THE INVESTIGATION OF THE DAMPING AND TOUGHNESS PROPERTIES OF 3D PRINTING FILAMENT MADE FROM GROUND TYRE RUBBER AND POLYPROPYLENE COMPOSITE

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2024

Faculty of Industrial and Manufacturing Technology and Manufacturing

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

Faculty of Industrial and Manufacturing Technology and Manufacturing

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this Choose an item. entitled " The investigation of the damping and toughness properties of 3D printing filament made from ground tyre rubber and polypropylene composites" is the result of my own 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.

Signature :

Name : MUHAMMAD AMMAR SUFFIAN BIN MAT TAMIDZI

Date : 31/1/2023

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 with Honours.

Signature :

Supervisor Name : DR. NUZAIMAH BTE MUSTAFA

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Universiti Teknikal Malaysia Melaka

DEDICATION

I want to dedicate my report to all the people who have encouraged and helped me along the way.

I dedicate my report, first and foremost, to my supervisor DR. NUZAIMAH BTE MUSTAFA, whose advice, and knowledge have been of great use. Your patience, helpful criticism, and unflinching support were crucial in helping to shape this report. Your commitment to quality and interest in my professional development has encouraged me to go above and beyond my comfort zone.

In addition, I want to sincerely thank my staff for their collaboration and continuous support. This initiative would not have been feasible without your cooperative attitude, openness to sharing your knowledge, and dedication to attaining our common objectives. I appreciate the faith and confidence you placed in me since it inspired me to do my finest work.

I want to express my gratitude to my friends and family for their continuous support and tolerance throughout the challenging parts of this endeavour. Your confidence in my skills and your ongoing affirmations of them gave me the emotional support I required to stay motivated and focused.

I owe a debt of gratitude to the research participants who gave freely of their time, wisdom, and experiences. Your willingness to take part and contribute insightful data was essential in enhancing the report's conclusions. The calibre and scope of the research stimulated have significantly benefited from your contributions.

Finally, I dedicate this report to all individuals who pursue learning, growth, and innovation. We are all driven to contribute meaningfully to our professions by our shared

commitment and enthusiasm. May this report be a little step towards increasing our knowledge and promoting change.

All of you who have contributed to this adventure are appreciated. Your steadfast assistance, inspiration, and support have been crucial in making this report possible. I am appreciative of the chance to work with such extraordinary people.

ABSTRACT

An alternative to the environmental problems caused by tyre waste is utilizing watse tyre into the composite. The waste tyre were crushed into ground tyre rubber (GTR) and incoporated into the composite matrix. GTR has drawn interest because of its distinct qualities and prospective uses across several sectors. The goal of this study is to produce 3D printing filament with the material made of ground tyre rubber and polypropylene (r-RubPPc) with different fiber loading. Second, to investigate toughness and damping properties of 3D printed sample for r-RubPPc composite. The methodology used in this study is to determine the damping properties and toughness of the r-RubPPc composite with different percentage of GTR fiber loading (1%, 3% and 5%). Vibration test was conducted to study the damping properties of r-RubPPc composites. The result shows damping properties increased by 58% with the increasing to 5% of rubber content. The main cause of these desirable variations is the elastomeric properties of rubber particles, which become more prevalent as the 3D printed composite's rubber content rises. Rubber is extensively utilized for dampening vibrations in a variety of structures because to its high bulk modulus and low elastic modulus. However the damping properties of r r-RubPPc treated with silane experienced decrement by 23%. This shows silane treatment enhance adhesion between GTR fiber and PP matrix which resulted in lesser voids in the composite filament which has been shown in morphological of the silane treated filament. The lesser voids resulted from well embedded GTR fiber in PP matrix. According to results from water absorption test, silane improved the interfacial adhesion between PP and GTR, with a significant decrease of 23% observed for the 3% of GTR treated with silane. Impact test findings shows an increase in toughness of r-RubPPc composite as the amount of rubber in the 3D printed specimen increases. The result shows the percentage of 3% GTR fiber loading is in an optimum state that can be added to PP for filament fabrication and 3D print specimens.

ABSTRAK

Alternatif kepada masalah alam sekitar yang disebabkan oleh sisa tayar adalah menggunakan sisa tayar ke dalam komposit. Sisa tayar dihancurkan menjadi getah yang hancur (GTR) dan dimasukkan ke dalam matriks komposit. GTR telah menarik minat kerana kualiti yang berbeza dan penggunaan prospektif merentas beberapa sektor. Matlamat kajian ini adalah untuk menghasilkan filamen cetakan 3D dengan bahan yang diperbuat daripada getah tayar tanah dan polipropilena (r-RubPPc) dengan muatan gentian yang berbeza. Kedua, untuk menyiasat keliatan dan sifat redaman sampel cetakan 3D untuk komposit r-RubPPc. Metodologi yang digunakan dalam kajian ini adalah untuk menentukan sifat redaman dan keliatan komposit r-RubPPc dengan peratusan pembebanan gentian GTR yang berbeza (1%, 3% dan 5%). Ujian getaran telah dijalankan untuk mengkaji sifat redaman bagi komposit r-RubPPc. Hasilnya menunjukkan sifat redaman meningkat sebanyak 58% dengan peningkatan kepada 5% kandungan getah. Punca utama variasi yang diingini ini ialah sifat elastomerik zarah getah, yang menjadi lebih lazim apabila kandungan getah komposit cetakan 3D meningkat. Getah digunakan secara meluas untuk melembapkan getaran dalam pelbagai struktur kerana modulus pukal yang tinggi dan modulus anjal yang rendah. Walau bagaimanapun, sifat redaman r r-RubPPc yang dirawat dengan silane mengalami penurunan sebanyak 23%. Ini menunjukkan rawatan silane meningkatkan lekatan antara gentian GTR dan matriks PP yang mengakibatkan lompang yang lebih kecil dalam filamen komposit yang telah ditunjukkan dalam morfologi filamen yang dirawat silane. Lompang yang lebih kecil terhasil daripada gentian GTR yang tertanam dengan baik dalam matriks PP. Mengikut keputusan daripada ujian penyerapan air, silane meningkatkan lekatan antara muka antara PP dan GTR, dengan penurunan ketara sebanyak 23% diperhatikan untuk 3% GTR yang dirawat dengan silan. Penemuan ujian impak menunjukkan peningkatan dalam keliatan komposit r-RubPPc apabila jumlah getah dalam spesimen cetakan 3D meningkat. Hasilnya menunjukkan peratusan 3% pemuatan gentian GTR berada dalam keadaan optimum yang boleh ditambah kepada PP untuk fabrikasi filamen dan spesimen cetakan 3D.

ACKNOWLEDGEMENTS

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

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

My utmost appreciation goes to my main supervisor, Dr. Nuzaimah Bte Mustafa, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey for all her assistance, counsel, and motivation. Her steadfast patience in mentoring and imparting invaluable insights will be remembered.

Lastly, I would want to thank my parents, Mat Tamidzi Bin Din and Khadijah Binti Jusoh, for their unwavering support and encouragement throughout my life. My eternal affection also extends to my friends who lend me their vehicle and other critical items whenever I need them. I would also like to thank my family for their everlasting support, affection, and prayers. Lastly, I would like to convey my appreciation to everyone who has assisted, encouraged, and motivated me to continue my education.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
cm	-	Centimeter
mm	-	Milimeter
ζ	-	Damping factor
%	-	Percent
g	-	Gram
$^{\circ}$	-	Degree
µm	-	Micron meter
rpm	-	Revolution per minute
rPP	-	Recycled Polypropylene
GTR	-	Ground Tyre Rubber
PP	-	Polypropylene
h	-	Hour
FDM	-	Fused Deposition Modeling
CAD	-	Computed Aided Design
AM	-	Additive Manufacturing
ABS	-	Acrylonitrile Butadiene Styrene
HNO_3	-	Nitric Acid
H_2SO_4	-	Sulfuric Acid
$HClO_4$	-	Perchloric Acid
HDPE	-	High-Density Polyethylene
Si	-	Silicon
O	-	Oxygen
3DP	-	Three- dimensional printing
3D	-	Three-dimensional
η	-	Loss factor
Q	-	Quality factor

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CHAPTER 1

INTRODUCTION

1.1 Background

Through the application of layering materials, the process of 3D printing has the capability to transform geometric models into tangible objects. Significant advancements have been witnessed in various 3D printing techniques in recent times, displaying impressive progress. In 1980, Charles Hull introduced 3D printing technologies to the market, making them accessible for purchase

Currently, the primary application of 3D printing revolves around the production of steel bridges in Amsterdam jewelry collections, 3D printed corneas, PGA rocket engines, and other items associated with the food and aviation industries. The foundation of 3D printing technology lies in the layer-by-layer manufacturing process, enabling the creation of three-dimensional (3D) structures directly from CAD drawings. The advancement of 3D printing technology has been remarkably innovative and adaptable, offering new possibilities and inspiring numerous businesses aiming to enhance industrial efficiency.

Presently, 3D printing technology allows for the production of a wide range of materials, such as traditional thermoplastics, ceramics, graphene-based materials, and metals (L. Ze-Xian, 2016). This groundbreaking technology has the potential to bring about a transformative shift in the manufacturing landscape, revolutionizing various sectors. By leveraging 3D printing, manufacturing processes can be accelerated, leading to cost reductions. Additionally, consumer demand will play a more significant role in shaping production. Customers will have the opportunity to request customized products that meet their specific requirements according to their specifications and have a bigger say in the result. Customers will have the ability to influence the outcome of their desired products and exert greater control over the manufacturing process. Meanwhile, 3D printing facilities will be strategically located closer to consumers, enabling a more flexible and efficient manufacturing process with enhanced quality control. Moreover, the utilization of 3D printing technology significantly reduces the need for international travel. This is achieved by leveraging fleet monitoring technology for streamlined distribution when production facilities are situated near the destination, resulting in energy and time savings. The implementation of 3D printing technology may also lead to changes in business logistics, where logistics operations can oversee the entire process and provide comprehensive end-to-end services (B. Sniderman, 2016).

Nevertheless, there are certain drawbacks associated with the implementation of 3D printing in the industrial sector. One major concern is the potential reduction in the need for manual labor, which could significantly impact economies heavily reliant on low-skilled jobs. Moreover, the versatility of 3D printing enables users to create various objects, including potentially dangerous items like knives and firearms. To prevent the illicit transportation of firearms and thwart criminal activities, access to 3D printing technology should be limited to a select group. Additionally, the accessibility of blueprints means that anyone with such knowledge can easily produce counterfeit goods. The user-friendly nature of 3D printing technology allows for the simple creation of 3D items by merely designing and setting the data in the printing machine (A. Pirjan & D. M. Petrosanu, 2013).In conclusion, 3D printing technology has become a versatile and effective tool in the advanced manufacturing sector in recent years. Many nations have used this technology widely, particularly in the industrial sector. As a result, this article provides an overview of the various 3D printing methods, their applications, and finally the materials that are utilised in the manufacturing sector.

1.2 Problem Statement

Due to the rich minerals still present in these solid wastes, millions of tonnes of scrap tyres are amassed globally, raising broad environmental and economic concerns. There are several methods of disposal, including pyrolysis, incineration, retreading, landfilling, and incineration. However, the slow biodegradation of rubber, toxic emissions from burning rubber, or leachate pollution are to blame for environmental and societal issues (S. Ramarad, M. Khalid, C.T. Ratnam, A.L. Chuah, W. Rashmi, 2015). Based on the well-known 4R waste management concept, resource recycling from scrap tyres is presently the disposition option that seems the most viable (B. Adhikari, D. De, S. Maiti, 2000).

The phrase "3D printing" describes a process for swiftly and simply creating three dimensional (3D) items using digital computer-aided design (CAD) data. Direct metal laser sintering 3D printers can cost up to $500,000, whereas fused deposition manufacturing (FDM) machines only cost a few hundred dollars. Modern 3D printers can process a variety of materials and create completely functional pieces. Applications for 3D printing in robotics, car parts, weaponry, medicine, space exploration, and other fields have all been studied (Jason Lehrer, 2017).

A material made of polypropylene that may be used for fused deposition modelling (FDM) has been developed. Polypropylene (PP)'s substantial volumetric shrinkage and rheological behaviour are the key reasons why it is not frequently utilised as a filament for 3D printing. Although this polymer is already accessible as filament for 3D printing, there have been very few investigations on the qualities of a 3D printing grade (O.S. Carneiro, A.F. Silva, R. Gomes, 2015). The volumetric shrinkage and rheology of pure PP are directly related to why it is challenging to process with FDM technology and must be amended with other polymers and fillers.

1.3 Research Objective

The objectives of the research are as follows:

1) To produce 3d printing filament with the material made of GTR/PP with different fiber loading.
2) To investigate toughness and damping properties of 3d printed sample for GTR/PP composite.

1.4 Scope of Research

The scope of this research are as follows:

1) Testing and analyse morphological and mechanical of silane-treated ground tyre rubber and recycled polypropylene composite
2) Material that used in this study was ground tyre rubber and recycle polypropylene with loading 1%, 3% and 5% .

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The rising number of automobiles on the road leads to the generation of one billion trash tires globally each year (Fazli & Rodrigue, 2020). Recycling these materials is challenging due to their chemical cross-linking in three dimensions (Asaro et al., 2020; de Sousa & Ornaghi Júnior, 2020; Gopi Sathi et al., 2020). Because they cannot be re-melted, they cannot be processed using traditional methods like injection molding or extrusion. Grinding end-of-life tires (Hejna et al., 2021) and blending them with thermoplastic polymers is a popular recycling method for rubber waste (Gopalan et al., 2020).

Because it is difficult to handle and recycle worn tires, both academic and business organizations are worried about the environment (Zedler et al., 2022). This predicament is the result of a lot of significant factors. To begin with, tires are high-performance objects that contain a range of premium materials such as steel wires, textile cords, and different rubber compounds to meet stringent specifications. Consequently, the recycling process for used tires becomes exceedingly challenging. The vulcanization process and its association with the cross-linked structure of rubber present the most formidable hurdle in achieving successful tire recycling efforts. Unlike thermoplastics, which can undergo minimal heating or cooling changes to regain their original properties, vulcanized rubber is challenging to decross-link or, more accurately, devulcanize. According to the European Tyre & Rubber Manufacturers Association (ETRMA), over 95% of worn tires in Europe were collected and processed for material recycling and energy recovery in 2019

(European Tyre and Rubber Manufacturers' Association, 2021). Statistical information further indicates that the most common approaches for managing discarded tires across the 32 studied nations (EU27, UK, Norway, Turkey, Switzerland, and Serbia) include energy recovery accounts for 40% of the total, followed by unknown/stocks (5%), recycling (52%), and civil engineering (3%) (Guo et al., 2023). It is evident that the production of tire rubber (GTR) through methods such as shredding, granulating, or pulverizing discarded tires is merely one step in the larger process of achieving true recycling or potential upcycling. The provided data does not accurately depict the current state of the issue at hand. Therefore, the scientific community, which generally focuses on plastic recycling, has directed its attention towards rubber waste. Their aim is to find effective means of managing it and even enhancing the devulcanization process. This would allow the material to be reintegrated into the production of rubber composites for footwear as well as technical uses.

2.2 3D Printing

2.2.1 3D Printing History

Three-dimensional printing technology has barely been around for four decades. As a result of the revolutionary increase of research in science, engineering, and technology, this creation has attained maturity (Maddah, 2016). Time, numerous attributes, and technology may all be used to depict the historical growth of 3DP technology (Bertolino et al., 2021). Certain studies, for example, have divided the infancy stage from 1981 to 1999, the teenage stage from 1999 to 2010, and the adult stage from 2011 to the present into a few large pieces (Flynt J., 2019). 3D printers were prohibitively costly for much of their existence; however, prices have already decreased substantially from over $20,000 (before 2009) to $500-$1000 (Shahrubudin et al., 2019). To better comprehend the evolution of

3DP, this article explores the history using a timeline and names major stages of development (Satya & Sreekanth, 2020).

Around 1860, it is claimed that Francis Willene, a Parisian photographer, laid the groundwork for the 3DP concept. He invented "mechanical sculpture" to make 3D portraited sculpture with more precision and in less time (48 h) using a camera, image, and pantograph (Herron R., 1981). In 1892, Blancher proposed the notion of creating topographical maps using the layering technique, which served as the conceptual foundation for contemporary AM. There was a gap in the advancement of these principles until 1940 when Pereyra employed a similar technique to generate a 3D map. He achieved this by cutting out contour lines and attaching them to a cardboard sheet. In 1972, Matsubara from Mitsubishi Motors introduced a topological approach for producing layered materials through photo-hardening. This involved applying photopolymer resin onto refractory particles. DiMatteo (1974) demonstrated the versatility of this method, highlighting its applicability in manufacturing challenging components like propellers, air foils, 3D cams, and dies, which are typically difficult to produce using conventional machining methods (Beaman JJ., 1997). In 1977, Wyn Kelly Swainson filed the first patent application for this innovation. He employed a laser-sensitive monomer that facilitated covalent crosslinking on the surface of the material being created (Kabir et al., 2020).

Finally, the concept of 3DP (rapid prototyping) was established based on (Z. Wang et al., 2022) continuing hypothesis of integrating photopolymer with laser. They also applied for a patent, but it was denied since they couldn't submit the whole patent specification within a year after the application.

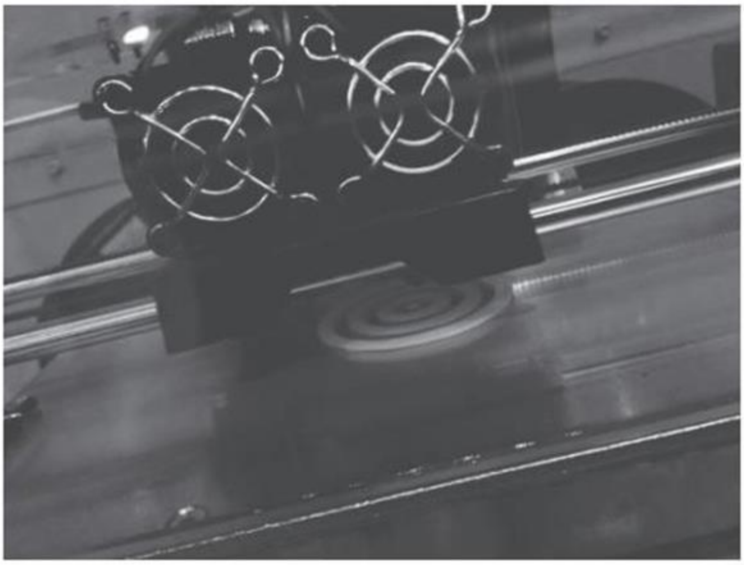

Figure 2.1 Addictive printer extruding ABS filament (Savini et al., n.d.)

