MECHANICAL PROPERTIES OF GLASS FIBER PINEAPPLE LEAF REINFORCED POLYESTER HYBRID COMPOSITE

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Faculty of Industrial and Manufacturing Technology and Engineering

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A project submitted
in fulfillment of the requirements for the degree of
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TAJUK: **MECHANICAL PROPERTIES OF GLASS FIBER PINEAPPLE LEAF REINFORCED POLYESTER HYBRID COMPOSITE**

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

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Tarikh: 06/02/2024

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DECLARATION

I declare that this project entitled "Experimental Analysis on Mechanical Properties of Glass Fiber Pineapple Leaf Reinforced Polyester Hybrid Composite" is the result of my research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name : *NURHUDA BINTI SARMAN*

Date : 06/02/2024

APPROVAL

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

Signature : ....

Supervisor Name : *DR ISKANDAR BIN WAINI*

Date : 7/2/2024

DEDICATION

All thanks to Allah for giving me the strength, patience, direction, and knowledge to accomplish this study. I am grateful to God Almighty for allowing me to join this program. A special award, I dedicate this thesis to my dear parents, Mr. Sarman Bin Abd. Hamid and Mrs. Noryanti Binti Osman. Finally, I'd like to thank my supervisor, Dr. Iskandar bin Waini for his help, guidance, and advice in completing this project.

ABSTRACT

Many byproducts, both plant and animal, from agriculture and industry accumulate daily. Reducing environmental impacts, advancing the circular economy agenda, and giving waste value all need using these materials, although doing so is challenging. Therefore, this research aims to develop a glass fiber pineapple leaf reinforced polyester hybrid composite and analyze its mechanical properties. Mechanical properties were determined by conducting tensile, flexural, impact, and water absorption tests on the difference ratio of composites. The composite ratios consist of 20% pineapple leaf and 80% polyester (20PL80P), 40% pineapple leaf and 60% polyester (40PL60P), 50% pineapple leaf and 50% polyester (50PL50P), 60% pineapple leaf and 40% polyester (60PL40P), and 80% pineapple leaf and 20% polyester (80PL20P). A composite material consisting of pineapple leaf, glass fiber, and polyester is fabricated utilizing a hand lay-up technique to obtain five different ratios. The testing specimen is created by cutting the fabricated material using a computer numerical control (CNC) router machine. Statistical methods are used to examine the data. The mechanical properties of glass fiber pineapple leaf reinforced polyester hybrid composite are analyzed numerically, and the results are visualized graphically. The ratio of glass fiber pineapple leaf reinforced polyester hybrid composite will affect all possible composites. Based on the mechanical testing composite ratios consisting of 40% pineapple leaf and 60% polyester (40PL60P) have stronger strength, higher maximum stress, and superior impact strength compared to other ratios. ANOVA findings showed P-values below $\alpha = 0.05$, requiring the Tukey test to distinguish composite ratio means.

ABSTRAK

Banyak hasil sampingan, tumbuhan dan haiwan, daripada pertanian dan industri terkumpul setiap hari. Mengurangkan kesan alam sekitar, memajukan agenda ekonomi pekeliling, dan memberi nilai sisa semua keperluan menggunakan bahan ini, walaupun berbuat demikian adalah mencabar. Oleh itu, penyelidikan ini bertujuan untuk membangunkan komposit hibrid poliester bertetulang gentian kaca daun nanas dan menganalisis sifat mekanikalnya. Sifat mekanikal ditentukan dengan menjalankan ujian tegangan, lentur, hentaman dan penyerapan air pada nisbah perbezaan komposit. Nisbah komposit terdiri daripada 20% daun nanas dan 80% poliester (20PL80P), 40% daun nanas dan 60% poliester (40PL60P), 50% daun nanas dan 50% poliester (50PL50P), 60% daun nanas dan 40% poliester 60PL40P), dan 80% daun nanas dan 20% poliester (80PL20P). Bahan komposit yang terdiri daripada daun nanas, gentian kaca, dan poliester dibuat menggunakan teknik letak tangan untuk mendapatkan lima nisbah berbeza. Spesimen ujian dibuat dengan memotong bahan yang direka menggunakan mesin penghala kawalan berangka komputer (CNC). Kaedah statistik digunakan untuk memeriksa data. Sifat mekanikal komposit hibrid poliester bertetulang daun nanas gentian kaca dianalisis secara berangka, dan hasilnya divisualisasikan secara grafik. Nisbah komposit hibrid poliester bertetulang daun nanas gentian kaca akan menjejaskan semua komposit yang mungkin. Berdasarkan nisbah komposit ujian mekanikal yang terdiri daripada 40% daun nanas dan 60% poliester (40PL60P) mempunyai kekuatan yang lebih kuat, tegasan maksimum yang lebih tinggi, dan kekuatan hentaman yang unggul berbanding nisbah lain. Penemuan ANOVA menunjukkan nilai P di bawah $\alpha = 0.05$, memerlukan ujian Tukey untuk membezakan min nisbah komposit.

