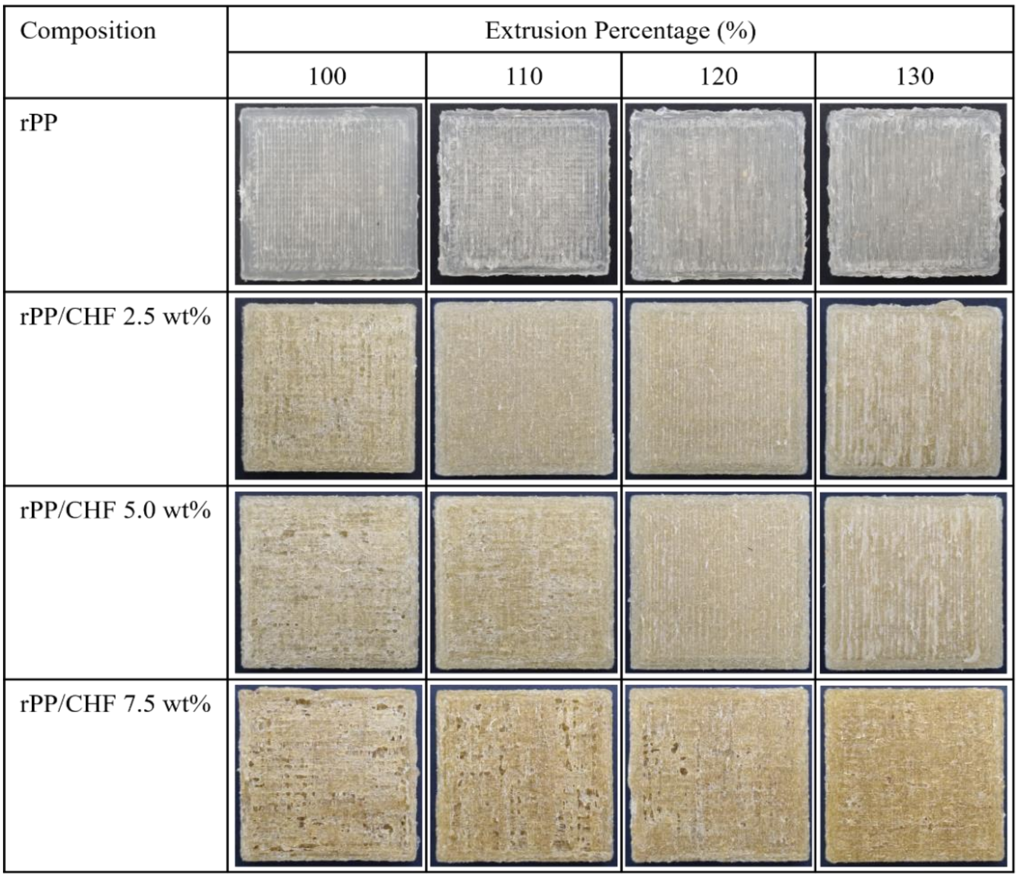

Figure 4.6: Comparison of the Effect of Varying Extrusion Percentage on Different Compositions.

with 2.5 and 5 wt%indicate that the tensile and modulus strength of the composite filament increased with temperature. This result may be due to with higher temperature the matrix flowability was better and hence better coverage on the addition of CHF by the matrix. Hence, some of the stress is distributed more evenly in the specimen. The higher temperature also promoted better interlayer adhesion in the composite material. The increase in temperature allows the polymer matrix becomes more viscous and the interlayer surfaces have increased mobility. This allows for improved interdiffusion and molecular entanglement between adjacent layers, leading to stronger adhesion. The results of composite filament show a different outcome compared to the neat rPP since the introduction of fiber largely affects the properties of a composite material.