2.3 Ground Tyre Rubber (GTR) composite

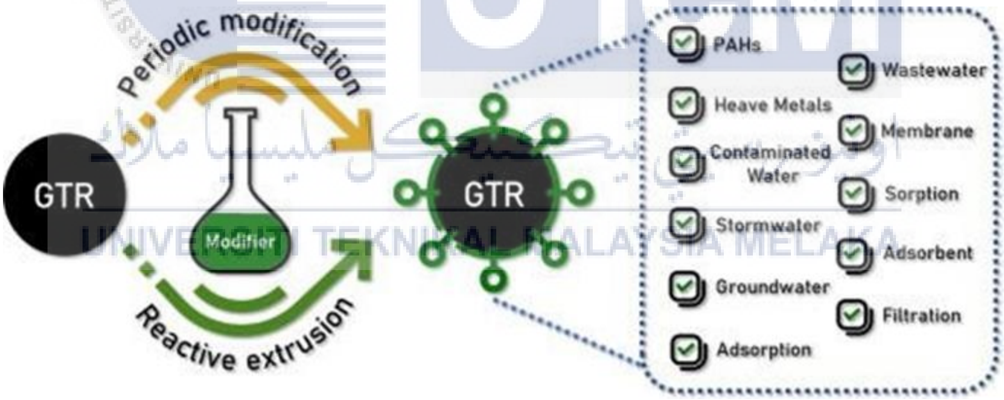

Figure 2.2 Modification of GTR (Zedler et al., 2022)

Ground tyre rubber (GTR) is derived from the physical and mechanical grinding of used tires (Q. Wang et al., 2019). GTR has found applications in various composite materials, including concrete (Hao et al., 2023), thermoplastics(Valente et al., 2023), bitumen/asphalt, rubber(Zhu et al., 2023), and thermosets, among others .By using GTR powder as a filler, less host material is required, resulting in overall cost savings for the final (Fazli & Rodrigue, 2020). Additionally, GTR fillers offer benefits such as lightweight construction, improved thermal stability, enhanced acoustic properties, resistance to aging and harsh weather conditions , and lightweight characteristics (Al Rashid & Koç, 2023). This makes the recycling of used tyres a desirable alternative for a variety of possible uses, such as asphalt and automobile parts(Astrauskas et al., 2023). Recent research has focused on the utilization of ground tyre rubber (GTR) products as fillers in various construction materials, including cement mortars and other building materials, asphalt, and polymers . For instance, the mechanical and thermal properties of a composite material composed of GTR and polypropylene, with a particular emphasis on the effects of sulfuric acid treatment . The study revealed that the acid treatment increased the surface roughness and porosity of the rubber particles, thereby enhancing the mechanical characteristics of the GTR-polypropylene composite(Herkal et al., 2023).

2.3.1 GTR Treatment

Waste tyre rubber can have its surface altered chemically using a variety of techniques depending on the use. The modification procedures greatly expand the industries in which GTR may be used, reducing the number of waste tyres that are produced and released into the environment(Kam et al., 2023). The etching, oxidation, hydroxylation, and radiation techniques used in the chemical procedures have enhanced the qualities of the finished composite product (Phiri et al., 2022). A typical method for changing the surface chemistry of different hydrophobic materials is called acid surface etching (Zedler et al., 2018). 400-600 m GTR particles have been treated with three different acids: 60% nitric (HNO_3), 96% sulfuric (H_2SO_4), and 60% perchloric ($HClO_4$). SEM images, which were utilised to verify and track the degree of surface change, revealed a rough surface with tiny holes and voids following treatment with H2SO4. However, $HClO_4$ has no effect on the compatibility properties of HDPE/GTR composites.

The addition of 20% weight percent of GTR treated with either H_2SO_4 or HNO_3 enhanced tensile strength by 24%. When $HClO_4$ was used, the composites' tensile strength was even lower than that of untreated GTR/HDPE composites.

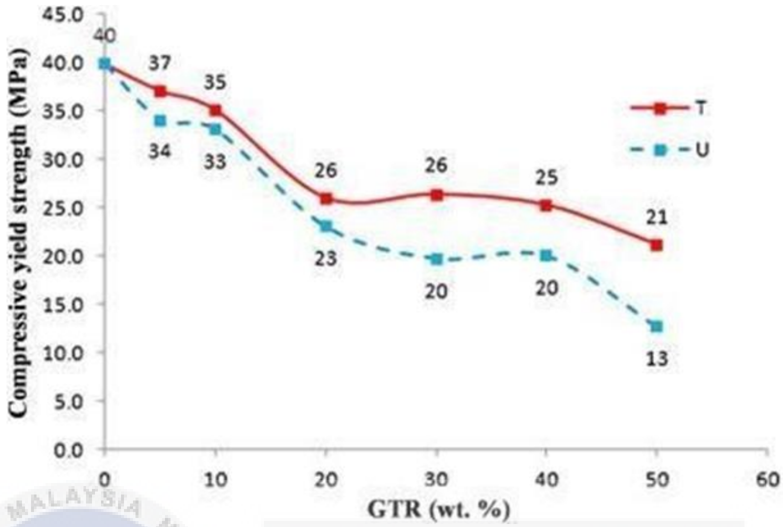

Figure 2.3 The effect of treated (T) and unmodified (U) GTR particles wt. % of size 5 mesh on the compressive yield strength of PP/GTR composites (Elenien et al., 2018)

The application of 97% H_2SO_4 treatment to the composites resulted in an increase in their compressive yield strength. The amount of GTR used in the composites ranged from 5 to 50 wt%. This information is derived from (Elenien et al., 2018) and has been reprinted with permission.

Silane coupling agents are widely used globally as surfactants for coating and bonding different materials. These agents typically possess two polar functional groups: inorganic and organic. The inorganic functional group forms a strong chemical bond (Si-O-Si) through dehydration condensation with the hydroxyl (-OH) groups present on the surface of the base material, ensuring a close attachment. On the other hand, the organic functional group interacts with specific elements in the other substance, facilitating a chemical connection between the silane and the substance. The base material and the additional material are tightly integrated through the formation of strong chemical bonds and intermolecular interactions . In Figure 2, the ground tyre rubber (GTR) is depicted with multiple fracture surfaces, rough textures, and porous areas with a significant specific surface area capable of absorbing oil and resin. The fracture surface is characterized by various edges and corners. The GTR surface shows a dense layer of silane coating. The film effectively fills and connects holes of different sizes and shapes, reducing granules and holes and ensuring the surface maintains its continuity. The presence of rough surfaces on the modified ground tyre rubber (MGTR) is noteworthy. The application of a thick silane coating to the MGTR increased its specific surface area, enabling it to absorb a greater amount of light components such as oil and adhesive substances. This enhancement in absorption can contribute to improved mechanical properties of the modified asphalt rubber (MAR), enhance the bond between MGTR and asphalt, and prevent irreversible deformation.

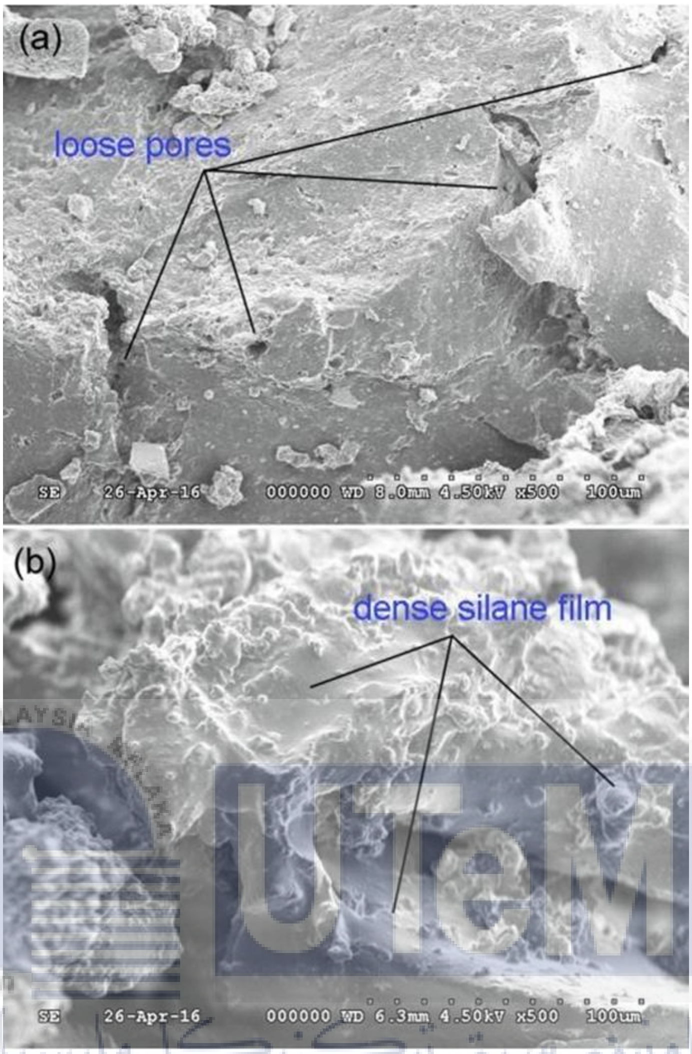

Figure 2.4 SEM results of GTR and MGTR: (a) GTR and (b) MGTR (Xiang et al., 2020a)

2.3.2 Current trend in waste tyre rubber recycling

Fresh data from European Tyre & Rubber Manufacturers Association (ETRMA) publications reveals that more than 95% of used tyres were collected and managed in Europe in 2019, with a focus on material recycling and energy recovery (European Tyre and Rubber Manufacturers' Association, 2021). The statistics indicate that the most prevalent approaches employed in the 32 countries studied (EU27, UK, Norway, Turkey, Switzerland, and Serbia) for handling waste tyres are civil engineering (3%), recycling (52%), energy recovery (40%), and unknown/stocks (5%). However, while analysing this data, two extremely important factors must be considered. First, because energy recovery necessitates the combustion of materials, waste from the process may be generated in the form of both solid and volatile contaminants, which must be collected and properly controlled(Yang et al., 2023). Furthermore, this process makes it hard to substitute high-quality waste tyre rubber for raw matrix, increasing demand for already scarce natural resources. A better comprehension of society, on the other hand, entirely justifies and promotes massive recycling(Gobetti et al., 2023).

Among the available options, recycling stands out as the most ecologically advantageous choice. Upon examining the data presented by ETRMA, it becomes evident that addressing the issue can be as simple as granulating tyres, which qualifies as a form of recycling. Additionally, the resulting "chips" from tyre granulation or shredding are sometimes utilized as an alternative fuel, contributing to energy recovery efforts(Zhao et al., 2023).

It is clear that the process of creating tyre rubber (GTR) from discarded tyres through shredding, granulating, or pulverising represents just one step in the overall journey towards true recycling or potential upcycling. The data provided fails to accurately portray the current state of affairs in this regard. That is why the scientific community, with a broader focus on plastics recycling, places significant importance on addressing the challenges posed by rubber waste. They are attempting to create effective ways to handle this waste and even enhance devulcanization procedures in order to reintegrate the material into the creation of rubber compounds for various technical applications, such as those found in shoes or tyres.

Because recycled or reclaimed/devulcanized rubber is utilised instead of natural resources, this sector's efforts are both economically and environmentally sound. This technique reduces production costs while simultaneously eliminating garbage disposal fees. Figure 1 depicts data from two well-known databases, Scopus® and Web of ScienceTM, emphasising the number of papers relevant to waste rubber and its devulcanization from 2011 to 2021 to support this argument. The facts presented support the aforementioned statement.

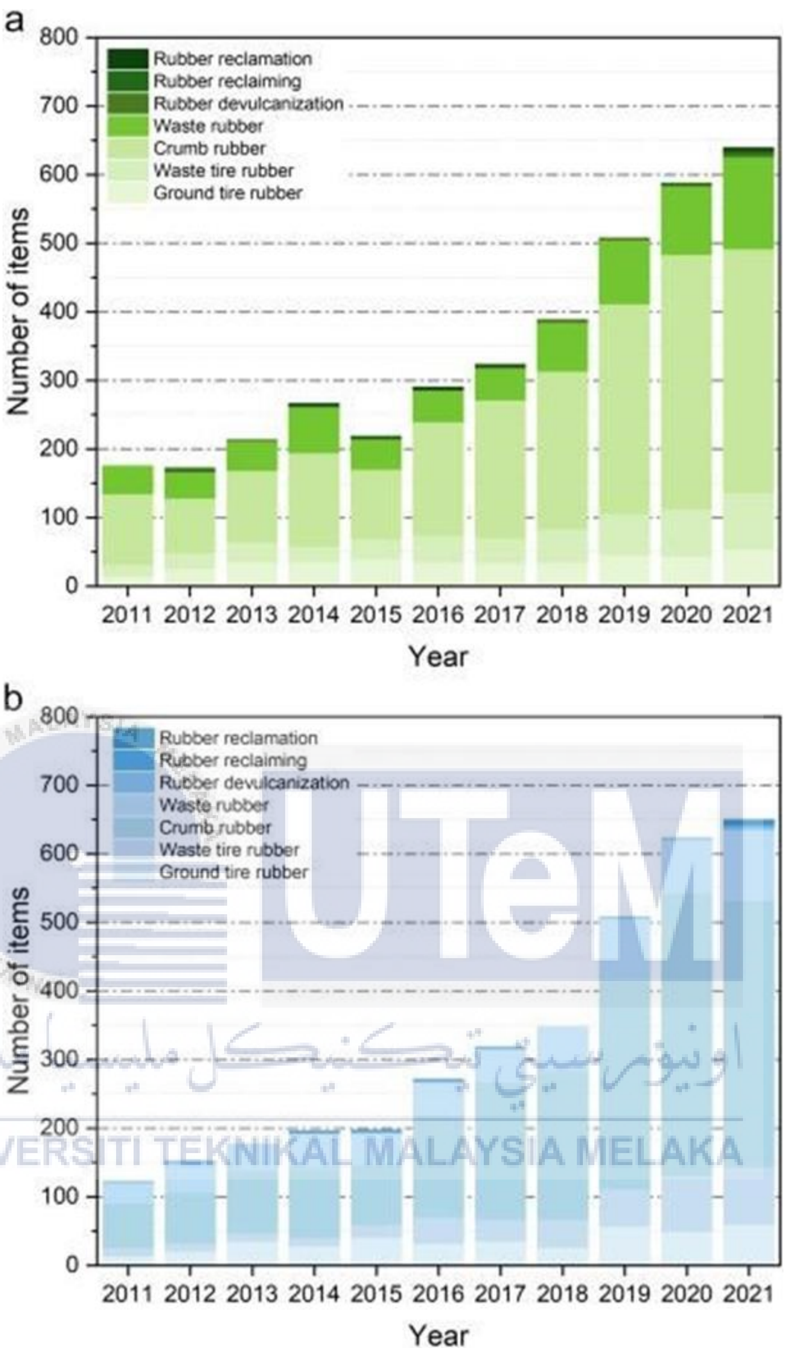

Figure 2.5 The number of publications related to the topic of waste tires from 2011 to 2021 generated through: A – Scopus® and B – Web of Science™ database.

As previously stated, the large difference in the number of entries for Web of ScienceTM and Scopus® (267 and 1190, respectively) is due to the data gathering policy. Furthermore, the subjects of the searches may overlap, allowing you to discover the same object using several phrases. Data show that the use of leftover rubber for environmental purposes is increasing. Because this tendency is expected to alter soon, the current state-of-the-art given in this concise summary may serve as incentive for more research and development in this field.

2.3.3 Composition and characteristic of Ground Tyre Rubber (GTR)

This pattern looks to be continuing in the next years. Adsorption using renewable, waste, or recycled materials is a hotly debated issue (Deriszadeh et al., 2019). The underlying challenge with the usage of waste-based goods is the lack of or poor characterisation of waste materials, whose chemical composition might vary substantially (Mosia et al., 2022). This may make it difficult to replicate favourable laboratory results and adapt them to commercial trials. As a result, this subchapter concentrated on and discussed aspects of GTR composition and characteristics (Archibong et al., 2021).

It is critical to emphasise that tyres are complex composite materials, and a typical track tyre is made up of six various types of steel wire, cords, and fabrics, as well as 14 different compounds (Phiri et al., 2021). Some of the compounds include the base, tread chimney, cushion, sidewall, bead area, plies, belts, overlay, shoulder wedge, inner liner, and gum strips (also known as squeegee or gum strips) are the components of a tread (Kiss et al., 2022). These components each have a specific purpose, and their combination resulted in a highperforming product (Sienkiewicz et al., 2017). However, the methods by which batches are created and, more crucially, their composition vary depending on the functions performed.

Shredding and grinding are now employed in 87.5% of all rubber recycling procedures used in used tyre recycling (Alkadi et al., 2019). To enhance the efficacy of rubber recycling, residual rubber should be classified according to its source (chemical makeup) before being crushed, powdered, or pulverised. This stage improves the quality of the finished goods and makes the process more repeatable.

Table 2:1 According (Fazli & Rodrigue, 2020) a comparison of standard tyre composition and the influence of tyre grinding method on GTR properties.

Composition	**Tire (%wt.)**		**GTR property**	**Grinding technology**	
	Car	**Truck**		**Ambient**	**Cryogenic**
Natural rubber	22	30	Specific gravity	Same	Same
Synthetic rubbers	23	15	Particle shape	Irregular	Regular
Carbon black	28	20	Surface area	Well-develope	Non-developed
Additives	14	10	Oxidation level	High	Low
Steel	13	25	Product purity	Low	High

When truck tyres are compared to automotive tyres, truck tyres contain more natural rubber and less carbon black (Fazli & Rodrigue, 2020). The composition of tyres, has a substantial influence on how well they work in terms of wear, rolling resistance, and skid resistance. Furthermore, the ratio of natural rubber to synthetic rubber has a significant impact on the success of rubber reclamation and devulcanization. Natural rubber is more heat-sensitive than synthetic rubber, according to thermogravimetric tests. Therefore, it ie essential to accurately define the specific typre of tire rubber (GTR) or ground rubber (with simillar appearance to GTR) used in this study.

Table 2:2 Examples of methods useful for GTR characteristics (Zedler et al., 2022)

GTR property	Method	Standard
Particle size distribution and average particle size	Sieve analysis	ASTM D5644
	Optical method	–
Surface area	BET method	–
Hydrophilicity/hydrophobicity	Contact angle test	–
Moisture content	Moisture analyzer	ASTM D6980
Devulcanization degree	Equilibrium swelling	ASTM D 6814
	TGA (TGA-FTIR, TGA-GC–MS)	ASTM D6370
	XRF/SEM-EDX	–
Chemical composition	FTIR	–
	XPS	–
	Elemental analysis	–
Molecular weight	GPC	–
Viscosity	Mooney viscosity	ASTM D1646
Glass transition temperature	DSC	–
Volatile organic compounds emission	GC–MS, GC-FID	–

At the moment, the most extensively used and relevant criteria for waste rubber processing are particle size distribution and average particle size. In binary systems, for example, GTR's smaller particle size improves matrix dispersion and increases active surface area. This raises the possibility of GTR, and the matrices used to interact at the interface.

According to (Mujal-Rosas et al., 2011) larger particles of GTR often result in decreased compatibility within systems transformed by GTR, leading to a deterioration in their mechanical properties. Knowing the particle size distribution of GTR is therefore critical. Whenever possible, the Brunauer-Emmett-Teller (BET) method should be employed to assess the specific surface area. The moisture content of the material is also significant for GTR, similar to other plastics. Regular monitoring of the moisture content is necessary, assuming that ongoing GTR research aims to find an optimal solution applicable on a semi-industrial scale using commonly standard technologies (for example, injection or extrusion equipment) or a polyurethane binder. Excessive moisture can induce physical and chemical changes in the structure, thereby compromising the the level of quality achieved.