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

Alhamdulillah, thanks to ALLAH SWT, with His permission and blessing, my Creator, my Sustainer, for everything I received since the beginning of my life. I have finally completed the Bachelor Degree Project 1. Thank you, appreciation, to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform and facilities. Without them, I would have never been able to run this project.

I want to extend my deepest gratitude to my supervisor, Dr. Iskandar Bin Waini, for his valuable comments and patience. Without his support, I would have never succeeded in achieving this project. He has given me feedback and supported and motivated me during this project.

In conclusion, I want to thank my beloved parents, Mr. Sarman Bin Abd. Hamid and Mrs. Noryanti Binti Osman, as well as my close friends. Who was there for me, encouraged me, and supported me during this project.

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LIST OF SYMBOLS AND ABBREVIATIONS

μm	-	Micrometer
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Material
CAD	-	Computer-aided design
cm	-	Centimeter
CNC	-	Computer numerical control
FRP	-	Fiber reinforced plastic
g/cm3	-	Gram per cubic centimeter
ISO	-	International Organization for Standardization
mm	-	Millimeter
PALF	-	Pineapple leaf fiber
PL20P80	-	Pineapple leaf 20% Polyester 80%
PL40P60	-	Pineapple leaf 40% Polyester 60%
PL50P50	-	Pineapple leaf 50% Polyester 50%
PL60P40	-	Pineapple leaf 60% Polyester 40%
PL80P20	-	Pineapple leaf 80% Polyester 20%
PLRP	-	Pineapple leaf reinforced polyester
PMC	-	Polymeric matric composite
SiO2	-	Silicon dioxide
SOP	-	Standard Operation Procedure

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CHAPTER 1

INTRODUCTION

1.1 Background

Many byproducts, both plant and animal, from agriculture and industry accumulate daily. Reducing environmental impacts, advancing the circular economy agenda, and giving waste value all need using these materials, although doing so is challenging. Hybrid composites increasingly use agro-industrial wastes as fillers in mechanical strengthening and thermal or acoustic insulation. One challenge in using these residues is that they tend to be hydrophilic, which contrasts the composite matrix's hydrophobic character. Natural fibers (such as those found in pineapple leaves, coconut leaves, and rice straw) and synthetic fibers (such as those found in glass or jute) offer better mechanical qualities than synthetic fibers due to their renewability, biodegradability, and recyclability.

Hybrid composites have the potential to display a range of characteristics that would be impossible with a single reinforcing type. Combining cheaper reinforcements like hybrid composites consisting of glass fibers and higher-priced, high-performance fibers can offer improved mechanical qualities at a reduced cost. There has been a lot of research into the potential benefits of hybrid composites made by combining glass fiber with other natural fibers, such as lighter construction and enhanced properties like impact strength, sound absorption, corrosion resistance, thermal stability, and water absorption.

Furthermore, classifying natural fibers further into plant-based, animal-based, and mineral-based categories. Plant, animal, and fruit fiber are examples of natural fibers. Yarn is spun from fibers, either continuous filaments with a hair-like structure or discontinuous elongated pieces. All naturally occurring fibers, whether from trees or not, are cellulosic. Cellulose, hemicellulose, and lignin make up the bulk of natural fibers. Cellulose makes the fiber more durable. Additionally, the main structural feature of the fiber cells is the cellulose-hemicellulose network, which is made up of hemicellulose molecules that are hydrogen bonded to the cellulose and act as a cementing matrix between each cellulose microfibril (Huzaifah et al. 2017).

Moreover, lignin acts as a coupling agent that increases the cellulose-hemicellulose's stiffness and gives the plants rigidity. In addition to these; there are six other categories of fibers; leaf fibers (pineapple, sisal, and abaca); seed fibers (cotton, and coir); core fiber (jute, hemp, and kenaf); grass and reed fibers (wheat, and rice); types (woods and roots); and other bast fibers (jute, flax, hemp, ramie, and kenaf). According to recent studies, natural fibers have been shown to perform just as well as glass fibers in some composite applications. Among the many advantages of composites made from natural fibers are their low dielectric constant, impact resistance, modulus, and high stiffness (Kumar, Bhowmik, and Kumar et al. 2017). Natural fibers have low density and high strength (Asokan, Firdoous, and Sonal Rev et al. 2012; Vinoth Kumar et al. 2020). Furthermore, natural fibers have many benefits, for example, value for money, low density, environment-friendly, availability in abundance, renewability, nontoxicity, high flexibility, easy processing, high specific strength and modulus, and biodegradability (Sathees Kumar et al. 2020). Generating newer materials to satisfy the needs of a given implementation can be achieved by selecting the right matrix and reinforcement mix components.