Furthermore, the result also showed that the increase of fiber content reduced the tensile strength. When fiber is added to the matrix, tensile strength decreases by approximately 12.5% with 2.5 wt% and 16% with 5 wt% fiber content. Among the tested ratios, the 2.5 wt% fiber content shows the highest strength compared to the other ratios. The test results suggest that the present fibers in the composite did not improve its mechanical properties, which is similar to several studies (Ariel Leong et al., 2021; Mazzanti et al., 2019; Morales et al., 2021). This can be attributed to the incompatibility of the fibers, as discussed in the previous section. Furthermore, the disordered arrangement of fibers in the specimen does not assist the transfer of tensile stresses, which contributes to the poor mechanical properties. J. Shesan et al. (2019) also concluded that interfacial interaction between fiber and the matrix is crucial to the composite since a good interfacial interaction will help to hold the filler in position and also help to distribute the stress within the material. As a result, the CHF in the specimen in this study did not contribute to improving the tensile properties, but instead decreased them.

Meanwhile, the trend of modulus strength of the composite filament can be observed from Figure 4.7. The result indicated that the addition of fiber content improves the modulus strength. The introduction of CHF in the composite results in an average 1% increase in modulus strength compared to neat rPP, as supported by the findings of Milosevic, Stoof, and Pickering (2017) and Ayrilmis et al. (2019). The increases in modulus strength suggest that the increase of fiber content led to a stiffer material. Thus, the composite filament can withstand a higher deformation compared to neat rPP.

Overall, the composite filament demonstrated superior tensile strength compared to the commercial wood filament. However, the wood filament exhibited a 43% higher modulus strength than the composite filament, which can be attributed to the different matrices used. While the commercial wood filament was composed of PLA, this study used recycled polypropylene as the matrix, resulting in a completely distinct material nature. The commercial wood filament was selected as a benchmarking material since it is the only plastic matrix-filled natural fiber composite filament available. Ayrilmis et al. (2019) reported a tensile strength of 28.7 MPa and a modulus strength of 3115 MPa for wood filament, which is similar to the tensile strength of the commercial wood filament used in this research but higher in modulus strength. This difference in modulus strength could be due to the wood filament used by Ayrilmis et al. (2019) having a higher wood-filled percentage of 30% compared to the commercial filament used in this study. In short, the composite filament outperforms the commercial wood filament in terms of tensile strength, with an improvement of approximately 18%. However, due to the distinct nature of their matrices, the commercial wood filament still has a higher modulus strength of almost 43%.

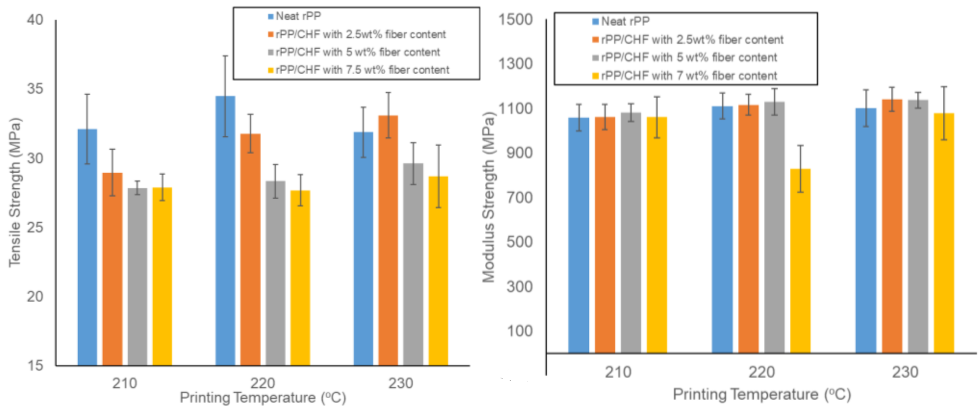

Figure 4.7: Result of Tensile and Modulus Strength.