In order to facilitate devulcanization, various approaches are currently being employed in the management of GTR, which involve partial reclamation of the material. These approaches are interconnected, necessitating the calculation of glass transition temperature, molecular weight, viscosity, and degree of devulcanization are all factors to consider. During the reclamation process, the physical and chemical composition of the waste rubber changes (Asaro et al., 2018), resulting in a reduction in the size of gel particles in favour of the sol fraction and an increase in the degree of reclamation. Furthermore, the structural changes cause a drop in the molecular weight of the sol fraction as well as a change in the glass transition temperature of the material. Consequently, GTR undergoes physical transformations that allow for Mooney viscosity investigations to be conducted as the process advances.

The final step involves the identification of organic flammable substances that are released into the atmosphere during the heating of GTR. When GTR is heated, a range of typical compounds including cyclooctane, decane, limonene, undecane, dodecane, tridecane, and tetradecane are released as natural rubber degrades, as are benzene, toluene, ethylbenzene, xylene, styrene, benzaldehyde, and -methylstyrene (styrene products) (Saeb et al., 2022). Some of these compounds can serve as "markers" to evaluate the effectiveness of devulcanization or main chain degradation.

Proper quality control of waste rubber and waste rubber-based goods is required for recycling technology to improve. According to newly published research (Skoczyńska et al., 2021), the amount of heterocyclic aromatic compounds produced by commercially available recycled rubber mats exceeds European Union limits.

2.4 Polypropylene (PP)

Polypropylene (PP) is the most often used thermoplastic material because it has great mechanical properties, is affordable, processable, and chemically stable. It is semicrystalline and the most widely used material due to its high mechanical strength, low cost, processability, and chemical stability(Arrigo et al., 2022a).The manufacturing procedure as well as shear-induced crystallization influence the mechanical and thermomechanical properties of PP (Karian, 2003a). Thermal shrinkage caused by PP crystallization complicates 3D printing by interfering with filament strand bonding, layering interfusion, and layer adhesion to the build plate(He et al., 2023). PP is a viable material for FFF 3D printing processes due to its market cost and inherent qualities, but more research is needed to properly understand the relationship between process, structure, and property, as well as any prospective mechanical property advancements (Rodríguez-Liébana et al., 2022).

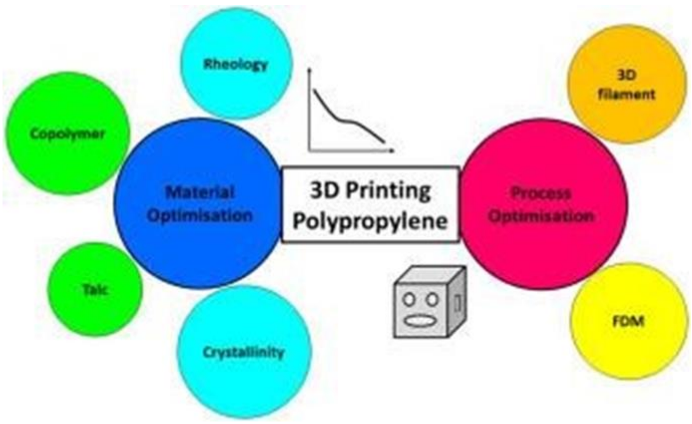

Figure 2.6 Polypropylene optimisation

A polypropylene-based material has been developed for fused deposition modelling (FDM). Indeed, the substantial volumetric shrinkage and rheological behaviour are the primary reasons why polypropylene (PP) is not widely employed as a 3D printing filament. Material alterations have a considerable influence on rheological behaviour, offering essential properties that allow and increase material printability, according to experimental data. A 20 wt% talc loaded heterophasic PP copolymer has been optimised. Thermal characterisation and rheological studies were used to analyse the materials' unusual characteristics. To generate a good filament, several process factors (extrusion temperature, screw speed, cooling conditions) were tested. Finally, a model part was printed with various settings to test printing quality using morphological analysis.

2.4.1 Recycled of Polypropylene (PP)

In 1951, scientists Paul Hogan and Robert Banks, and later Natta and Rehn from Germany and Italy, were the first to polymerize polypropylene. While both polyethylene (PE) and polypropylene (PP) are non-polar materials, PP is more durable and heat resistant than PE. Plastics can naturally degrade in the environment due to a variety of processes such as photodegradation, thermo-oxidative degradation, hydrolytic degradation, and biodegradation. However, this degradation will take 50 to 60 years. As a result, recycling is a realistic option since it helps protect natural resources. Recycling, on the other hand, reduces the amount of plastic rubbish thrown in landfills or burnt (Arrigo et al., 2022b). Effective techniques for handling plastic rubbish are especially needed in places with a higher volume of mixed debris due to population growth. The new slogan of the several state plastic pollution control boards to decrease plastic waste is "Reduce, Reuse, Recycle, and Recovery."

A variety of approaches can be used to separate the plastics. The flotation of polymers based on their physical and chemical characteristics is the core strategy employed in all approaches. Pyrolysis, solvent extraction, chemical/feedstock techniques, mechanical recycling, and solvent extraction are some of the commonly used recycling technologies (Singh et al., 2017). Virgin plastics may be recycled two to three times before degrading under heat pressure and losing life. According to research, plastic trash accounts for 8% of municipal solid rubbish collected in India, with HDPE and LDPE accounting for 67%, PP accounting for 10%, and PET accounting for 8.66%. According to data, HDPE/PP materials account for a sizable amount of waste. RPP is found in many common products, including both household and electronic goods. Mechanical recycling of polymers, according to (Vanapalli et al., 2019), gives a strong benefit for recycling without changing the molecular structure of the materials. Landfilling is the least desirable option. RPP, on the other hand, is a superb binding material with a wide range of applications in the building industry.

Enhancing the mechanical properties of recycled polypropylene (RPP) is achieved through the reinforcement of fillers such as wood, glass fibers, and various plastic blends. In this regard, researchers in the field of materials science have conducted a limited number of studies to compare the properties of recycled polymers with those of virgin polymers. In 2007, (Fernandes & Domingues, 2007), and their colleagues conducted research on both virgin and RPP. They explored the applicability of RPP in the automotive industry by testing two blends: one consisting of 30% virgin polypropylene and 70% RPP, and the other with 50% virgin polypropylene and 50% RPP. During their research, it was found that the impact resistance of recycled polypropylene (RPP) decreases to a greater extent compared to other mechanical properties such as tensile strength and elongation. As the proportion of RPP increases, the impact strength consistently decreases. In a study by

(Raj et al., 2013), the tensile and impact strength of RPP and virgin polypropylene were examined at different ratios. (Bhattacharya & Bepari, 2014) conducted a feasibility study on the use of RPP in injection molding parameters using a grey relational analysis. They observed that incorporating 5% recycled material yielded results comparable to those obtained with 100% virgin material.

According to (Hyie et al., 2019), a combination of 25% recycled polypropylene (RPP) and 75% virgin polypropylene (PP) results in a material with favorable flexural strength. In a study on recycled high-density polyethylene (RHDPE), it was found that the density, recovery percentage, and impact strength of RHDPE increased as the ratio of recycled to virgin HDPE grew, while the tensile strength remained constant. (Reis et al., 2013) investigated the strain dependency of RHDPE and discovered that the strain rate has an influence on the material's tensile strength, ductility, and elastic modulus. The tensile strength of recycled mixed plastic increases with higher temperatures. This study proposed the use of thermal stabilizers either within the material or as a coating to prevent mechanical degradation. In a study by (Shin et al., 2019), recycled polymers with hexagonal boron nitride (hBN) fillers were developed, resulting in improved properties such as higher thermal conductivity of 14 W/mK. According to (Badgayan et al., 2019) who enhanced high-density polyethylene (HDPE) with nanofillers, it is considered one of the top engineering polymers. The objective of this research is to assess the mechanical properties of recycled polypropylene (RPP) and recycled high-density polyethylene (RHDPE), including dynamic mechanical analysis. Both materials undergo a comparative investigation to evaluate their respective properties.

2.4.2 Application of Polypropylene (PP)

Various extrusion methods are employed in the production of fibers, including slit film and slit tape. Polypropylene (PP) offers several advantages such as strength, chemical resistance, stain resistance, and a low specific gravity, resulting in higher mass relative to weight. PP fibers find applications in various forms, including slit film, staple fibers, nonwoven fabrics, and monofilaments. Slit film refers to a wide web film produced through extrusion and is commonly used in carpet backings. PP is now preferred over natural jute fibers for carpet backings as jute fibers tend to degrade faster in high humidity environments. High humidity conditions lead to increased water absorption, promoting mold growth. Slit film also finds applications in twine, woven sacks for feed and fertilizers, sandbags, bulk container bags, tarpaulins, matting, soil erosion screens, and geotextiles, which help stabilize soil beds. Continuous filament fibers produced through extrusion are more common compared to slit-film fibers. Staple fibers, on the other hand, are shorter strands with lengths varying from less than an inch to just under a foot, depending on the specific application.

Figure 2.7 Monofilament extrusion process (Karian, 2003b)

Nonwoven textiles are the most common single fibre use for PP. Nonwoven textiles are classified into three types: melt-blown, spun-bonded, and thermo-bonded. Each textile has distinct characteristics and looks from the others. Melt-blown textiles, for example, are soft, but spun-bonded materials are strong. However, this sort of fabric is usually used in mixes of two types. The melt-blowing technology yields incredibly fine fibres, allowing the production of lightweight, flexible fabrics with low strength. Fabrics constructed from thin melt-blown fibres are employed in medical applications due to their ability to allow the passage of water vapour while restricting the entry of liquid water and aqueous solutions. Extruding PP through a plate with many small holes produces monofilaments, which are then quenched in a water bath to cool the textiles. By twisting bundles of monofilament together, we may create strong, moisture-resistant rope, twine, and fishing nets; these materials are ideal for use in maritime applications (Karian, 2003b).

During the injection molding process, polymer granules undergo heating until they reach a molten state. Subsequently, the molten material is injected into a closed mold, typically consisting of two sections that are securely joined to withstand the pressure of the molten material. Once inside the mold, the injected material is allowed to cool and solidify. In Figure 8, it can be observed that the mold is then separated into two halves, and the molded product is removed. Injection molds often feature intricate and complex geometries, providing designers with endless design possibilities. Thin-wall injection molding is employed for applications requiring durable packaging containers. These containers typically have a thickness of less than 25 mils, and in some cases, even thinner. Applications that use containers. The thickness is rarely greater than 25 mils and is frequently less. Water bottles and food storage containers, for example, require robust packing. Water bottles come in a range of shapes and sizes, including tall, flat, square, and round. njection molding is the preferred method for efficiently manufacturing containers with various shapes (Karian, 2003b). Common household products, including storage solutions, toys, sporting equipment, paintbrushes, and garden furniture, can be produced using this technique. PP closures, such as screw caps for bottles and jars, are prime examples of injection-molded products. Moreover, injection molding finds extensive use in the medical field, with applications ranging from disposable needles to appliances and hand tools like coffee makers, can openers, blenders, and mixers (Karian, 2003b).

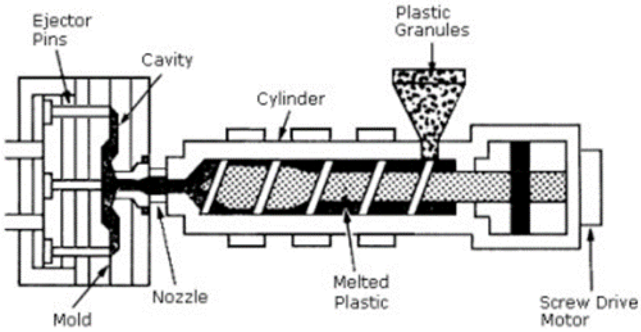

Figure 2.8 Injection moulding process

Polypropylene is a common material in cars. Battery casings and AC ducting are two examples of the first use. Because PP has the lightest thermoplastic density of 0.9 g/mL, most polymers in current automobiles are composed of PP because manufacturers seek to make their vehicles lighter overall to assist consumers save money on petrol. Furthermore, the interior trim and a few exterior elements are totally made of PP or PP compounds. All PP interior trim components, such as doors, pillars, quarter panels, and consoles, are moulded. PP became a popular material for car exterior parts due to the necessity for weight reduction. Car bumpers are built of a special PP material known as thermoplastic olefin (TPO). TPO is also used in the grills, body side claddings, rocker panels, and air dams of some cars (Karian, 2003b).

According to a 2005 survey, the bulk of polypropylene is used in textiles and injection moulding.

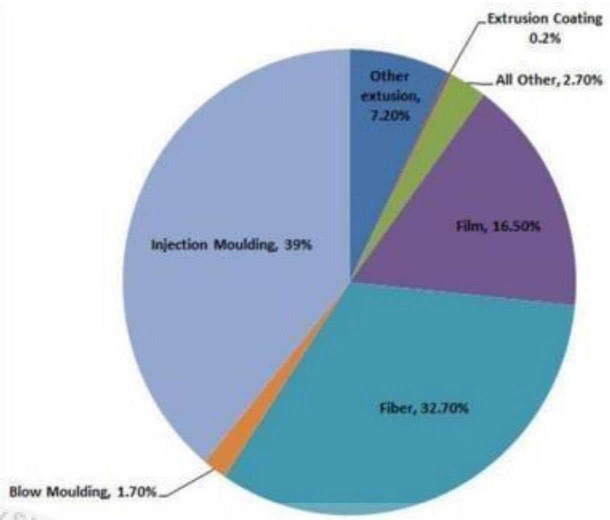

Figure 2.9 Global consumption of polypropylene by end use application

Medical or laboratory equipment, wastebaskets, cooler containers, dishes, pitchers, rugs, plastic tubs, plastic containers, pharmacy prescription bottles, coolers, stationery folders, storage boxes, light shades, loudspeaker drive units, and water filters or air conditioning-type filters are some of the other applications for polypropylene. Furthermore, PP is used in the manufacture of clothes and apparel-related goods like as diapers and sanitary products, where it has been treated to absorb water (hydrophilic) rather than naturally reject it (hydrophobic). PP is suitable for cold-weather base layers and undergarments. Another fascinating PP use is the usage of polypropylene sheet foam.

Table 2:3 Applications of Polypropylene Sheet Foam

Transportation	Injection molded plastic products; automotive, aerospace & nautical parts and accessories; glass and mirrors
Furniture	Wood office & residential furniture; metal, ceramic and glass hardware; mirrors; wood cabinets
Electronics	Computers; televisions; audio systems; radios; components and parts
Construction	Concrete curing blankets; aluminum extruded products; functional and decorative hardware; protection for buried pipelines

The PP extrusion method produces films. There is less than 10 mils of film present. The film makes use of commercial clothing, cigarettes, and food products. Films are classified into two types: cast films and oriented films (Karian, 2003b). Cast films are produced by spreading a thin layer of liquid plastic onto a surface and allowing it to cool or the solvent to evaporate, resulting in a stabilized form. These films typically have a thickness ranging from 1 to 4 mils. Softness is a crucial characteristic of cast films, and both homopolymers and random copolymers are utilized in their production. Cast films find application in the manufacturing of various products, including bags, pages, sheet protectors, tapes, and pressure-sensitive labels. Another type of film is created through the extrusion of plastic through a circular die, which is then cooled to produce bi-axially oriented polypropylene film (BOPP). BOPP films are frequently manufactured using the tenter process (film thickness ranging from 0.5 to 2.5 mils) and the tubular method (film thickness ranging from 0.2 to 22 mils). BOPP films provide excellent gloss and clarity properties. They are printed when certain supplementary surface treatment methods are used. BOPP films are mostly used in flexible packaging, primarily for snack food packaging. BOPP film has a heat-sealable layer and is resistant to moisture vapour, allowing food to stay crisp and delicious. BOPP films are also used to package a variety of sticky adhesives as well as bakery items. A type of BOPP film known as opaque film is employed in the packaging of various products including candies, chocolate bars, soaps, and labels on soft drink bottles (Karian, 2003b)

Additionally, BOPP films are utilised to store energy in electrical applications. To boost electric energy density, hydroxylated polypropylene (PP-OH) is still the best material. PPOH, which contains 4.2 mol% OH, has a dielectric constant () of 4.6. The dielectric constant of cross-linked polypropylene (x-PP) is around 3. The network topology of polypropylene reduces electrical loss and narrows breakdown distribution. As a result, the dielectric constant remains constant throughout a broad temperature range (-20 to 100 °C) and frequency range (0.1 to 1 MHz). As a dependable thin film energy storage capacitor with a high releasing energy density >7 J/cm3 under an electric field of E=600 MV/m, PPOH is used in a variety of electrical applications. Dielectric constant and energy density figures for PP-OH are two to three times better than those for BOPP.

2.4.3 Properties and Type of Polypropylene (PP)

To understand the different variants of polypropylene, one must delve deep and adopt a fresh perspective on thermoplastics categories. Commodity thermoplastics, including polyethylene, polypropylene, polystyrene, and polyvinyl chloride, can be classified into two types. These types include PP homopolymers and copolymers, rigid and plasticized PVC, as well as high, low, and linear low density PE materials. On the other hand, engineering thermoplastics are another category used in electrical and mechanical engineering applications. These polymers have the potential to replace other materials such as metals and load-bearing components. Some examples of engineering thermoplastics are acetal, nylon, polycarbonates, polysulfone, and ABS terpolymers.

Thermoplastics, on the other hand, have the advantage of softening with heat and hardening with cold, making them valuable in processes such as extrusion and injection moulding where waste materials may be recycled(Santos et al., 2023). Polypropylene comes in three stereospecific forms: atactic, which has an irregular arrangement of methyl groups, syndiotactic, which has methyl groups alternating on both sides, and cyclic.

Syndiotactic PP with a crystallinity of 30% has a melting temperature of 130°C, whereas totally isotactic PP melts at 171°C. The petrochemical industry finds polypropylene highly attractive due to its advantageous characteristics. Notably, polypropylene exhibits semi-rigidity, translucency, durability, chemical resistance, fatigue resistance, and heat resistance. Additionally, it possesses a high glass transition point, excellent resistance to bending stress, low water absorption, good electrical resistance, dimensional stability, high impact strength, and non-toxicity.. Because PP is stiffer than HDPE, biaxial orientation generates films and containers with superior optical and barrier properties. Table 3 shows properties of isotactic homo-polypropylene as an example.

Table 2:4 Properties of Isotactic Homo-polypropylene(Shubhra et al., 2013)

Property	Unit	Value
Density	g/cm^3	0.91-0.94
Tensile strength	Psi (Pound/sq. in.)	3200-5000
Water absorption, 24hr	%	0.01
Elongation	%	3-700
Softening point, T_g	°C	140-150
Melting point, T_m	°C	160-166
Thermal expansion	10-5 in./in. °C	5.8-10
Specific volume	cm^3 /Ib	30.4-30.8

Polypropylene is classified into three main types. Firstly, there is the polypropylene homopolymer (HPP), which consists solely of propylene monomers and exists as a semi-crystalline solid. Secondly, there is the random copolymer (RCP) of polypropylene, which incorporates ethylene as a co-monomer in varying amounts ranging from 1% to 8% within the PP chains. Lastly, there is the impact copolymer (ICP), which is essentially an HPP with a blended RCP phase containing 45-65% ethylene. Co-polymers refer to polymeric compounds that contain multiple types of monomers in their chains, while homo-polymers pertain to polymeric compounds with identical monomers.