Pineapple, or piña (Anannus comosus), is harvested from the leaves of the plant grown for pineapple fruit. Pineapple fiber contains approximately (70-82%) cellulose, with a range of lignin content of (5-12%) and ash (1.1%) (M. Rahman, Das, and Hasan 2018). In the early stages of the pineapple harvest, a rosette of fibrous leaves forms. The blade-like leaves are around 91 centimeters in length, 5 to 7.5 centimeters in width, and dark green color with spines that resemble claws along the borders. Pineapple fiber is soft and white with a sheen. Pineapple's ultimate fiber length is 7-18 mm, and the diameter is 20-80 µm. The tensile strength of pineapple fiber is high, ranging from 413 MPa to 1627 MPa; it has a low elongation at a break of no more than 3.4%. The fiber is very strong, durable, and flexible. It excels in several key areas, including low price, low density, low processing expense, environmental friendliness, lack of health risks, great adaptability, younger plants, simple collecting, and widespread availability (Umanath et al. 2020). Due to a lack of education regarding the commercial potential of pineapple leaves, many are now being thrown away in Malaysia. Hand-scraped fibers have traditionally been woven into very fine piña cloth in the Philippines for clothing and linens. In recent years, India, Japan, and China have explored more efficient processing of pineapple fiber using machine decorticators and successfully spun it commercially, especially after blending it with other fibers. Coarser pineapple fibers are used for paper making and mats. Its high strength makes pineapple fiber suitable for composites with natural and synthetic resins.

Reinforcing fibers for polymer matrix composites are often made of glass fibers. Glass fibers have great insulating characteristics, are inexpensive, have high tensile strength, and are chemically resistant. The drawbacks of this material are its poor tensile modulus and greater density compared to other fibers available in the market. Additionally, its excellent hardness results in excessive wear on molding die and cutting tools due to its sensitivity to abrasion during handling. Furthermore, this material exhibits a low fatigue resistance. Common types of glass fibers used include E-glass, S-glassC-glass is another type used in chemical uses where acids need to be less likely to corrode. The (FRP) industry relies heavily on E-glass since it is the most cost-effective reinforcing fiber currently on the market. Initially created for missile casings and aviation parts, S-glass has the highest tensile strength of any currently used fibers (Saravana Kumar et al. 2018). Despite this, it is more expensive than E-glass because of its different components and the higher cost of manufacturing.

Polyester is one of the polymers that is used in most applications all over the world. It can be produced with a wide range of qualities, including hard and brittle, soft and flexible, and everything in between. It has a low viscosity, a short cure time, and a low cost. These are its advantages. In most cases, its qualities are inferior to those possessed by epoxies. The substantial volumetric shrinkage in the polyesters is the primary drawback of using them rather than epoxies. It is easier to take parts out of the mold, but it also causes uneven depressions on the surface of the molded object. These are known as "sink marks" because the resin shrinks faster than the fibers.

Regarding exterior surfaces that need a high shine and a pleasant appearance, sink marks are not ideal. One way to hide surface flaws is to use low-shrinkage polyester resins, also called low-profile polyester resins. These resins have a flexible component, like polystyrene. As the curing process continues, phase shifts in the thermoplastic component make it possible for microvoids to emerge. These microvoids counteract the natural shrinking of the polyester resin as it cures. Polyester possesses superior mechanical qualities, such as improved impact and flexural strength, superior fatigue resistance, and a lower coefficient of friction. Polyester also has a lower coefficient of friction. Therefore, polyester is appropriate for use in the textile sector, as well as in packaging and labeling industries, as well as in the automobile industry (Anand et al. 2022).

1.2 Problem Statement

As is well known, a growing awareness of the state of the global environment has been a significant factor in the development of the next generation's materials, products, and processes based on natural resources. The demand for sustainable alternatives and the growing awareness of the damaging effects of traditional materials and manufacturing techniques on the environment are the main causes of this increased awareness. The present development of natural fiber in the reinforced composites market can be directly attributed to the growing environmental consciousness worldwide. Natural fibers are advantageous due to their regenerative nature, satisfactory mechanical qualities, low environmental impact, and low cost.