The tensile results for rPP/CHF with 7.5 wt% fiber content were not discussed due to inconsistencies in the test results, which were found to be caused by the presence of voids and pores in the specimen. Figure 4.8 shows a cross-section of the tensile specimen with visible pores. These factors produced the results obtained to be unreliable. However, there was no indication of under-extrusion on the surface of the tensile specimen, as demonstrated in Figure 4.9. The findings obtained are also due to the instability in printing with inconsistent filament diameter and clogging of the printer nozzle due to the high content of CHF.

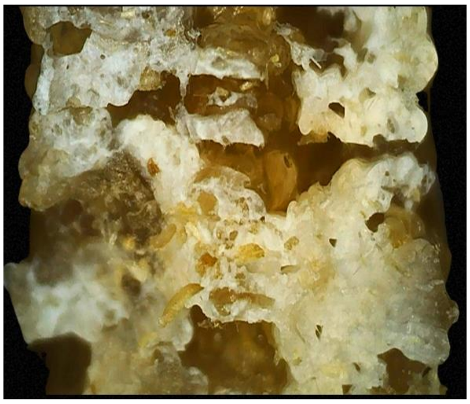

Figure 4.8: Magnification View of Cross Section of Tensile Specimen.

Figure 4.9: Surface Appearance of the Tensile Specimen.

4.3 Melt Flow Index Analysis

Figure 4.10 shows the melt flow index (MFI) values in g/10min of different materials, such as neat rPP, rPP/CHF composites with 2.5 wt%, 5 wt%, and 7.5 wt% fiber content, and commercial wood. The MFI values of the rPP/CHF composites decrease with increasing fiber content, which suggests that the addition of CHF reduces the flowability of the rPP matrix thus increasing the melt viscosity of the material. The highest MFI value is observed in neat rPP, which was around 25% higher than rPP/CHF with 7.5wt% fiber content. The

MFI value of the commercial wood filament is lower than all the rPP/CHF composites, this shows that it has the lowest flowability.

The polymer composite typically decreases as the fiber content increases due to the increased viscosity and shear resistance of the composite. This finding is similar to Ahmad et al. (2021), who also found that the viscosity increased with increasing fiber content. Ariel Leong et al., 2021 composite filament also with CHF showed the same result as the increase of natural fiber, the MFI of the composite would decrease. A typical MFI value for injection moulding PP is rated at between 30–70 g/10min as reported by Spear, Eder and Carus (2015), and since the raw material used in this research is injection moulded PP container, the MFI results in this research corresponded with it at at least 45 g/10min. For FDM application, the melt flow index reported that more than 10 g/10min is suitable for 3D printing for PLA (Wang et al., 2018). Hence, the MFI value obtained from the current research from the rPP/CHF with 2.5 to 7.5 wt% fiber content, which was greater than 45 g/10min, was suitable for FDM printing.