Homopolymer PP (HPP) is the most widely used polypropylene substance in industry. HPP's two phases contain both crystalline and non-crystalline parts. Both atactic and isotactic PP can be found in amorphous (non-crystalline) regions. Isotactic PP may crystallise in amorphous regions and does so gradually over time. To put it another way, because there is only one propylene unit throughout the chain, most of which are isotactic, HPP has a crystalline structure. As a result, while HPP has a high level of stiffness at room temperature and a high melting point, it also has a poor level of transparency and a low impact strength.

Propylene is copolymerized with small amounts of ethylene (typically 7% or less) to produce random copolymers (RCP), which are ethylene/propylene copolymers produced in a single reactor. The regular structure of polypropylene is disrupted by ethylene, which lowers the polymer's crystalline regularity. Because of the inverse connection between ethylene concentration and crystalline thickness, as ethylene concentration rises, crystal thickness steadily decreases, decreasing the melting point. Co-polymers frequently provide higher flexibility, a lower melting point, and somewhat better impact properties. Impact copolymers (ICP) are physical mixes of HPP and RCP that include 6-15% ethylene by weight. At low temperatures, impact polymers give greater impact resistance.

The combination's rubber phase, or RCP, is designed to have an ethylene content of 40 to 65 percent. The rubber-like reinforcement considerably increases impact strength, especially at low temperatures (below 20°C). While preserving rigidity, an excellent stiffness/impact balance is obtained. The size, shape, and distribution of the rubber particles affect both the ICP product's impact resistance and the ICP product itself. Table 4 compares the advantages and disadvantages of PP in general between homopolymers and copolymers.

Table 2:5 Advantages and Disadvantages of Polypropylene

Advantages of PP		Disadvantages of PP
Homo-polymer	Copolymer	Degraded by UV (Ultraviolet)
Process ability, Good	Process ability, High	Flammable, but retarded grades available
Impact resistance, Good	Impact resistance, High	Attacked by chlorinated solvents and aromatics
Stiffness, Good	Stiffness, High	Difficult to bond
Food contact, Acceptable	Food contact, Not preferable	Several metals accelerate oxidative degrading
		Low temperature impact strength is poor

The market distribution for various types of polypropylene (PP) is generally as follows: impact copolymer (ICP) accounts for around 20-30%, random copolymer (RCP) ranges from 5% to 10%, and homopolymer (HPP) comprises approximately 65-75% of the market share. Depending on the specific application, multiple grades of PP are often available. Commercial grades offer a wide range of molecular weight distributions, co-monomer types and contents, as well as additives. Polypropylene's exceptional physical properties make it the preferred material for demanding applications like films, fibers, tapes, sheets, thermoforming, injection molding, and blow molding. Tables 5 and 6 provide information on mechanical and thermal properties of commercial polypropylene, including comparisons of thermal conductivity and recoverable energy content with similar polymers.

Table 2:6 Mechanical & Thermal Properties of Polypropylene

Property	Iomopolymer			Copolymer	
Melt flow index	3	0.7	0.2	3	0.2
Tensile strength (MPa)	34	30	29	29	25
Elongation at break (%)	350	115	175	40	240
Flexural modulus (MPa)	1310	1170	1100	1290	1030
Brittleness temp. (°C)	+15	0	0	−15	−20
Vicat softening point (°C)	154-150	148	148	148	147
Rockwell hardness (R-scale)	95	90	90	95	88.5
Impact strength (ft Ib)	10	25	34	34	42.5

Table 2:7 Thermal Conductivity & Recoverable Energy of Plastics

Polymer	Thermal conductivity (W mK-1)	Polymer	Available energy (MJ kg^{-1})
EPS*	0.035	PS	42
PUR**	0.025-0.035	PET	25
Phenolic	0.035	PVC	18
PP	0.17	PP	46
PE	0.17	PE	46

During the recycling process of polymers, there is a reduction in their mechanical and optical properties, and these optical properties are particularly important in applications involving food packaging. To address the need for sufficient opacity in recycled materials, a commercial grade of polypropylene called semi-crystalline isotactic polypropylene (iPP) has been previously investigated (De Santis & Pantani, 2013). Semi-crystalline iPP structures exhibit various crystal modifications, including monoclinic (α), trigonal (β), and orthorhombic (γ) forms. Crystallinity, shape, and surface properties all influence optical transparency in semicrystalline polymers. When transparency is compromised, there is more haze. As a result, lower crystallinity increases product clarity.

The opacity of polypropylene can be enhanced by increasing the proportion of the α phase and the average size of the spherulites, as noted in the study by (De Santis & Pantani, 2013). Another commercially available grade of polypropylene, known as modification of isotactic polypropylene (β-iPP), offers distinct properties. For instance, β-iPP exhibits significantly improved toughness and impact strength compared to α-iPP. The β-phase of polypropylene fully develops when it crystallizes under conditions of a strained melt or with the presence of a temperature gradient. However, because each grade has distinct better advantages, β-modification cannot replace or cancel its use. The studies (De Santis & Pantani, 2013) indicated that iPP grades have excellent mechanical qualities as well as appropriate optical properties.

2.5 Silane

Silanes are a type of chemical compound that contains silicon (Si) atoms (Maruyama et al., 2019). Silanes can exist as orthoesters and exhibit bifunctional or dual reactivity (Petchwattana et al., 2019). The organic functional component, such as vinyl (-CH=CH2), allyl (-CH2CH=CH2), amino (-NH2), and isocyanato (-N=C=O), can undergo polymerization with an organic matrix. In either case, alkoxy groups like methoxy (-O-CH3) and ethoxy (-O-CH2CH3) can interact with an inorganic substrate, forming covalent bonds between the matrices (Nafis et al., 2023). Silanes may or may not contain reactive groups in general, with chloride (-Cl) being an example of a reactive group (Xiang et al., 2020b). In metal pretreatment applications, a propylene link (-CH2CH2CH2-) can be formed between the silicon atom and the organic functionality in silanes.

Silanes can be monofunctional (containing just one Si atom with three alkoxy groups) or bisfunctional (containing two Si atoms with three alkoxy groups each), as in bis(3-trimethoxysilyl) propyletylenediamine. There are also trisfunctional silanes with three alkoxy groups that have three Si atoms, such as tris(3-trimethoxysilylpropyl) isocyanurate. Vinyltriethoxysilane is an example of a monofunctional silane.

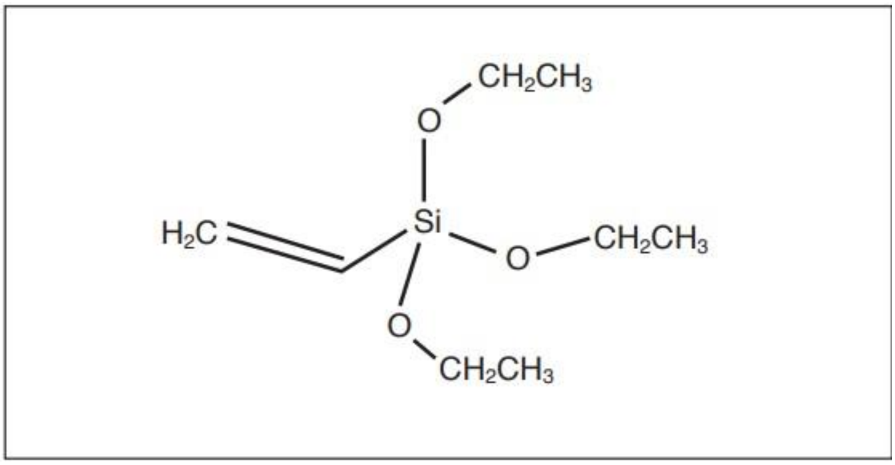

Figure 2.10 Monofunctional silane, vinyltriethoxysilane

Silanes, which are compounds that combine organic and inorganic properties, have the ability to act as mediators and enhance adhesion between different organic and inorganic materials because of their versatile reactivity. Depending on their function and the material they are applied to, they can be called primers, coupling agents, or sizes. Silanes also excel at treating the surfaces of fillers. For roughly the past four decades, silanes have found extensive use in a wide range of industrial applications. In general, organosilanes can be categorized as anionic or cationic, as well as hydrophilic or hydrophobic, as observed in studies by Clark HA et al. in 1963 and Rosen MR et al. in 1978.

2.6 Summary

In conclusion, there are many interesting and important discoveries from previous research on the silane influence on PP/GTR filament in 3D printing. This literature review's findings include information on the creation of the FDM 3D printer, the material used in 3D printing, the chemical procedures used to treat fibre, and the many types of composite filament used in 3D printing. All this information was gathered, and it will aid in the ongoing inquiry into the effect of silane on the properties of GTR/PP filament used in 3D printing. Every literature review inquiry is critical to preserving the ratio of ground tyre rubber loading to assure the success of this investigation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

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

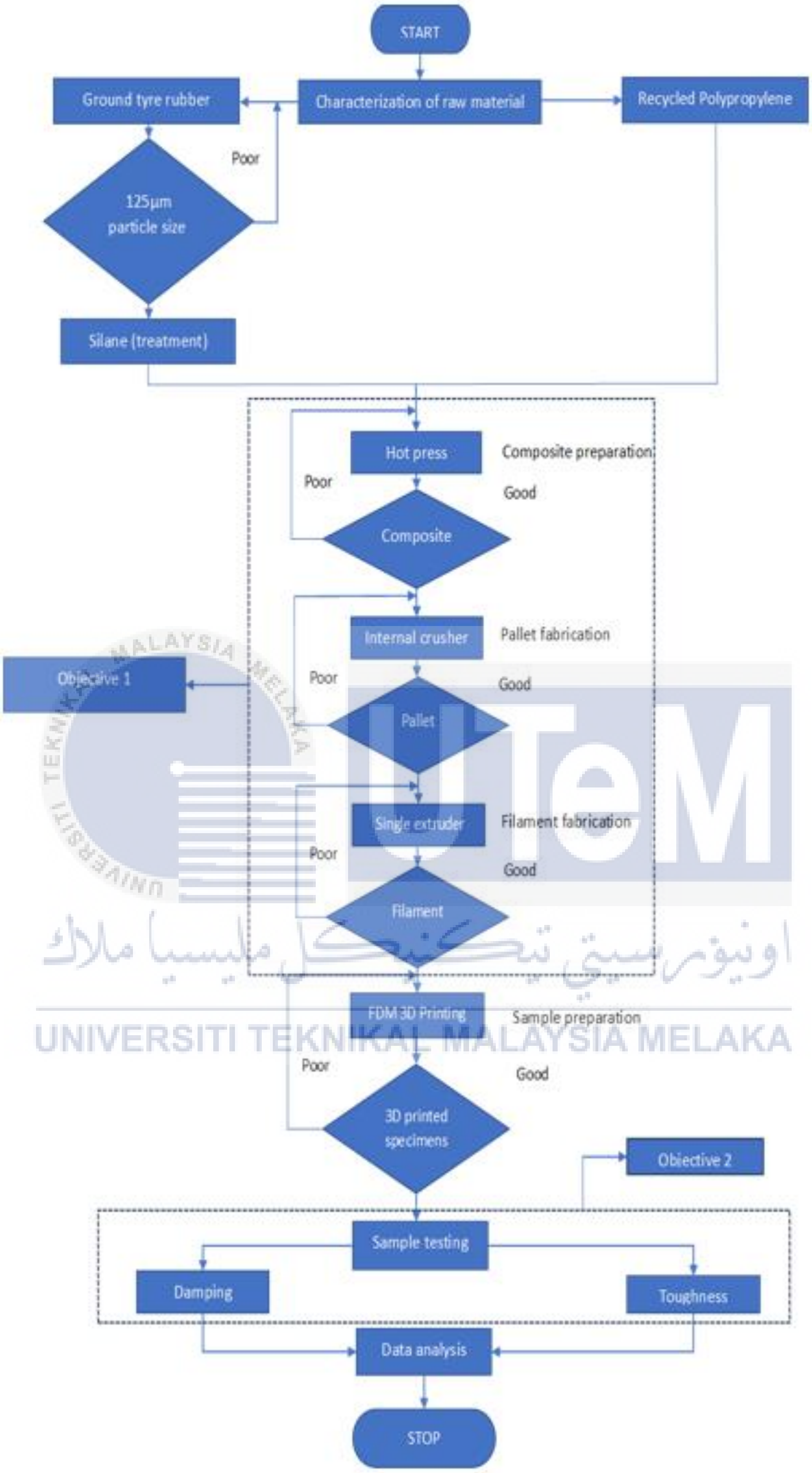

Figure 3.1 The process flow of this study

3.2 Raw Materials

In this experiment, there are 3 mains of raw materials to be combine as a composite. All this material was collected in different condition.

3.2.1 Ground Tyre Rubber (GTR)

The recycled ground tyre rubber that have been used for this this study with 125 µm particle sizes.

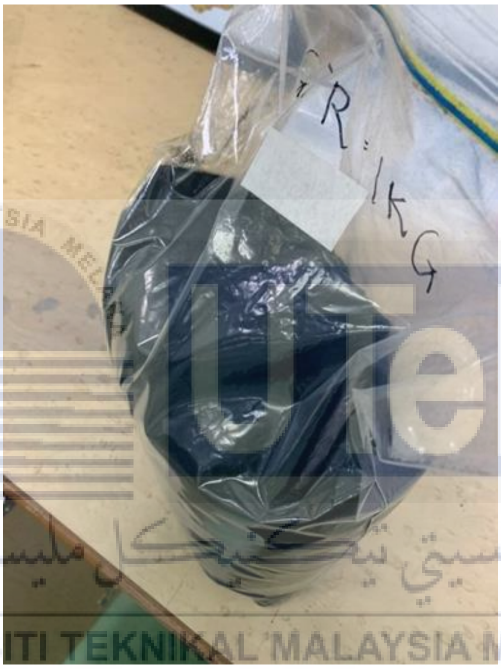

Figure 3.2 Recycle Ground Tyre Rubber

3.2.2 Polypropylene (PP)

Lotte Chemical supplied granulated pellets of recycled PP with a melt flow rate of 33.8 g/10 min (with 5000 g weight at 230 °C) for the experimental examination (figure 3.2). Table 3.1 compiles the vendor requirements for the items utilised in the project.

Figure 3.3 Granulated pellets of recycled PP

Table 3:1 Specifications of filament materials (Kristiawan et al., 2021)

Material	Density (g/cm3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Pellet diameter
Recycled PP	0.574	22.5	1.24	5.04 mm

3.2.3 Silane

Figure 3.4 uses the amino-silane (3-Aminopropyl) tiethoxysilane (APTES), which is mostly utilised as a dispersant. For bio-conjugation, APTES adds an amino group to the functional silane. SIGMA-ALDRICH (M) SDN BHD promoted.

Figure 3.4 (3-Aminopropyl) triethoxysilane

3.3 Preparation of Raw Material

3.3.1 Preparation of Ground Tyre Rubber (GTR)

The ground tyre rubber (GTR) used for this study was sieved with a sieving machine referring to figure 3.5. The ground tyre rubber with particle size 120 meshes was used for this study.

Figure 3.5 Sieving Machine

3.3.2 Preparation for recycle polypropylene

The recycle polypropylene (PP) was prepare by lab in pellet condition. The total that used is refer by the composite loading which is 500g per sample. This (rPP) were order from supplier for this project purpose and it at good condition to conduct this experiment. Figure 3.6 show the sample of the material.

Figure 3.6 Recycled Polypropylene (PP)

3.4 Ground Rubber Tyre (GTR) Treatment

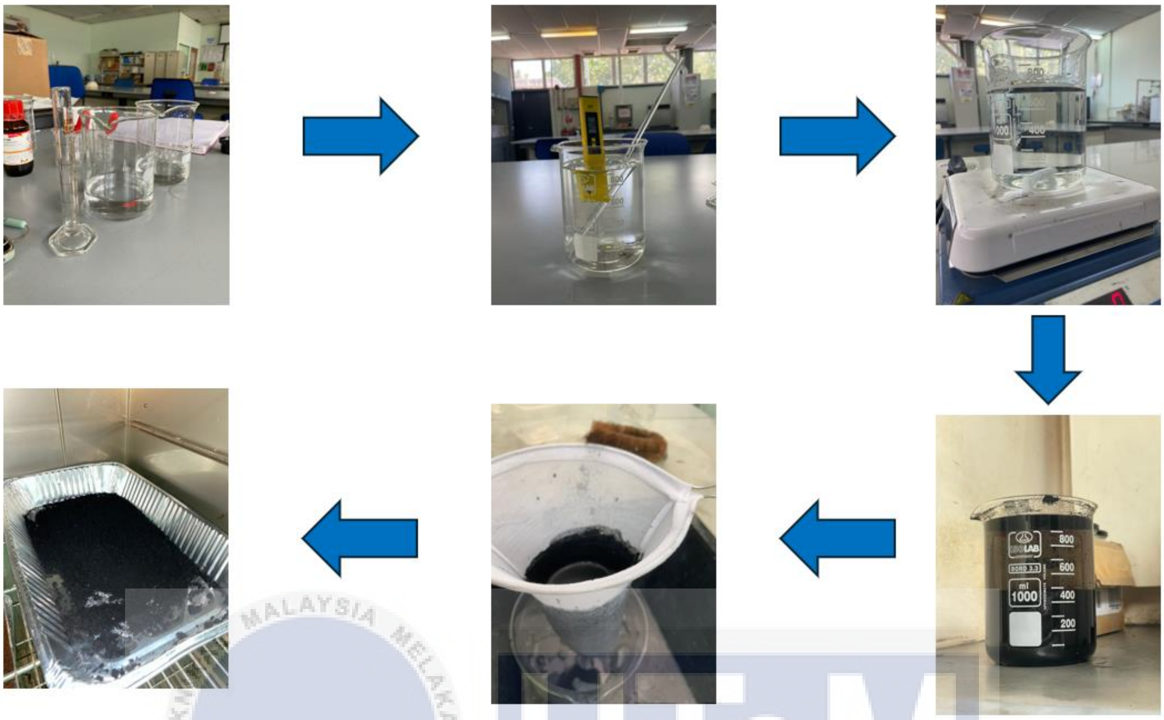

Figure 3.7 Silane treatement of GTR

The ground tyre rubbers were extracted using silane solvent that are mixed with methanol and distilled water like figure 3.7 to remove the foreign matter. The weight % of the rubber dissolved for hydrolysis in a combination of methanol and distilled water was employed for silane treatment. The solution's pH was adjusted to 3.5, and it was agitated constantly for 30 minutes. The ground tyre rubber fibre will be submerged in a silane solution for 3 hours before being dry in 60 °C oven for 72 hours. To totally eradicate any moisture effect from the ground tyre rubber (GTR), they were properly cleaned with distilled water and then oven dried (Xiang et al., 2020a). Figure 3.7 show the combination of two type of chemical silane and methanol.

Figure 3.8 Combination of two type of chemical silane(left) and methanol(right)

Figure 3.9 Distilled Water

Figure 3.10 Acetic Acids

3.5 Sieving Process of ground tyre rubber

The sieve technique is used to determine the particle size of ground tyre rubber. This experiment used ground tyre rubber with a particle size of 125 μm or smaller. Scanning electron microscopy (SEM) was used to analyse the morphology of the ground tyre rubber particle (SEM).