Pineapple is a well-known tropical fruit that is grown for its edible fruit all over the world. Unfortunately, the leaves are the main component of the pineapple plant that is currently being wasted. The leaves are typically burned or left to rot after the fruit has been harvested. Both farmers and residents in the surrounding areas were unaware of the commercial potential of pineapple leaves and relied on antiquated production methods. These discarded leaves can be put to good use through methods like vermicomposting and the utilization of fibers as reinforcement in composite production.

This study chose pineapple leaf because it contains a high cellulose concentration, is relatively inexpensive, less dense, requires less effort to dispose of, is abundantly available, and can be used as a polymer reinforcement. In addition, a significant amount of study has been conducted on using pineapple leaf reinforcement with some materials, such as polypropylene and low-density polyethylene (Chollakup et al. 2011). These investigations concluded that fiber-reinforced composites' properties are affected by various distinct parameters. These parameters include fiber-matrix adhesion, fiber orientation, fiber length, fiber aspect ratio, and fiber volume fraction.

In a previous case study, some researchers investigated the mechanical properties of glass fiber reinforced polyester composite (GFPC) were compared with pineapple leaf fiber reinforced polyester composites (PLPC) and pineapple leaf reinforced epoxy composites (PLEC) to develop above-knee prosthetic sockets (Odusote and Kumar et al. 2016). The results showed that pineapple fiber-reinforced epoxy composites had better flexural, impact, and tensile properties than fiberglass and pineapple fiber-reinforced polyester composites. Because of this, composites made from pineapple leaf fiber have lower overall weight and superior mechanical characteristics. As a result of this, composites can be applied in a wide variety of contexts, including automotive parts, electronic packaging, construction, and consumer items. Additionally, it will aid in the development of environmentally friendly composite materials.

1.3 Research Objective

This study investigates the mechanical properties of a glass fiber pineapple leaf-reinforced polyester hybrid composite. The specific objectives of this study are as follows:

i. To fabricate the glass fiber pineapple leaf reinforcing polyester hybrid composite with a difference ratio.
ii. To evaluate the mechanical properties of glass fiber pineapple leaf reinforce polyester hybrid composite based on tensile, flexural, impact, and water absorption tests.
iii. To obtain the best ratio preparation of glass fiber polyester hybrid composite filled with pineapple leaf.

1.4 Scope of Research

The study scopes focused on the mechanical properties of a glass fiber pineapple leaf-reinforced polyester hybrid composite. The contents of the research include:

i. Fabricate the composite ratio of 20% pineapple leaf and 80% polyester (20PL80P), 40% pineapple leaf and 60% polyester (40PL60P), 50% pineapple leaf and 50% polyester (50PL50P), 60% pineapple leaf and 40% polyester (60PL40P), and 80% pineapple leaf and 20% polyester (80PL20P) using the hand lay-up technique.

ii. To perform the CNC router machine to cut the specimen.

iii. To perform mechanical tests based on the American Society for Testing and Material (ASTM), such as tensile test (ASTM D3039), impact test (ASTM D6110), flexural test (ASTM D790), and water absorption test (ASTM D570).

iv. To analyze the result of the tensile test, impact test, flexural test, and water absorption test using Statistical software such as Microsoft Excel to generate ANOVA analysis for each ratio.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims to comprehensively analyze previously published research publications, conference papers, and other pertinent sources that address the mechanical properties of glass fiber pineapple leaf reinforced polyester hybrid composite. Besides, it analyzes the experimental methodologies, the results obtained, and the elements contributing to the composite material's observable mechanical behavior. The outcomes of this review will enhance the comprehension of the mechanical properties of glass fiber pineapple leaf-reinforced polyester hybrid composite. Furthermore, it will aid in creating improved composite materials suitable for diverse engineering applications.

2.2 Composite

Composites are attractive because they blend the properties of different materials in ways that do not happen in nature. Two or more integral materials with considerably other physical and chemical properties are mixed. They generate material with characteristics distinct from those of the individual elements (Dattatreya et al. 2023). This type of material is referred to as a composite. These parts can deeply penetrate, and their characteristics complement each other effectively. The resulting composite is not uniform and possesses characteristics absent in individual constituents. Composites are structures of at least two different, readily discernible materials combined to provide an enhanced end product (Nijssen. R.P.L et al. 2015). During the production of a composite item, the substance and the arrangement are frequently created simultaneously. Typically, the material and structure are made simultaneously rather than using raw, unprocessed materials that are molded, shaped, and put together. That is why it's called a "material structure". Composites are formed by mixing polymer resin with fibers. These portions are "identifiable with the naked eye" and do not mix.