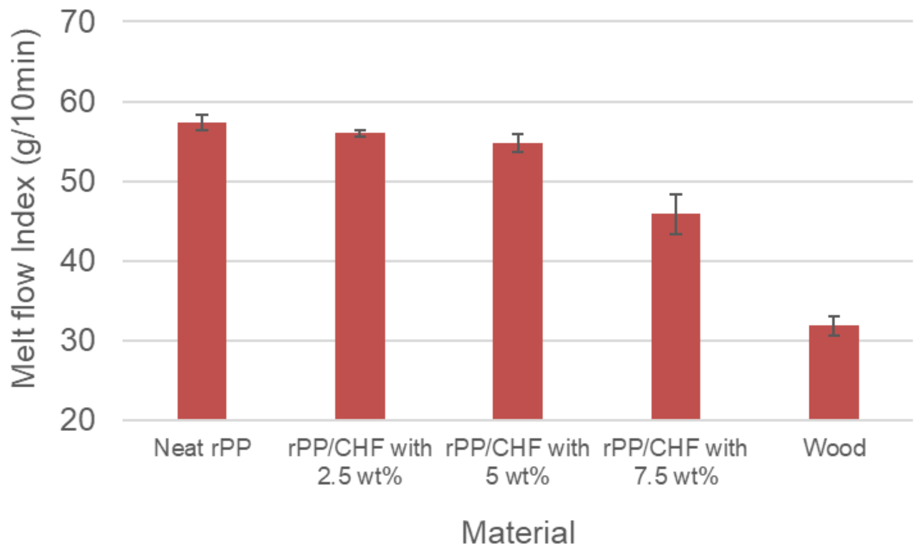

Figure 4.10: Melt flow Index for Different Materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study successfully developed a rPP/CHF composite using recycled materials and agricultural waste. This study has concluded several insights including CHF extraction process, filament extrusion parameters, and the effects of fiber content on the matrix's mechanical properties and melt flow index. As the fiber content increased, the surface appearance of the composite filaments become darker and rougher. However, upon closer inspection, voids and pores were found inside the filament, indicating poor interfacial bonding and adhesion between the polymer and the fiber. The rPP/CHF composite filament with 10 wt% fiber content failed to extrude into filament as frequent filament breakage during extrusion. Next, tensile test results showed that the strength of the composite material decreased as fiber content increased from 2.5 wt% to 5 wt%. However, the results for the rPP/CHF composite with a 7.5 wt% fiber content were excluded due to inconsistencies caused by the presence of voids and pores in the specimen affecting the result. Furthermore, the study also revealed that higher temperatures increased the strength of the printed composite material. Other than that, the melt flow index of the composite filament decreases with the increase of fiber content. Overall, this research has demonstrated the potential use of rPP/CHF composite filament in FDM applications.

5.2 Recommendation for future work

This study revealed the presence of pores and voids inside the filament affecting the result of the study. Additionally, the maximum fiber content that could be extruded in this research was only 7.5 wt%, while commercial composite filament fiber loading can reach up to 20 wt%. Further studies are needed to explore ways to increase the fiber content. To solve the pores and voids issues, chemical treating the corn husk fiber as mentioned by Mir Md, Chan and Koay (2021) NaOH treatment can improve the interfacial interlocking between the matrix and the fiber. Next, according to Milosevic, Stoof and Pickering (2017), Maleic anhydride grafted polypropylene (MAPP) also could be used as the coupling agent to improve the interfacial bonding.

Furthermore, since it was observed that the filament diameter was inconsistent during the extrusion of the filament, has greatly affected the printing quality. Hence, implementing a self-spooling and dimension-controlled filament extruder could enhance the extruded filament's quality.

Other than that, it was found that the size of the corn husk fiber used in this research exceeded the desired size specifications which caused issues in extruding and also the printed quality of the specimen. Therefore, it is recommended to use a better grinder in order to grind the corn husk fiber into finer grain.

Next, the composite filament's thermal properties and morphological test were not tested in this study due to limited apparatus availability. By conducting Thermogravimetric Analysis (TGA) and using SEM could provide further insights into the composite filament's thermal and morphological properties.

Moreover, since the load cell used in this study is 100kN, which would provide a lower accuracy to the reading, a smaller load cell and extensometer could be used to increase the result accuracy.

Finally, to assess the reliability and durability of the composite filament, besides the tensile and thermal test, other tests such as flexural and fatigue strength tests and environmental exposure tests could be done to assess the quality of the composite filament.

REFERENCES

Adekanye, S.A., Mahamood, R.M., Akinlabi, E.T. and Owolabi, M.G., 2017. Additive manufacturing: The future of manufacturing: Dodajalna (3D) Tehnologija: Prihodnost Proizvajanja. *Materiali in Tehnologije*, 51(5), pp.709–715. https://doi.org/10.17222/mit.2016.261.

Ahmad, M.N., Ishak, M.R., Taha, M.M., Mustapha, F. and Leman, Z., 2021. Rheological and morphological properties of oil palm fiber-reinforced thermoplastic composites for fused deposition modeling (Fdm). *Polymers*, 13(21). https://doi.org/10.3390/polym13213739.