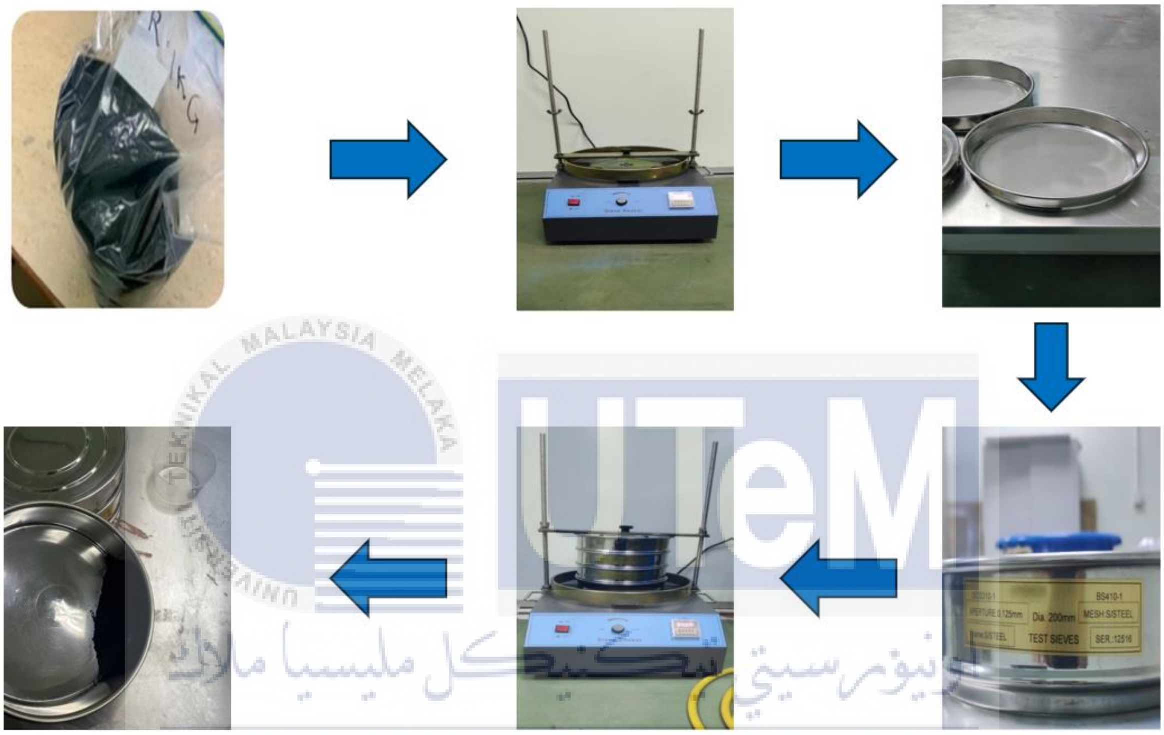

Figure 3.11 Sieving process of GTR fibre

The process of sieving ground tyre rubber fibres started by using purchased fibres. Then sieve machine need to be prepared in proper and neat position. Five size of sieve which were 0.5mm, 0.4mm, 0.3mm, 0.2mm and 0.125mm arranged according to the size to obtain exact size of ground tyre rubber particles. In addition, 0.125mm sieve were used as last sieve in the arrangement. Next, the sieves were put on and the machine turned on for 30 minutes. This process repeated until appropriate amount of ground tyre rubber obtained. Finally, the 0.125mm particle size of ground tyre rubber will be prepare for silane treatment process.

3.6 Preparation of Polypropylene/Ground Tyre Rubber composite

Ground tyre rubber at varying content (1% wt., 3% wt. and 5% wt.) was thoroughly being press by using hot press with the recycle polypropylene. It was made in a lab at faculty of technology manufacturing department. The order of addition was the following, first the recycle polypropylene, then the ground tyre rubber.

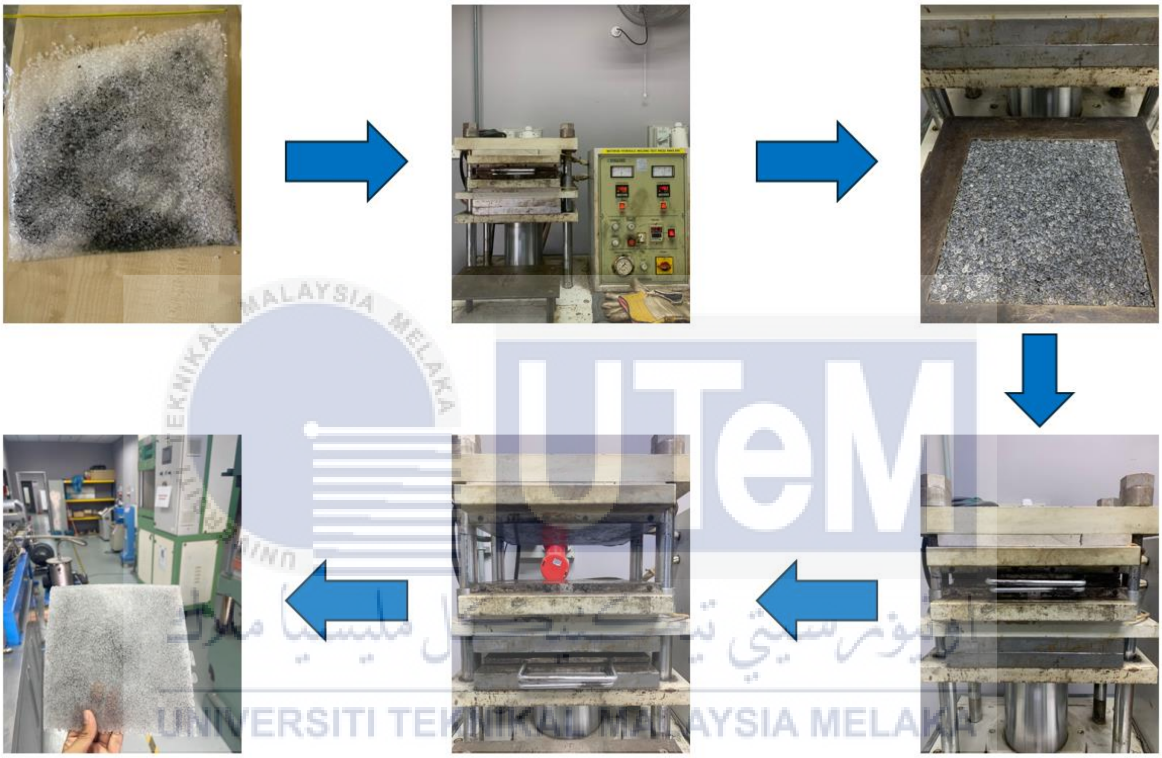

Figure 3.12 Mixing process of rPP and GTR

First, prepared the recycled PP with the value of weight needed. Then put recycled PP and GTR together in one packaging beg based on calculated ratio weight. Shaked the packaging bag for couple minutes in all direction to make it mixed well when go into the hot press. Next, prepared the mold for the hot press process and two stainless steel plate. Put the composites in the mold. Spread the composite all over the mold. Closed both side top and bottom with plate to make the composite cannot get out. Placed the mold into the hotpress. Wore glove to prevent injury while placing the mold. After that, setup the hot press with the following value. First process will be the hot process to make the composite mix well at 185˚C (Friedrich, 2021). Second process will be run after finishing the first process which is cooling press. Function is to make the mixed composite in a hard shape. Finally, bring out the mold and take the mixed composite to the pellet crush process.

The sum of the ground tyre rubber and recycled polypropylene (PP) was used as a reference to measure the contents, as seen in table 3.2

Table 3:2 Ratio weight

Sample	Ground tyre rubber fiber	Recycled Polypropylene
1	1% = 9.52g	790.48g
2	2% = 28.56g	771.44g
3	3% = 47.46g	752.64g

Figure 3.13 Hot press machine

3.7 Pellet Fabrication

The composite that has been cool then will go to crush process to make it as pellet form. This process will be repeated 2 or 3 times to make sure the size of the pellet is in (what range of size). Figure 3.11 show the type of crusher machine and figure 3.12 show the example of pellet that will produce.

Figure 3.14 Cheso Crusher Machine

Figure 3.15 Pellet form

3.8 Preparation of filament

3.8.1 Extrusion process

The filament was made using a single extruder, as depicted in the figure 3.13 displayed below.

Figure 3.16 Single Extruder

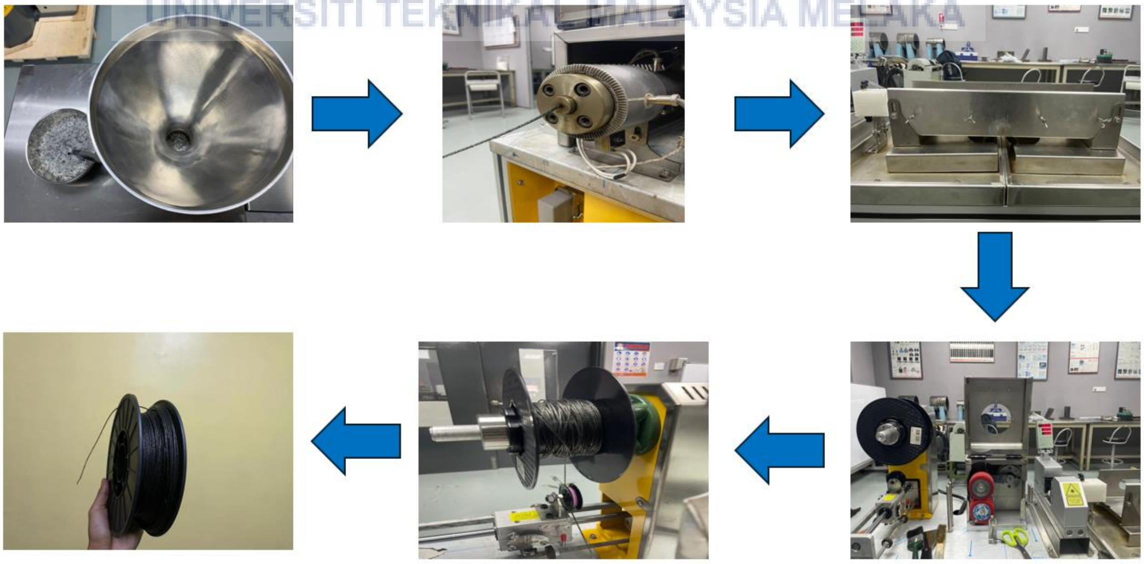

Figure 3.17 Process of filament extrusion

To extrude the filament of the composite material, a single screw extruder with a die nozzle of 1.75 mm was employed, and the material was delivered into three heating zones. The initial preheating temperatures for the barrel and die nozzle zones were determined to be 180°C and 200°C, respectively. The composite material must be heated before use within the hopper. Furthermore, at a forward barrel screw rotation speed of (240-245 rpm), molten material was being driven upwards to its die nozzle. To pre-heat the pellets/mixture, the feed cooling zone was likewise set to a cold temperature. For each feeding interval, a certain weight of composite material was fed into the barrel after the specified temperatures for the manufacture of composite filaments were reached. The hot extruded filament go through a natural cooling process that uses ambient temperature at a speed of 18 -20 rpm. The extruded filament needed to be wound into the spooler, where it was loaded onto the rollers for filament storage and spooled at a speed of 300 mm/s (Fig. 3.17) (Barczewski et al., 2020).

Figure 3.18 The filament storage roller

Table 3:3 The filament extrusion processing parameter

Categories	Values
	(r-RubPPc) Filament
Barrel Temp (˚C)	200
Die/nozzle Temp (˚C)	180
Screw extrusion speed (rpm)	240-245
Filament pulling roller speed (rpm)	10-12
Filament winding roller speed (rpm)	16-21

3.9 Preparation of specimen

An FDM 3D printing equipment was used to create the filaments (of whichever sort). Ultimaker Cura 4.8.0 open-source software was used to build (.stl) files for printing. Solidworks 2021 was used to create the CAD model of standard impact test specimen (ASTM D256, ISO 180) and vibration test specimen Six composite filaments were utilised to construct vibration and impact test samples. Nozzle diameters of 0.4 mm and 0.8 mm were employed while printing with r-RubPPc filaments. A bed temperature of 85 °C and a nozzle temperature of 180-220 °C are required for printing filament. After heating the filament to melting point and feeding it through a 1mm needle at a rate of 20m/min, the layer is 0.30mm thick. The initial layer of the 3D-printed specimen had difficulty adhering to the printer build plate. Commercially accessible PP filaments are typically formed of a mix or composite to reduce warping. When employing Pritt adhesive and Kapton tape, the initial print layer failed to adhere to the printer bed, resulting in an early conclusion to the printing process (Kristiawan et al., 2021).

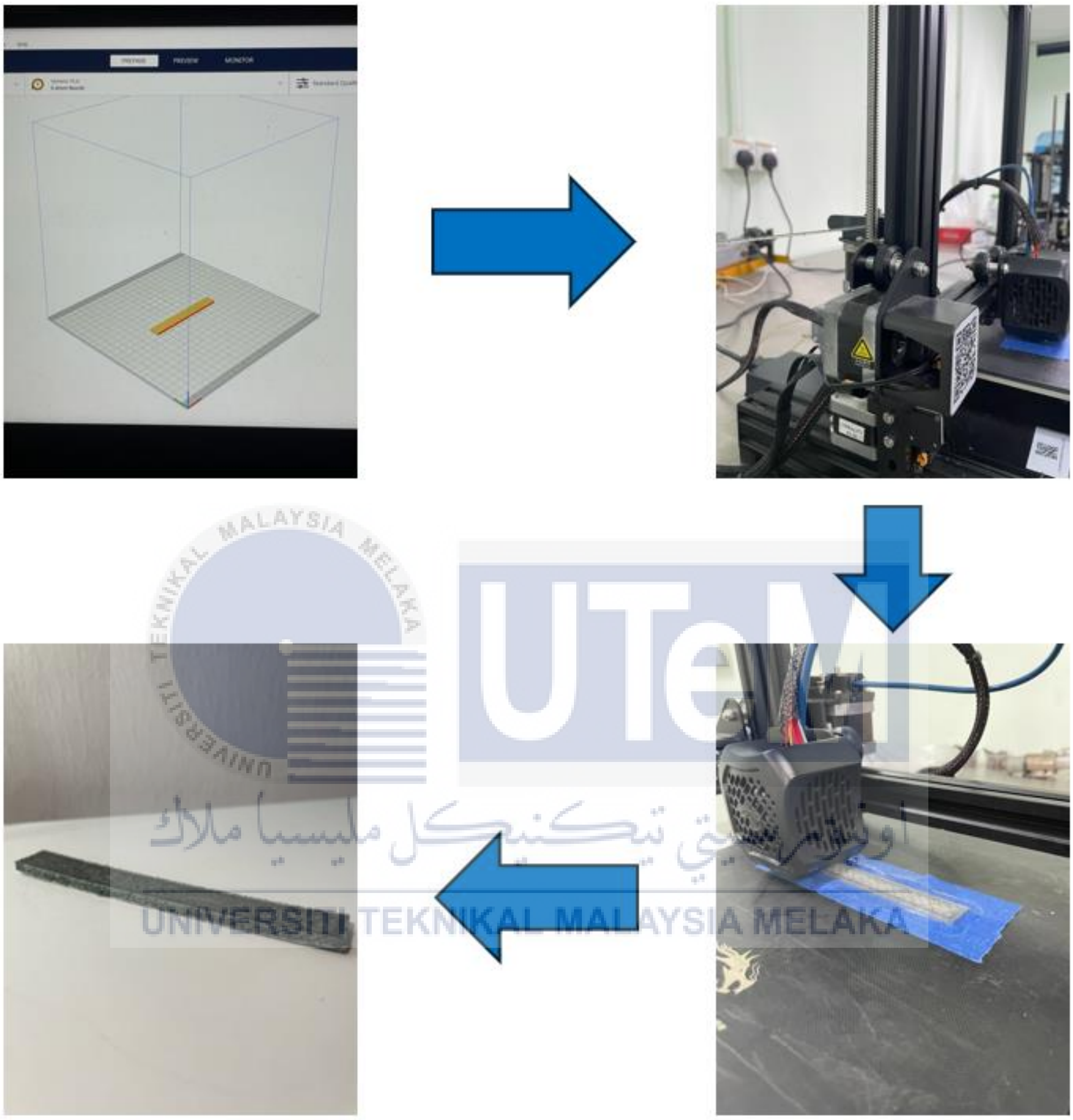

Figure 3.19 Process of specimen 3D printing

Table 3:4 Printing setting

Parameters	Values
	(r-RubPPc) Filament
Temperature of printing (˚C)	220
Initial layer temperature (˚C)	220
Build plate temperature (˚C)	85
Build plate temperature, initial layer (˚C)	85
Infill pattern	Grid
Infill density (%)	80
The height of the layer (mm)	0.2
Top and bottom layer (layers)	0.8
The print speed (mm/s)	100
Build plate adhesion type	Brim
Support placement	Touching buildplate
Support overhang angle (˚C)	0

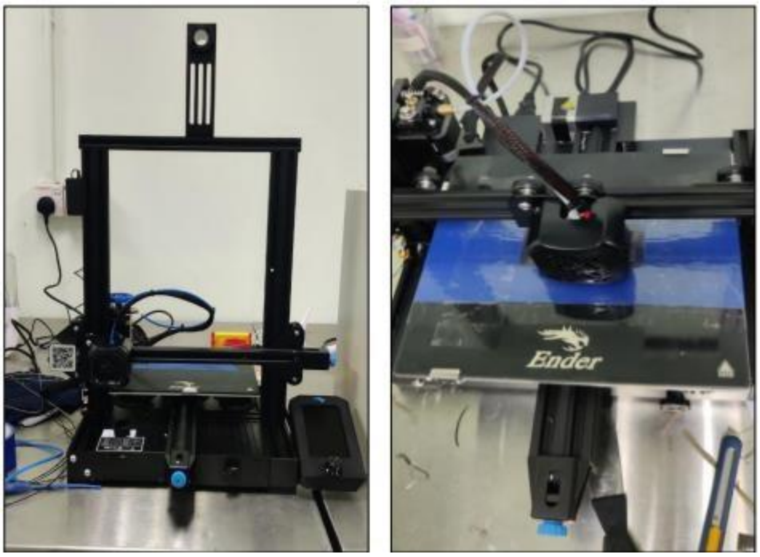

Figure 3.20 FDM 3D printing

3.10 Characterization of specimen

3.10.1 Impact test

Impact testing was performed using a Charpy impact tester to determine the impact toughness and notch sensitivity of materials (Abidin et al., 2019). Figure 3.21 shows the dimension of impact specimen designed by using SolidWorks followed the ASTM D256. Figure 3.22 shows six samples were tested: 1% untreated GTR, 1% silane-treated GTR, 3% untreated GTR, 3% silane-treated GTR, 5/% untreated GTR, AND 5% silane-treated GTR. Impact properties were determined in accordance with ASTM D256 utilising a Charpy impact tester.

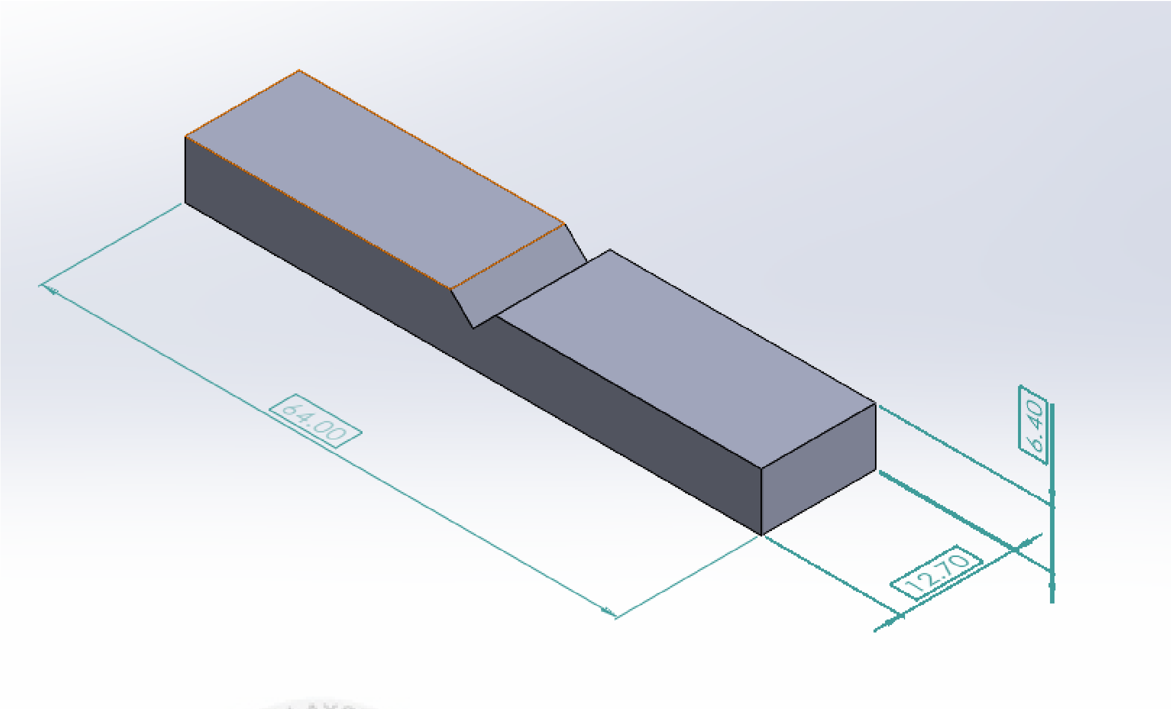

Figure 3.21 Dimension of r-RubPPc impact specimen

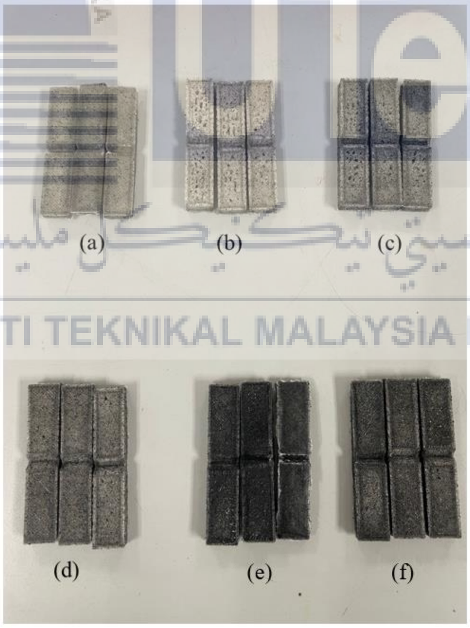

Figure 3.22 Samples of Charpy impact test : (a) 1% untreated GTR, (b) 1% silane-treated GTR, (c) 3% untreated GTR, (d) 3% silane-treated GTR, (e) 5% untreated GTR, (f) 5% silane-treated GTR

The impact test were started by placed a test specimen horizontally on the supports and anvils so that it is hit on the face opposite the notch. The notch should be centered between the anvils. Raise the pendulum and secure it in the release mechanism, then reset the indicating mechanism. Allow the pendulum's striking edge to strike the specimen before releasing it. Take note of the breaking energy indicated.

Figure 3.23 Charpy impact tester

The Charpy impact tester that was used is shown in Figure 3.23. Where the specimen was placed in between the anvils is visible. The fracture specimens are shown in Figure 3.24 following their direct impact by the impact test pendulum.

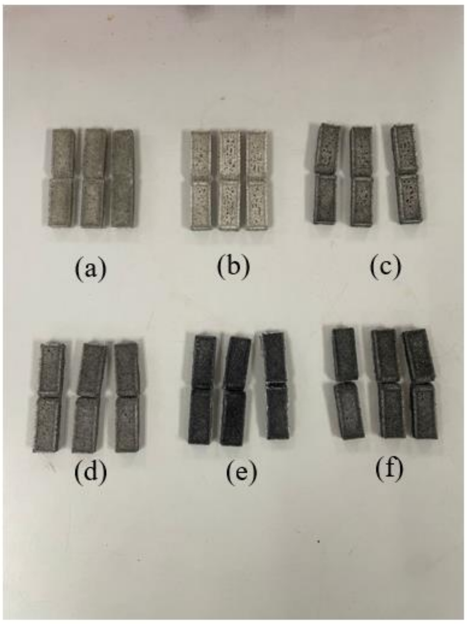

Figure 3.24 Fracture specimens : (a) 1% untreated GTR, (b) 1% silane-treated GTR, (c) 3% untreated GTR, (d) 3% silane-treated GTR, (e) 5% untreated GTR, (f) 5% silane-treated GTR

3.10.2 Vibration test

Vibration characterisation tests and experimental modal analysis were performed using the experimental setup indicated in Fig. 3.25. The gadget consists of a accelerometer sensor, a data logger (Quattro Data Physics), and a computer. SolidWorks software have been used to design the vibration testing specimen and Figure 3.24 showed the dimension of specimen in the software. The 3D printed specimen was clamped in a transverse position, as shown in Figure 3.25. These experiments entailed vibrating a 3D-printed specimen and measuring the movement of the tip. The accelerometer sensor measured the ringdown signal, or time-series magnitude of the specimen tip, and sent the data to the data logger. The accelerometer sensor was directly attached to the specimen. The data logger finally transmitted the time-series displacement data to the computer. To estimate the damping ratio,, the acquired ringdown signal was calculated by using equation below :

$$\zeta = \frac{1}{2\pi N}\ ln(\frac{\mathrm{X0}}{\mathrm{XN}})$$

where X_N is the amplitude of *N*-th peak after X_0.

Additionally, the collected time-series data were to determine the the quality factor, Q, and the loss factor, η .

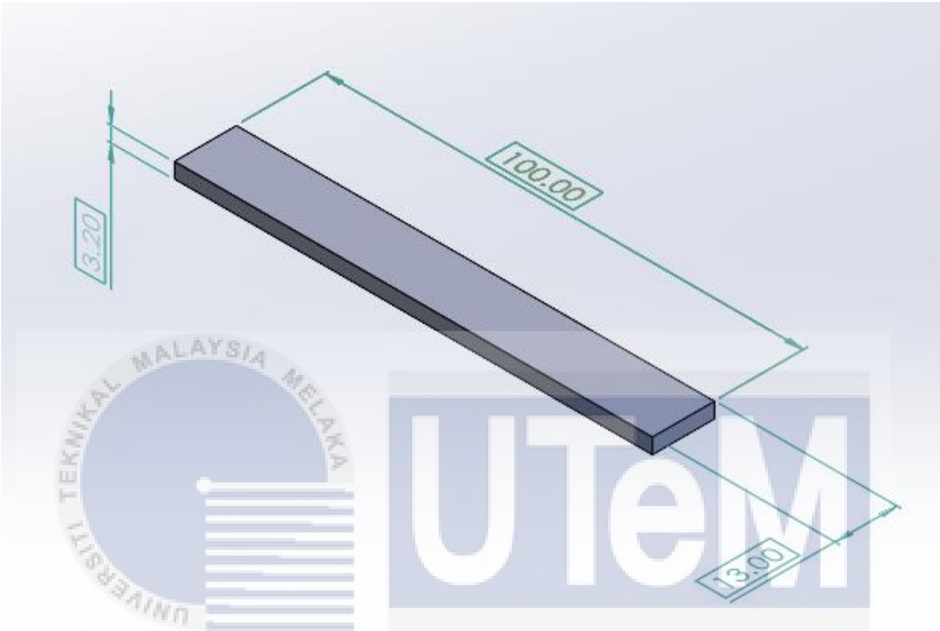

Figure 3.25 Dimension of r-RubPPc vibration specimen

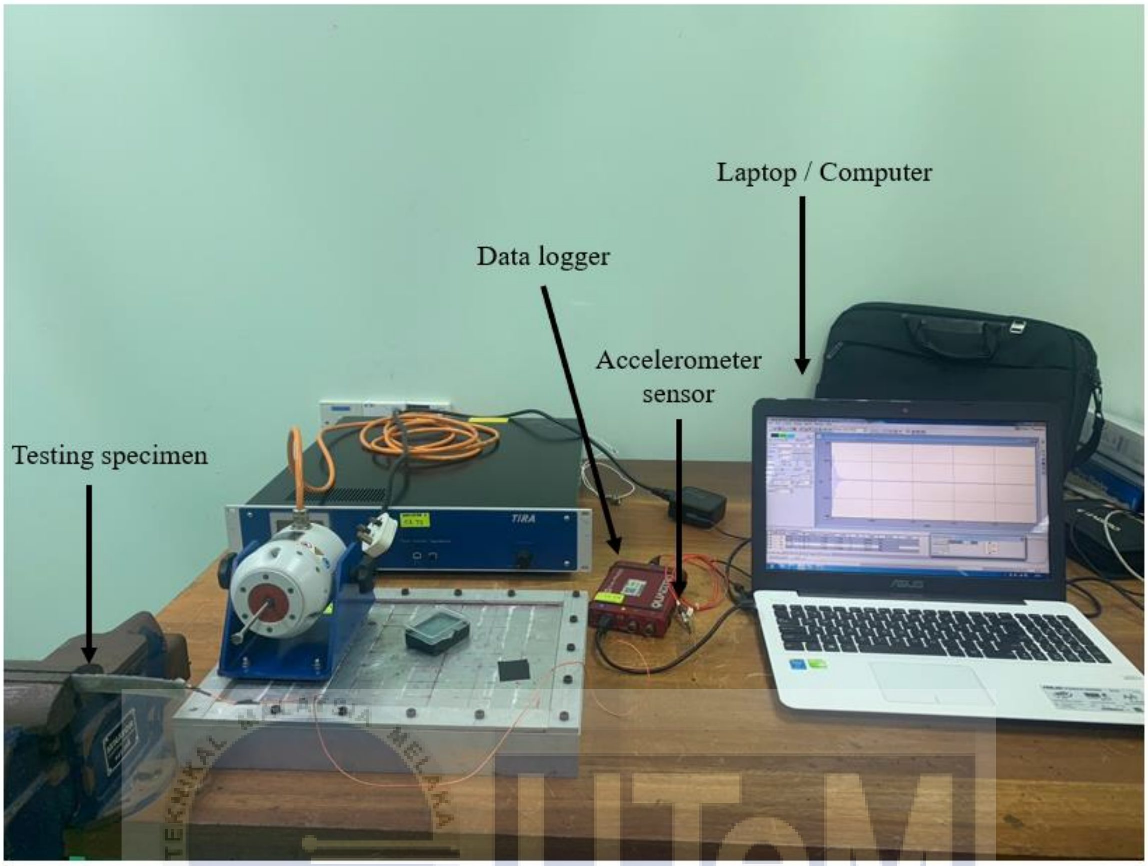

Figure 3.26 Experimental setup used for modal analysis and vibration characterization of the 3D printed GTR-PP composites

3.10.3 Water Absorption

The composite specimens utilized to investigate water absorption characteristics were similar to the filaments as indicated in figure 4.3(a), the water absorption test started with the drying of r-RubbPPc filaments with various percentages of GTR fiber loading in an oven at 110 C for 24 hours. The weight of the dried filament was measured, as indicated in figures 4.3(b) and 4.3(c), prior to its 24-hour immersion in distilled water at room temperature. After drying off the damp filament surface, the specimens were weighed again. The water uptake of composites was calculated using equation:

$$\text{Water Absorption (\%)} = \frac{W_{sat} - W_{dry}}{W_{dry}} \times 100$$

where W_{sat} (g) is weight of water saturated and, W_{dry} (g) is the weight of dried specimen (Leite et al., 2018).

(a) (b) (c) (d)

Figure 3.27 Process water absorption test of r-RubPPc

3.10.4 Morphology of r-RubPPc filament

The morphological microstructure of r-RubPPC filament was captured using a digital microscope. Figure 3.28 depicts the type of microscope used for these testing.

Figure 3.28 Dino-Lite digital microscope

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The expected results of tensile and modulus elasticity, vibration characterisation, ground tyre rubber characterisation, filament characterization, and specimen characterization are investigated in this chapter. Figure 4.1 quickly outline the entire fabrication procedure of r-RubPPc filaments and 3D printed product.

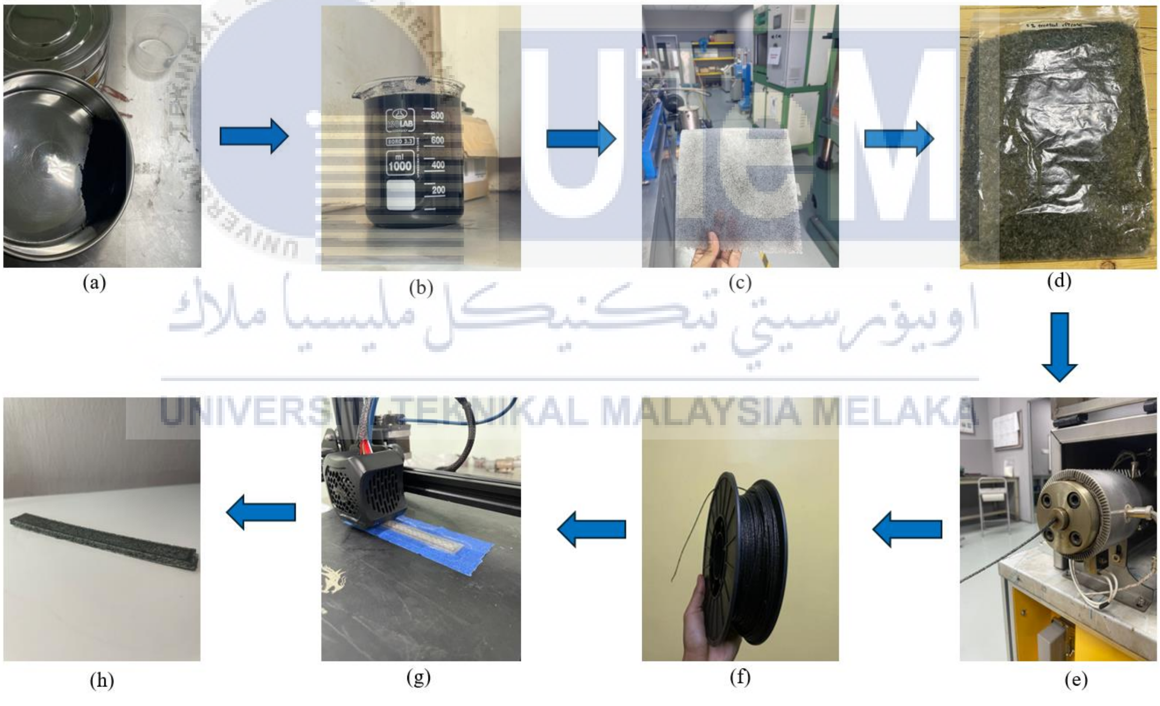

Figure 4.1 Fabrication process of r-RubPPc filament and 3D printed product (a) sieving fiber, (b) silane treatment, (c) hotpress of mixture, (d) crusher, (e) filament extrusion, (f) r-RubPPc filament, (g) 3D printing process and (h) 3D printed product

4.2 Fabrication of r-RubPPc Filament

The r-RubPPc filament was created utilizing USEON's single screw extrusion. Figure 4.1 depicts the development of filament using a single screw extruder. Figure 4.2 depicts the following manufactured filaments: recycled PP, 1% untreated GTR, 1% silane-treated GTR, 3% untreated GTR, 3% silane-treated GTR, 5% untreated GTR, 5% silane-treated GTR. All filaments were extruded at nozzle temperatures ranging from 180 C to 200 C, with filament pulley speeds varying from 10 rpm to 12 rpm. The nozzle temperature and pulley speed were adjusted to create a filament diameter of 1.75mm (Barczewski et al., 2020).

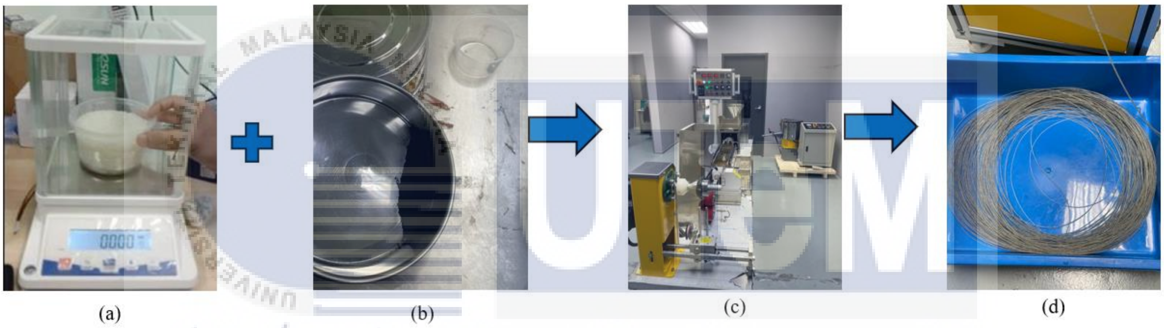

Figure 4.2 Fabrication process of r-RubPPc filament: (a) Recycled PP (b) GTR fiber (c) Single screw extruder (d) r-RubPPc filament

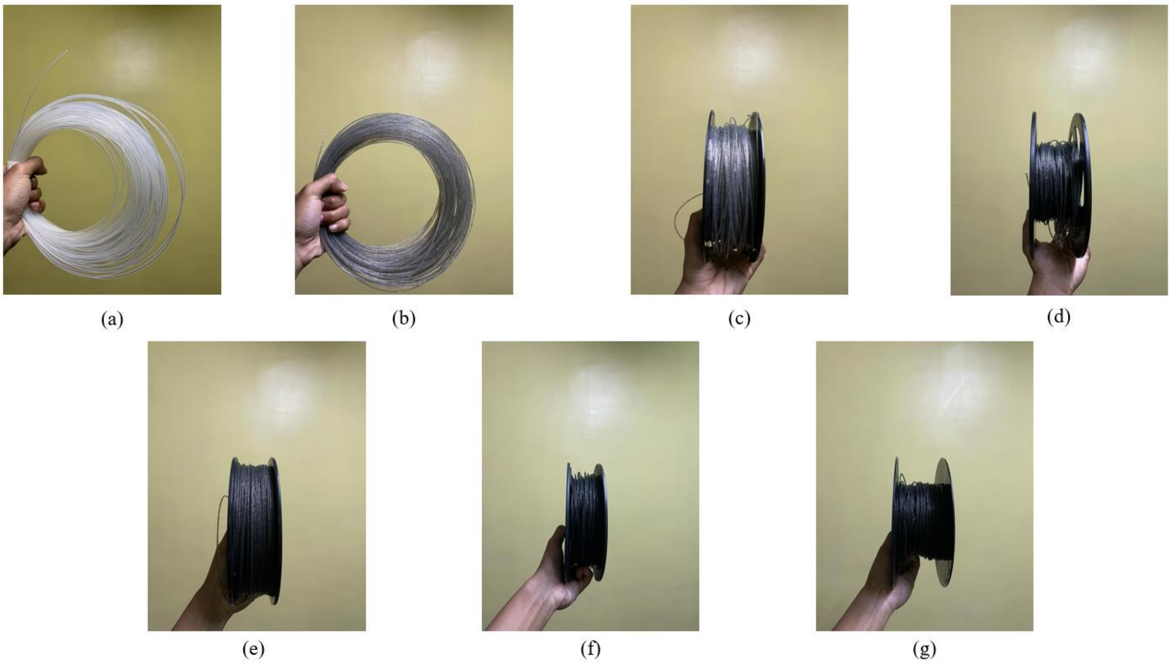

Figure 4.3 r-RubPPc filament : (a) recycled PP, (b) 1% untreated GTR, (c) 1% silane-treated GTR, (d) 3% untreated GTR, (e) 3% silane-treated GTR, (f) 5% untreated GTR, (g) 5% silane-treated GTR

4.3 Fabrication of 3D printed r-RubPPc Product

The 3D printed r-RubPPc product was fabricated utilizing Ender-3 3D printer. Figure 4.4 depicts the development of 3D printed product by using 3D printer machine. The fabrication started with using a slicer software which was Ultimaker Cura . Nozzle diameters of 0.4 mm and 0.8 mm were employed while printing with r-RubPPc filaments. A bed temperature of 85 °C and a nozzle temperature of 180-220 °C are required for printing filament. After heating the filament to melting point and feeding it through a 1mm needle at a rate of 20m/min, the layer is 0.30mm thick. The initial layer of the 3D-printed specimen had difficulty adhering to the printer build plate (Kristiawan et al., 2021).