Alsabri, A., Tahir, F. and Al-Ghamdi, S.G., 2022. Environmental impacts of polypropylene (PP) production and prospects of its recycling in the GCC region. *Materials Today: Proceedings*, 56, pp.2245–2251. https://doi.org/10.1016/j.matpr.2021.11.574.

Ariel Leong, J.J., Koay, S.C., Chan, M.Y., Choo, H.L., Tshai, K.Y. and Ong, T.K., 2021. Composite Filament Made from Post-used Styrofoam and Corn Husk Fiber for Fuse Deposition Modeling. *Journal of Natural Fibers*. https://doi.org/10.1080/15440478.2021.1941488.

Ayrilmis, N., Kariz, M., Kwon, J.H. and Kitek Kuzman, M., 2019. Effect of printing layer thickness on water absorption and mechanical properties of 3D-printed wood/PLA composite materials. *International Journal of Advanced Manufacturing Technology*, 102(5–8), pp.2195–2200. https://doi.org/10.1007/s00170-019-03299-9.

Bachhar, N., Gudadhe, A., Kumar, A., Andrade, P. and Kumaraswamy, G., 2020. 3D printing of semicrystalline polypropylene: towards eliminating warpage of printed objects. *Bulletin of Materials Science*, 43(1). https://doi.org/10.1007/s12034-020-02097-4.

Carneiro, O.S., Silva, A.F. and Gomes, R., 2015. Fused deposition modeling with polypropylene. *Materials and Design*, 83, pp.768–776. https://doi.org/10.1016/j.matdes.2015.06.053.

Chandara, H.C., -, S. and -, S., 2016. PLASTIC RECYLING IN INDONESIA BY CONVERTING PLASTIC WASTES (PET, HDPE, LDPE, and PP) INTO PLASTIC PELLETS. ASEAN Journal of Systems Engineering, [online] 3(2), p.65. https://doi.org/10.22146/ajse.v3i2.17162.

Chen, Y., Awasthi, A.K., Wei, F., Tan, Q. and Li, J., 2021. *Single-use plastics: Production, usage, disposal, and adverse impacts*. *Science of the Total Environment*, https://doi.org/10.1016/j.scitotenv.2020.141772.

Cunico, M.W.M., Kai, D.A., Cavalheiro, P.M. and de Carvalho, J., 2019. Development and characterization of 3D printing finishing process applying recycled plastic waste. *Virtual and Physical Prototyping*, 14(1), pp.37–52. https://doi.org/10.1080/17452759.2018.1521248.

Dey, A. and Yodo, N., 2019. *A systematic survey of FDM process parameter optimization and their influence on part characteristics*. *Journal of Manufacturing and Materials Processing*, https://doi.org/10.3390/jmmp3030064.

Dobrosielski, C., 2022. WertelOberfell Unveils Boot Designed to Adapt to Wearer's Foot – Sourcing Journal. [online] Sourcingjournal.com. Available at: <https://sourcingjournal.com/footwear/footwear-innovations/werteloberfell-adaptable-boot-auxetic-wear-shoe-3d-printing-ignotum-362886/> [Accessed 21 August 2022].

Egbo, M.K., 2021. *A fundamental review on composite materials and some of their applications in biomedical engineering*. *Journal of King Saud University - Engineering Sciences,* https://doi.org/10.1016/j.jksues.2020.07.007.

García-Lara, S. and Serna-Saldivar, S.O., 2019. Corn history and culture. In: *Corn: Chemistry and Technology, 3rd Edition*. Elsevier. pp.1–18. https://doi.org/10.1016/B978-0-12-811971-6.00001-2.

Gu, F., Wang, J., Guo, J. and Fan, Y., 2020. Dynamic linkages between international oil price, plastic stock index and recycle plastic markets in China. *International Review of Economics and Finance*, 68, pp.167–179. https://doi.org/10.1016/j.iref.2020.03.015.

Hahn, J., 2021. Asao Tokolo 3D prints Tokyo 2020 podiums from donated plastic waste. [online] dezeen. Available at: <https://www.dezeen.com/2021/07/15/podiums-tokyo-2020-olympics-asao-tokolo/> [Accessed 21 August 2022].

Herlina Sari, N., Wardana, I.N.G., Irawan, Y.S. and Siswanto, E., 2018. Characterization of the Chemical, Physical, and Mechanical Properties of NaOH-treated Natural Cellulosic Fibers from Corn Husks. *Journal of Natural Fibers*, 15(4), pp.545–558. https://doi.org/10.1080/15440478.2017.1349707.

Hwang, J., Choi, D., Han, S., Choi, J. and Hong, J., 2019. An assessment of the toxicity of polypropylene microplastics in human derived cells. *Science of the Total Environment,* 684, pp.657–669. https://doi.org/10.1016/j.scitotenv.2019.05.071.

Ibrahim, M.I.J., Sapuan, S.M., Zainudin, E.S. and Zuhri, M.Y.M., 2020. Preparation and characterization of cornhusk/sugar palm fiber reinforced Cornstarch-based hybrid composites. *Journal of Materials Research and Technology*, 9(1), pp.200–211. https://doi.org/10.1016/j.jmrt.2019.10.045.

Jaisingh Sheoran, A. and Kumar, H., 2020. Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Review and reflection on present research. In: *Materials Today: Proceedings*. Elsevier Ltd. pp.1659–1672. https://doi.org/10.1016/j.matpr.2019.11.296.

Kambli, N., Basak, S., Samanta, K.K. and Deshmukh, R.R., 2016. Extraction of natural cellulosic fibers from cornhusk and its physico-chemical properties. *Fibers and Polymers*, 17(5), pp.687–694. https://doi.org/10.1007/s12221-016-5416-0.

Kariz, M., Sernek, M., Obućina, M. and Kuzman, M.K., 2018. Effect of wood content in FDM filament on properties of 3D printed parts. *Materials Today Communications*, 14, pp.135–140. https://doi.org/10.1016/j.mtcomm.2017.12.016.

Khan, I. and Kumar, N., 2020. Fused deposition modelling process parameters influence on the mechanical properties of ABS: A review. In: *Materials Today: Proceedings*. Elsevier Ltd. pp.4004–4008. https://doi.org/10.1016/j.matpr.2020.10.202.

Kleczinski, N., 2022. Impression 3D : Des Barrières De Béton Transformées En Mobilier Urbain À Partir De Briques De Lait Recyclées. [online] NeozOne. Available at: <https://www.neozone.org/innovation/impression-3d-des-barrieres-de-beton-transformees-en-mobilier-urbain-a-partir-de-briques-de-lait-recyclees/> [Accessed 21 August 2022].

Kreiger, M.A., Mulder, M.L., Glover, A.G. and Pearce, J.M., 2014. Life cycle analysis of distributed recycling of post-consumer high density polyethylene for 3-D printing filament. *Journal of Cleaner Production*, 70, pp.90–96. https://doi.org/10.1016/j.jclepro.2014.02.009.

Krishna, L.S.R. and Srikanth, P.J., 2021. Evaluation of environmental impact of additive and subtractive manufacturing processes for sustainable manufacturing. In: *Materials Today: Proceedings*. Elsevier Ltd. pp.3054–3060. https://doi.org/10.1016/j.matpr.2020.12.060.

Laherrère, J., Hall, C.A.S. and Bentley, R., 2022. How much oil remains for the world to produce? Comparing assessment methods, and separating fact from fiction. *Current Research in Environmental Sustainability*, [online] 4, p.100174. https://doi.org/10.1016/j.crsust.2022.100174.