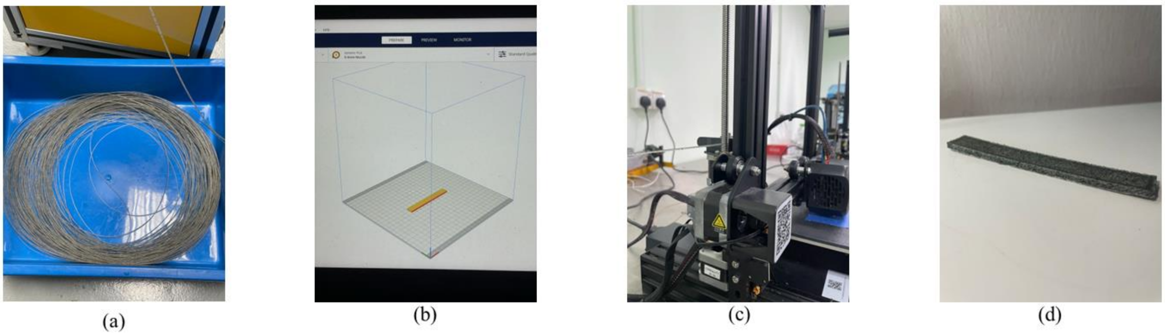

Figure 4.4 Fabrication process of 3D printed r-RubPPc product: (a) r-RubPPc filament (b) Ultimaker Cura software (c) 3D printer machine (d) 3D printed product

4.4 Characterization of r-RubPPc filament.

4.4.1 Physical properties of r-RubPPc Filament

Dino-Lite digital microscope has been used to capture the images of filament surface. Figure 4.5 shows a microscopic image of r-RubPPC filaments. Filaments exhibit a different black colour tone for each r-RubPPc filament. Better filament strength resulted from silane-created layers on the fibre surface that promoted increased fiber density and generated on the rubber surface that improved adhesion with recycled PP (Xiang et al., 2020a). Because there are voids in the sample, the density of the filament is reduced. The primary sources of development are moisture absorption during storage and air trapping during extrusion. Poor strength was the outcome of weak interfacial adhesion between the fiber and the matrix caused by voids and gaps. This is demonstrated by the fact that more GTR fibers with improved matrix interface adhesion are present when silane treatment is applied (Xiang et al., 2020a).

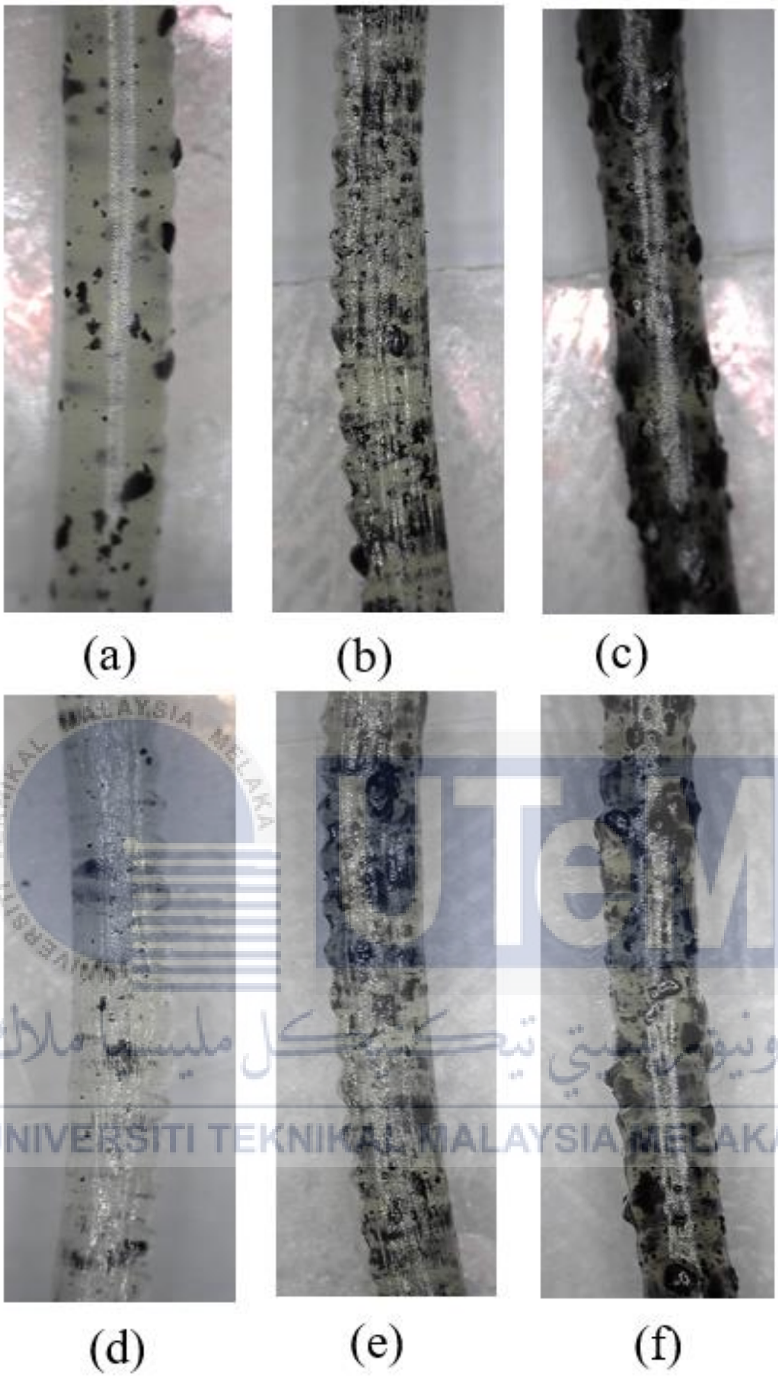

Figure 4.5 Microscopic image of filament for 40x magnification (a) 1% untreated GTR, (b) 3% untreated GTR, (c) 5% untreated GTR, (d) 1% silane-treated GTR, (e) 3% silane-treated GTR, (f) 5% silane-treated GTR

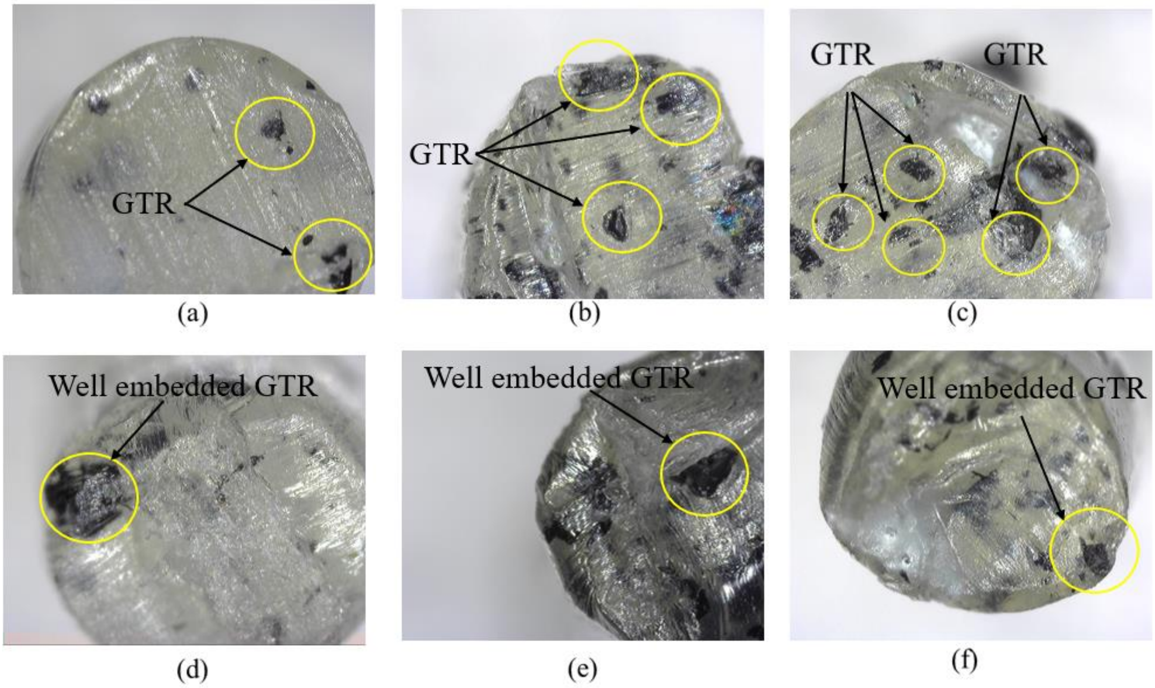

Figure 4.6 Surface image of r-RubPPc filament for 230x magnification under microscope (a) 1% untreated GTR, (b) 3% untreated GTR, (c) 5% untreated GTR, (d) 1% silane-treated GTR, (e) 3% silane-treated GTR, (f) 5% silane-treated GTR

Figure 4.6 shows the surface image of r-RubPPc filaments which demonstrates that GTR treated with 2% silane were superior in terms of well embedded GTR fibres in PP matrix. These outcomes are consistent with the impact test findings, which show that 3% of GTR specimens that have been silane-treated are in ideal condition and may be combined to PP to create filament and 3D-printed specimens.

4.4.2 Water abrorption test of r-RubPPc filament

Durability was significantly impacted by the water absorption behavior of r-RubPPc both with and without silane; in the presence of silane, water absorption rates (WAR) for 3% of GTR fiber loading filament decreased noticeably as shown in figure 4.3. The composites without presence of silane exhibited considerably higher WAR values than the other composite samples which is 25%. The decreased in water absorption of the compatibilized r-RubPPc was because silane improved the GTR-matrix interfacial adhesion (Maruyama et al., 2019). Adding silane could prevent the water penetrate between the GTR-matrix interface. In addition, the WAR greatly decreased upon further increasing the percentage of fiber loading at 3% of GTR. The presence of 2% silane acted as compatibilizer which improved the interfacial adhesion for 3% of GTR fiber in r-RubPPc filament. The 3% fiber loading of GTR toward R-WoPPc give the less water absorption rate that improve the mechanical properties.

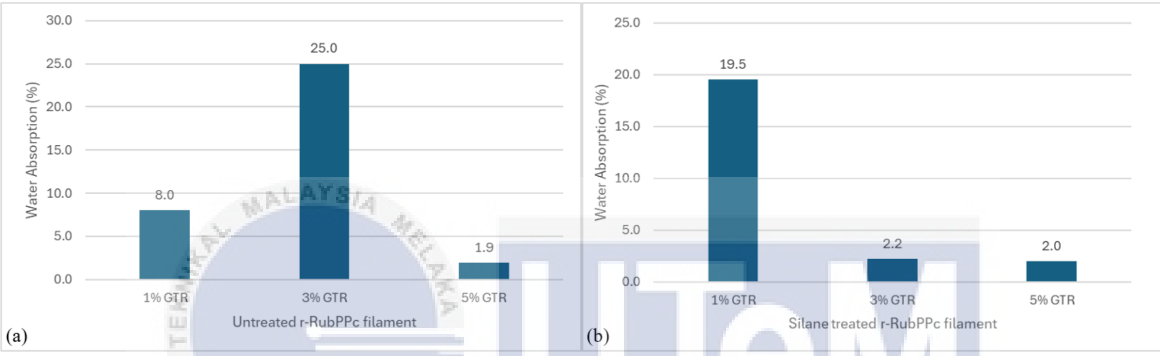

Figure 4.7 Water aborption of r-RubPPc filament : (a) Untreated r-RubPPc filament, (b) Silane treated r-RubPPc filament

Water absorption of r-RubPPc composites with silane play an important role in the determination of composite applications. Figure 4.4 depicts the water absorption results of silane treated r-RubPPc filaments at different percentage of GTR fiber loading. The water absorption was increased with the increased of GTR fiber loading. The water absorption of 1% GTR was found to be higher than that of the 1% and 5%. The difference between the absorption weight of r-RubPPc with silane indicates the presence of voids. The effects of silane treatment on void situation of r-RubPPc value are shown in Fig 4.7. (Xiang et al., 2020a) also stated that it is also worth noting that the MGTR still retained rough surfaces after surface modification, and the specific surface area was increased by the thick silane coating, implying that it could absorb more relative light components such as oil and resin.

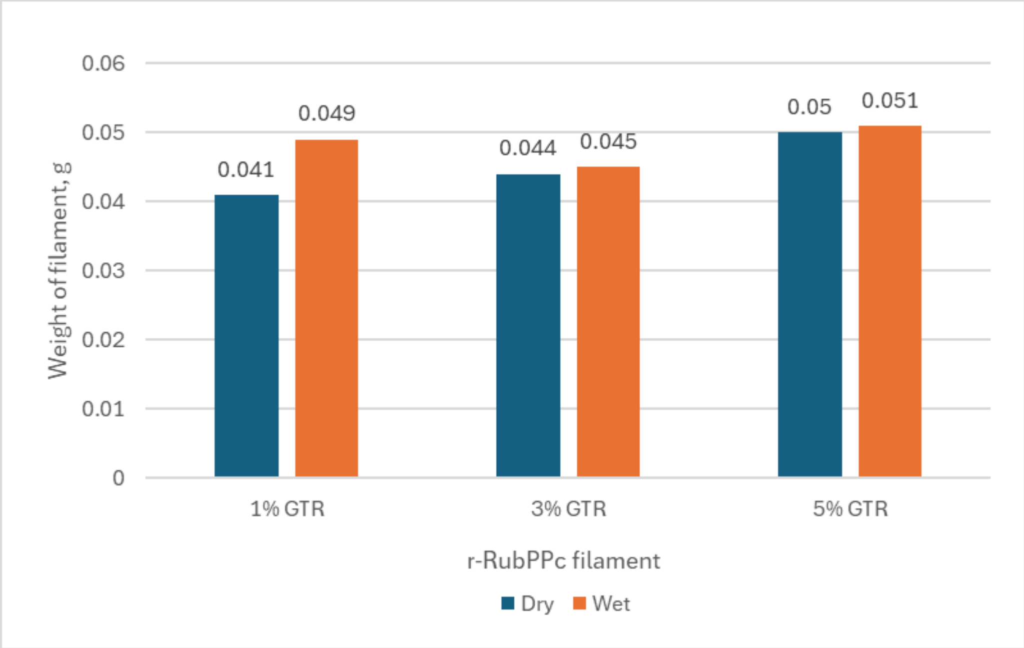

Figure 4.8 The weight of silane treated r-RubPPc filament

4.5 Mechanical properties of r-RubPPc 3D pinted product

4.5.1 Toughness properties

The capacity of a material to absorb energy and undergo plastic deformation prior to breaking is referred to as its toughness properties. An impact test is a frequently employed technique to evaluate a material's toughness by exposing it to an abrupt force or impact. Figure 4.9 depicts the results of mechanical characteristics testing utilizing impact test methods. (Mujal-Rosas et al., 2011) investigated these properties in the PP matrix for various concentrations and GTR particle sizes. However, the behavior of the composites differs depending on the amount of GTR in the matrix.

GTR dispersed in the copolymer matrix also changes the impact strength of the obtained materials. The 1% fiber loading of GTR for untreated specimen and silane-treated specimen broke due to the impact of the pendulum, and the recorded impact strength value was approximately 3.43J and 3.73J respectively. By adding silane to the composite, the absorbed energy increased as shown at 1% fiber loading of GTR. Silane treatment produced stronger interface adhesion state between fiber and matrix (Xiang et al., 2020a).

Figure 4.9 Energy absorption for different fiber loading of GTR in r-RubPPc specimen

As shown in Figure 4.9, the increasing of rubber content at 3% wt. and 5% wt. has increased the same quantity of absorbed energy to 3.92 J. During the impact test, samples with more GTR fiber showed greater levels of energy absorption. The material's dominance of the elastic phase, which is characterized by a decreasing tensile modulus with increasing GTR concentration, is what causes this result. Moreover, a rise in the value of the elongation at break is connected with the higher impact strength of compounds containing up to 5% of GTR fiber loading. It shows that the cohesiveness of the compound has increased, most likely because to the hard thermoplastic layer around the individual GTR particles being thinner (Saeb et al., 2022).

Among the three various percentages of GTR fiber loading (1%, 3%, and 5%), the 3% and 5% GTR fiber loading absorbs the most energy. The percentage of 3% GTR fiber loading has the same absorbed energy value as the percentage of 5% GTR fiber loading, thus it can be inferred that the percentage of 3% GTR fiber loading is in an optimum state that can be added to PP for filament fabrication and 3D print specimens. The Charpy impact strength tests of the r-RubPPc samples modified with silane confirm the increase in mechanical adhesion between both fiber and matrix and also observed an increase in GTR content in the material in the impact tensile tests.

4.5.2 Damping properties

The vibration response and characteristics of the 3D printed r-RubPPc specimen are analyzed in Figs. 4.9–4.11. The measured time-series waveforms for each specimen are shown in Figure 4.9. Fig. 4. also provides a summary of the significant properties from the modal analysis of the 3D printed r-RubPPc specimens, including the Quality factor, Q, Loss factor, η, and Damping factor ζ.