Lee, C.H., Padzil, F.N.B.M., Lee, S.H., Ainun, Z.M.A. and Abdullah, L.C., 2021. Potential for natural fiber reinforcement in pla polymer filaments for fused deposition modeling (Fdm) additive manufacturing: A review. *Polymers*, https://doi.org/10.3390/polym13091407.

Lokantara, I., 2020. A Review on Natural Fibers: Extraction Process and Properties of Grass Fibers. International Journal of Mechanical Engineering and Technology, 11(1), pp.84–91.

Maddah, H. and Maddah, H.A., 2016. Polypropylene as a Promising Plastic: A Review Related papers Polyolefin in Packaging and Food Industry. In Polyolefin Compounds and Materials : Fundamen… Zdenko Spitalsky, Igor Novak Springer Series on Polymer and Composite Materials Polyolefin Compounds and Materials Fundament … Igor Novak Polyolefin in Packaging and Food Industry Polypropylene as a Promising Plastic: A Review. American

Journal of Polymer Science, 6(1), pp.1–11. https://doi.org/10.5923/j.ajps.20160601.01.

Mazzanti, V., Malagutti, L. and Mollica, F., 2019. FDM 3D printing of polymers containing natural fillers: A review of their mechanical properties. *Polymers*, https://doi.org/10.3390/polym11071094.

Milosevic, M., Stoof, D. and Pickering, K.L., 2017. Characterizing the mechanical properties of fused deposition modelling natural fiber recycled polypropylene composites. *Journal of Composites Science*, 1(1). https://doi.org/10.3390/jcs1010007.

Mir Md, S.S., Chan, M.Y. and Koay, S.C., 2021. Mechanical properties of polyester/corn husk fibre composite produced using vacuum infusion technique. *Polymers and Polymer Composites*, 29(9_suppl), pp.S1532–S1540. https://doi.org/10.1177/09673911211056782.

Mohamed, O.A., Masood, S.H. and Bhowmik, J.L., 2015. Optimization of fused deposition modeling process parameters: a review of current research and future prospects. *Advances in Manufacturing*, 3(1), pp.42–53. https://doi.org/10.1007/s40436-014-0097-7.

Morales, M.A., Atencio Martinez, C.L., Maranon, A., Hernandez, C., Michaud, V. and Porras, A., 2021. Development and characterization of rice husk and recycled polypropylene composite filaments for 3d printing. *Polymers*, 13(7). https://doi.org/10.3390/polym13071067.

Mosleh, N., Rezadoust, A.M. and Dariushi, S., 2021. Determining process-window for manufacturing of continuous carbon fiber-reinforced composite Using 3D-printing. *Materials and Manufacturing Processes*, 36(4), pp.409–418. https://doi.org/10.1080/10426914.2020.1843664.

Ngo, T.D., Kashani, A., Imbalzano, G., Nguyen, K.T.Q. and Hui, D., 2018. *Additive manufacturing (3D printing): A review of materials, methods, applications and challenges*. *Composites Part B: Engineering*, https://doi.org/10.1016/j.compositesb.2018.02.012.

Nikitakos, N., Dagkinis, I., Papachristos, D., Georgantis, G. and Kostidi, E., 2020. Economics in 3D printing. In: *3D Printing: Applications in Medicine and Surgery*. Elsevier. pp.85–95. https://doi.org/10.1016/b978-0-323-66164-5.00006-4.

Pakkanen, J., Manfredi, D., Minetola, P. and Iuliano, L., 2017. About the use of recycled or biodegradable filaments for sustainability of 3D printing: State of the art and research opportunities. In: *Smart Innovation, Systems and Technologies*. Springer Science and Business Media Deutschland GmbH. pp.776–785. https://doi.org/10.1007/978-3-319-57078-5_73.