Furthermore, it can be shown from Fig. 4.7 that adding more rubber to the 3D printed specimens significantly affected the observed damping ratio, quality factors, and loss factors. For instance, increasing the amount of rubber from 1% to 3% weight in the 3D printed composite improved the composites' silane content and damping factor, ζ. (Nguyen et al., 2022) stated that when the rubber component in the 3D printed composites grew, so did the average diameter of the rubber particles. Longer contact lines exist between specimens with bigger rubber particles and the PP host matrix. As a result, there was an improvement in energy dissipation along those lines, which improved the r-RubPPc specimens' overall damping qualities through 3D printing. The 3D printed r-RubPPc specimens are good candidates for vibration isolation applications due to their desired improvement in total damping capabilities (Herkal et al., 2023).

A closer look at Fig. 4.10 reveals that increasing the rubber content from 1 % wt. to 3 % wt. for untreated r-RubPPc specimen caused the damping factor, ζ to increased for 16% . Futhremore, in the increasing of rubber content from 3 % wt. to 5 % wt. in r-RubPPc specimen caused the damping factor, ζ to increase higher at 58 %. Therefore, at low rubber percentages, or 1% wt., the PP host material mostly controlled the behavior of these 3D printed r-RubPPc examples. But a noticeable improvement in damping qualities was seen when the 3D printed composite's rubber content became even higher. Each composite has voids due to the lack of surface treatment, which increases the composite's capacity to absorb energy. The decline in the loss factor, η, is consistent with the increase in the damping value, μ. Figure 4.11 (b) shows the decrement value of loss factor, η as increasing the rubber content from 1 % wt. to 3 % wt. for untreated -RubPPc specimen from 12.95 × 10-2 to 11.16 × 10-2. This translates to a loss factor drop of almost 14%. Conversely, the loss factor, η, dropped from 11.16 × 10-2 to 7.08 × 10-2 when the rubber content for the untreated RubPPc specimen increased from 3% to 5% of weight

Additionally, Figure 4.10 demonstrates that there is a statistically significant difference in the damping factor for silane-treated r-RubPPc specimens with 1%, 3%, and 5% rubber content. According to (Xiang et al., 2020a) silane treatment strengthened the interface adhesion condition between the fiber and matrix. Additionally, there is a 0.6% rise in the damping factor between 3% and 5% treat. The toughness characteristics of silane-treated r-RubPPc specimens may be connected to these results, since an increase in rubber content at 3% and 5% weight has resulted in an increase in the amount of absorbed energy. The main cause of these desirable variations is the elastomeric properties of rubber particles, which become more prevalent as the 3D printed composite's rubber content rises. Rubber is extensively utilized for dampening vibrations in a variety of structures because to its high bulk modulus and low elastic modulus (Nguyen et al., 2022).

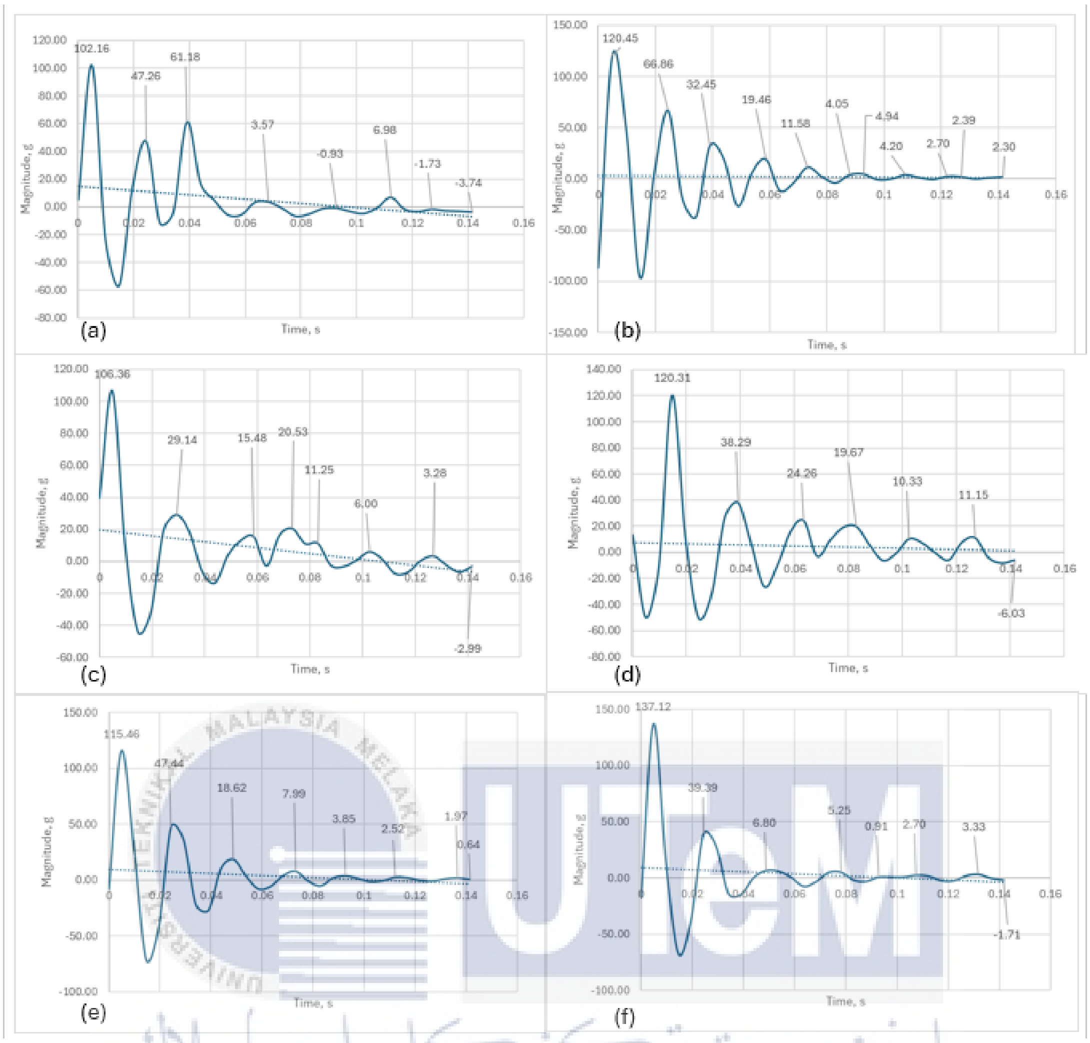

Figure 4.9 The ringdown waveform from 3D printed r-RubPPc specimen: a) 1% untreated GTR, b) 1% silane treated GTR, c) 3% untreated GTR, d) silane treated GTR, e) 5% untreated GTR and f) 5% silane treated GTR

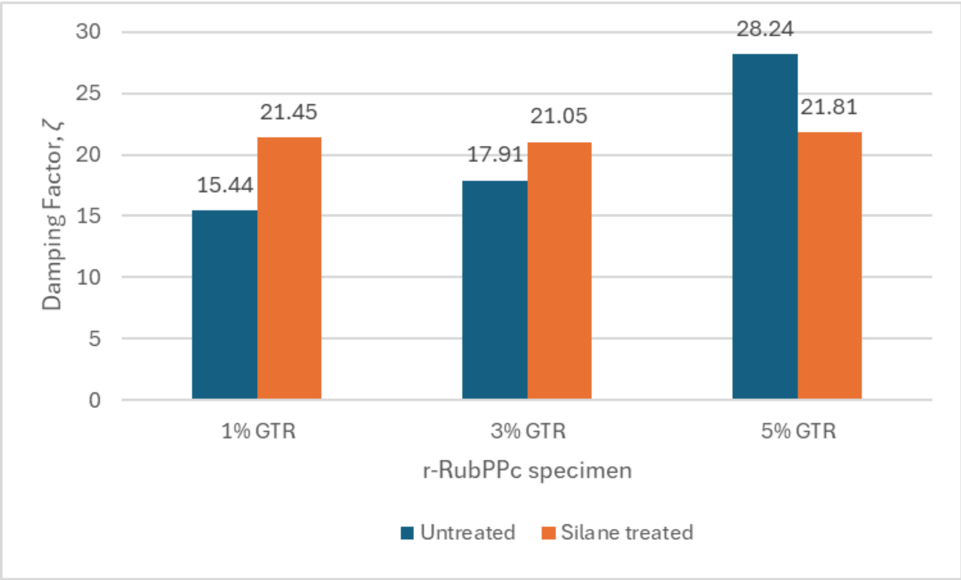

Figure 4.10 Damping factor, ζ of r-RubPPc specimen

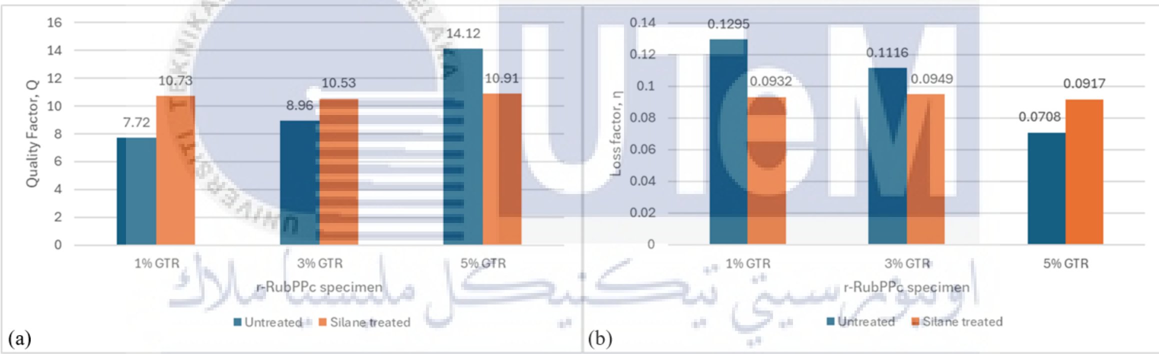

Figure 4.11 Parameters obtained from the modal analysis of the 3D printed r-RubPPc composite (a) Quality factor, Q and (b) Loss factor, η

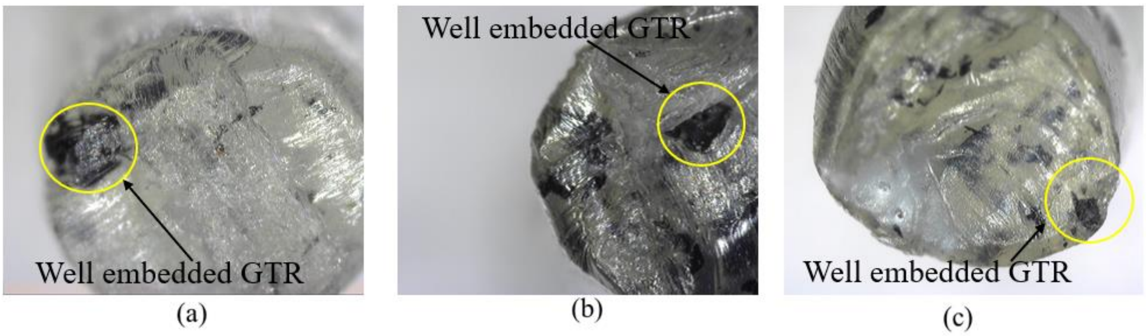

Figure 4.12 Surface image of r-RubPPc filament for 230x magnification under microscope (a) 1% silane-treated GTR, (b) 3% silane-treated GTR, (c) 5% silane-treated GTR

4.6 Summary

The result of this study in this section were silane treatment improved the interfacial adhesion between recycled polypropylene and ground tyre rubber . Futhermore a substantial silane layer was evident on the GTR surface and the film sealed the holes of all sizes and shapes. The loose particles were joined together to reduce granules and holes while retaining surface continuity.

It is expected that by increasing the percentage weight for GTR, the energy absorption increase. However, the behaviour of the composites differs depending on the amount of GTR in the matrix. This tendency originates from a weak interface connection between the particles, with cracks and fractures that rapidly reduce the mechanical properties. This means that, regardless of particle size, interfacial adhesion reduces as the content of old tyres increases, resulting in a drop in stiffness under all conditions.

The vibration test results demonstrate the benefit of using GTR particles in the 3D printed composite. As the amount of rubber in the specimens increased, so did their ability to isolate vibrations. It should be noted that adjusting the settings resulted in more rubber in the 3D printed specimens. As a result, energy dissipation along those lines improved, which improved the overall damping properties of the composites. Because of the intended enhancement in total damping capabilities, 3D printed GTR-PP composites are excellent alternatives for vibration isolation applications.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

To accomplish the study goals of (1) producing r-RubPPc filament for 3D printing with varying fiber loading and (2) examining the toughness and damping properties of 3D printed samples for r-RubPPc composite, several tests have been carried out. Thus, a few key findings were drawn from the entire investigation, and they are as follows:

1) Water absorption rates (WAR) for 3% of GTR fiber loading filament decreased noticeably. The composites without presence of silane exhibited considerably higher WAR values than the other composite samples which is 25%. The decreased in water absorption of the compatibilized r-RubPPc was because silane improved the GTR-matrix interfacial adhesion. Adding silane could prevent the water penetrate between the GTR-matrix interface. In addition, the WAR greatly decreased upon further increasing the percentage of fiber loading at 3% of GTR. The presence of 2% silane acted as compatibilizer which improved the interfacial adhesion for 3% of GTR fiber in r-RubPPc filament. The 3% fiber loading of GTR toward R-WoPPc give the less water absorption rate that will improve the mechanical properties.
2) GTR dispersed in the copolymer matrix also changes the impact strength of the obtained materials. The 1% fiber loading of GTR for untreated specimen and silane-treated specimen broke due to the impact of the pendulum, and the recorded impact strength value was approximately 3.43J and 3.73J

respectively. By adding silane to the composite, the absorbed energy increased as shown at 1% fiber loading of GTR. Silane treatment produced stronger interface adhesion state between fiber and matrix and increase the toughness of r-RubPPc specimen. Among the three various percentages of GTR fiber loading (1%, 3%, and 5%), the 3% and 5% GTR fiber loading absorbs the most energy. The percentage of 3% GTR fiber loading has the same absorbed energy value as the percentage of 5% GTR fiber loading, thus it can be inferred that the percentage of 3% GTR fiber loading is in an optimum state that can be added to PP for filament fabrication and 3D print specimens.

3) The increasing the rubber content from 1 % wt. to 3 % wt. for untreated r-RubPPc specimen caused the damping factor, ζ to increased for 16% . Futhremore, in the increasing of rubber content from 3 % wt. to 5 % wt. in r-RubPPc specimen caused the damping factor, ζ to increase higher at 58 %. Therefore, at low rubber percentages, or 1% wt., the PP host material mostly controlled the behavior of these 3D printed r-RubPPc examples. But a noticeable improvement in damping qualities was seen when the 3D printed composite's rubber content became even higher. Each composite has voids due to the lack of surface treatment, which increases the composite's capacity to absorb energy.

A few conclusions might be obtained from this study, namely " THE INVESTIGATION OF THE DAMPING AND TOUGHNESS PROPERTIES OF 3D PRINTING FILAMENT MADE FROM GROUND TYRE RUBBER AND POLYPROPYLENE COMPOSITE." It has been demonstrated that adding silane enhances the filament's surface condition and bonding conditions. The improvement of the interfacial adhesion between recycled polypropylene (rPP) and ground tire rubber (GTR) in r-RubPPc composites is shown by the rise in toughness and damping as well as the reduction in water absorption characteristics of the r-RubPPc with the silane as compatibilizer. It was demonstrated that raising the GTR fiber loading to a large extent of the r-RubPPc increased the composite's impact modulus. It can be deduced that the percentage of 3% GTR fiber loading is in an ideal state and may be added to PP for filament production and 3D print specimens because it has the same absorbed energy value as the percentage of 5% GTR fiber loading. This demonstrated that the compatibilizers had a favorable impact on the filler-matrix interfacial adhesion.

5.2 Recommendations

Investigating the impact of silane as a compatibilizer for ground tire rubber fiber and any kind of polymer is one area in which this research might go further. Additional research can be conducted by increasing the loading of the GTR fiber by 5% or 10%. Additionally, the filaments' characteristics may be investigated using techniques like the differential scanning calorimetry (DSC), wire pull test, thermogravimetric analysis (TGA), and Fourier transform infrared spectroscopy (FTIR). When choosing a chemical treatment, such as silane + NaOH or NaOH, the fiber composition should be considered at its highest level. The process of combining fiber and polymer in an internal mixer may also be studied in the preparation for the composite. By using silane as a compatibilizer, this can enhance the composite's mechanical and physical qualities. For a close-up look at the specimen, it should be examined using a scanning electron microscope (SEM).

5.3 Project potential

The results of this study have a good chance of being applied by the industry as a commercial bio composite filament in the industrial sector. For instance, the majority of take-out food and drink containers are from PP. PP provides excellent interlayer adhesion while being lightweight. The lightweight nature of PP means that less filament is needed to print a three-dimensional item. Because of this, PP filament is ideal for printing applications related to packaging and storage. Furthermore, this filament is compatible with any FDM 3D printer, and the pellet may be extruded using any type of extrude

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APPENDICES

APPENDIX A Gantt Chart PSM 1

Gantt Chart PSM 1																	
No	Task Project	Plan/Actual	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Registration of PSM title	Plan														
		Actual														
2	Briefing of PSM and project explanation by supervisor	Plan														
		Actual														
3	Drafting and writing of Chapter 2 Literature Review	Plan														
		Actual														
4	Presentation of draft Chapter 2 with supervisor	Plan														
		Actual														
5	Submission of Chapter 2	Plan														
		Actual														
6	Briefing of Chapter 1 with supervisor	Plan														
		Actual														
7	Writing of Chapter 1	Plan														
		Actual														
8	Submission of Chapter 1	Plan														
		Actual														
9	Discussion of Chapter 3 with supervisor	Plan														
		Actual														
10	Draft and writing of Chapter 3	Plan														

		Actual														
11	Submission of Chapter 3	Plan														
		Actual														
12	Writing Chapter 4 , expected outcome and abstract	Plan														
		Actual														
13	Submission of report PSM 1 first draft	Plan														
		Actual														
14	Last correction of the report	Plan														
		Actual														
15	Submission of report to supervisor and panels	Plan														
		Actual														
16	Preparation slides and presentation PSM 1	Plan														
		Actual														

APPENDIX B Gantt Chart PSM 2

Gantt Chart PSM 2																
No	Task Project	Plan/Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Meeting and discussion with supervisor, Dr Nuzaimah	Plan														
		Actual														
2	Preparation of raw material	Plan														
		Actual														
3	Silane treatment of fiber	Plan														
		Actual														
4	Preparation of composites	Plan														
		Actual														
5	Fabrication of pellet	Plan														
		Actual														
6	Filament extrusion	Plan														
		Actual														
7	Preparation of 3D printed specimen	Plan														
		Actual														
8	Characterization of filament and 3d printed specimen - Morphology - Toughness - Damping - Water absorption	Plan														
		Actual														
9	Analysis of results obtained	Plan														
		Actual														
10	Draft and writing the report PSM 2	Plan														

		Actual														
11	Submission of draft report PSM 2	Plan														
		Actual														
12	Correction on report PSM 2	Plan														
		Actual														
13	Resubmit of draft report PSM 2	Plan														
		Actual														
14	Last correction of the report	Plan														
		Actual														
15	Submission of report to supervisor and panels	Plan														
		Actual														
16	Preparation slides and presentation PSM 2	Plan														

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **THE INVESTIGATION OF THE DAMPING AND TOUGHNESS PROPERTIES OF 3D PRINTING FILAMENT MADE FROM GROUND TYRE RUBBER AND POLYPROPYLENE COMPOSITE**

SESI PENGAJIAN: **2023-2024 Semester 1**

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