Paul Guin, J., Bhardwaj, Y.K. and Varshney, L., 2018. Radiation grafting: A voyage from bio-waste corn husk to an efficient thermostable adsorbent. *Carbohydrate Polymers*, 183, pp.151–164. https://doi.org/10.1016/j.carbpol.2017.11.101.

Rahim, T.N.A.T., Abdullah, A.M. and Md Akil, H., 2019. *Recent Developments in Fused Deposition Modeling-Based 3D Printing of Polymers and Their Composites*. *Polymer Reviews*, https://doi.org/10.1080/15583724.2019.1597883.

Sari, N.H., Fajrin, J., Suteja and Fudholi, A., 2020. Characterization of swellability and compressive and impact strength properties of corn husk fibre composites. *Composites Communications*, 18, pp.49–54. https://doi.org/10.1016/j.coco.2020.01.009.

Sarker, A., Deepo, D.M., Nandi, R., Rana, J., Islam, S., Rahman, S., Hossain, M.N., Islam, M.S., Baroi, A. and Kim, J.E., 2020. A review of microplastics pollution in the soil and terrestrial ecosystems: A global and Bangladesh perspective. *Science of the Total Environment*, https://doi.org/10.1016/j.scitotenv.2020.139296.

Shah, A., 2022. Emerging trends in robotic aided additive manufacturing. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2022.03.680.

Shahrubudin, N., Lee, T.C. and Ramlan, R., 2019. An overview on 3D printing technology: Technological, materials, and applications. In: *Procedia Manufacturing*. Elsevier B.V. pp.1286–1296. https://doi.org/10.1016/j.promfg.2019.06.089.

Singal, N., 2021. Signify launches tailored 3D printed light fixtures; to reduce carbon footprint. [online] Business Today. Available at: <https://www.businesstoday.in/technology/news/story/signify-launches-tailored-3d-printed-light-fixtures-to-reduce-carbon-footprint-291086-2021-03-18> [Accessed 21 August 2022].

Singh, R., Kumar, R. and Ranjan, N., 2019. Sustainability of Recycled ABS and PA6 by Banana Fiber Reinforcement: Thermal, Mechanical and Morphological Properties. *Journal of The Institution of Engineers (India): Series C*, 100(2), pp.351–360. https://doi.org/10.1007/s40032-017-0435-1.

Spear, M.J., Eder, A. and Carus, M., 2015. Wood polymer composites. In: *Wood Composites*. Elsevier Inc. pp.195–249. https://doi.org/10.1016/B978-1-78242-454-3.00010-X.

Wang, S., Capoen, L., D’hooge, D.R. and Cardon, L., 2018. Can the melt flow index be used to predict the success of fused deposition modelling of commercial poly(lactic acid) filaments into 3D printed materials? *Plastics, Rubber and Composites*, 47(1), pp.9–16. https://doi.org/10.1080/14658011.2017.1397308.

Wankhede, V., Jagetiya, D., Joshi, A. and Chaudhari, R., 2019. Experimental investigation of FDM process parameters using Taguchi analysis. In: *Materials Today: Proceedings*. Elsevier Ltd. pp.2117–2120. https://doi.org/10.1016/j.matpr.2019.09.078.

Wickramasinghe, S., Do, T. and Tran, P., 2020. FDM-Based 3D printing of polymer and associated composite: A review on mechanical properties, defects and treatments. *Polymers*, https://doi.org/10.3390/polym12071529.

William, L.J.W., Koay, S.C., Chan, M.Y., Pang, M.M., Ong, T.K. and Tshai, K.Y., 2021. Recycling Polymer Blend made from Post-used Styrofoam and Polypropylene for Fuse Deposition Modelling. In: *Journal of Physics: Conference Series*. IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/2120/1/012020.

Yilmaz, N.D., 2013. Effects of enzymatic treatments on the mechanical properties of corn husk fibers. *Journal of the Textile Institute*, 104(4), pp.396–406. https://doi.org/10.1080/00405000.2012.736707.