As a result, the composite produced is not uniform and possesses characteristics absent in individual constituents. The matrix preserves reinforcing elements and allows charge transfer in those places. Reinforcements, a discontinuous phase, are more potent than the matrix. Additional support could come from platelets, particles, or fibers. The good parts of the fibers and the matrix are used to their fullest, and the other part cancels out the bad parts of one element. There is a structure that neither part could create on its own. Composite materials have effectively substituted metallic materials in different industries due to their low weight, excellent shock absorption ability, and simple making process. There a several types of composites based on various factors (Chichane, Boujmal, and El Barkany et al.2023) (Figure 2.1):

- The base can be made of polymeric material, metal, or clay.
- The supports are made of biological or inorganic materials.

- Discontinuous morphology includes particles, platelets, or short fibers (aligned or randomly oriented) that are not the same length as the piece's dimensions. In contrast, continuous morphology refers to long fibers with a size similar to the piece's dimensions.

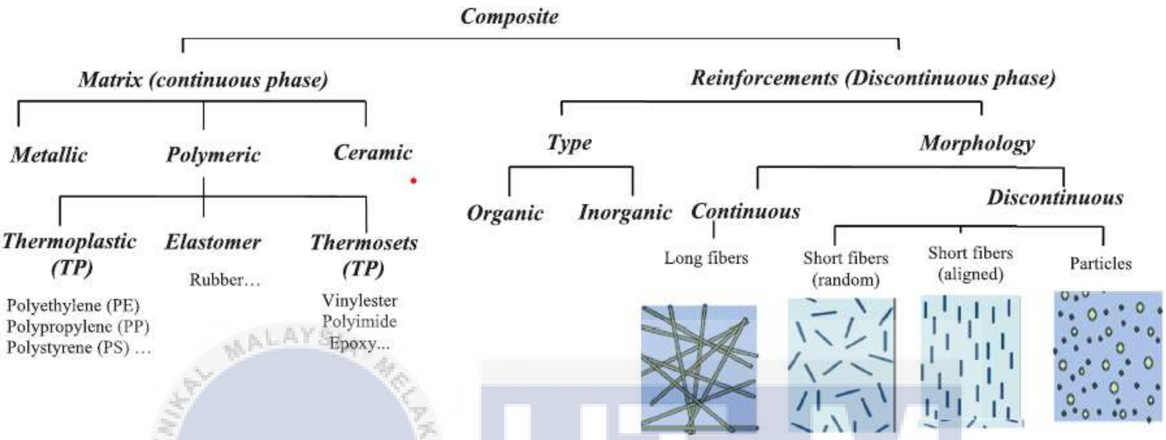

Figure 2.1 Types of composite material

2.2.1 Advantages and disadvantages of composite material

The advantages and disadvantages of composite material include:

Table 2.1 Advantages and disadvantages of composite material

Advantages	Disadvantages
• Weight saving. • A high degree of form, material, and process freedom.	• High material costs. • Sophisticated computational methods are sometimes required.

• Easy to color. • Translucent. • Capable of a high level of integrated function • Stiffness, strength, and thermal and electrical resistance can be designed. • Total maintenance expenses are reduced. • Water and chemical resistance is maintained. • Long-lasting materials may be used with little effort.	• Color and gloss preservation are not always predictable. • Finishing is not yet well developed. • Recycling is still in its infancy. • Often capital-demanding manufacturing processes (e.g., automated procedures). • Undesired stiffness and failure behavior.

2.3 Hybrid composite

Hybrid composites combine two or more components (phases) with different physical and mechanical properties. A hybrid composite is a composite with three or more elements in certain situations (Hasan, Zhao, and Jiang et al. 2019). A hybrid composite material is a mix of organic and inorganic substances mixed at a micrometric level (Chichane, Boujmal, and El Barkany et al. 2023). Hybridization is a blend created to create better and more efficient capabilities than individual parts. These substances frequently lead to structures that are light in weight, possess high stiffness, and have customized characteristics for particular uses, which ultimately reduce energy requirements and save weight (Birsen et al. 2023).

Hybrid composites can be categorized into subtypes based on characteristics, including bond strength, polymer matrix composition, reinforcing material size, and kind.

Classifying matrix materials is usually split into two groups (Haris et al. 2022). Examples of thermosets are epoxy and polyester. Some examples of thermoplastics are polypropylene, acrylonitrile butadiene styrene, and polycarbonate. Epoxy and polyester are also examples of thermoset materials. Hybrid composites exhibit their behavior due to individual constituents, where there is an equilibrium between the inherent pros and cons.

Moreover, by utilizing a hybrid composite comprising multiple fiber types, the benefits of one fiber type can supplement the deficiencies of the other. It could help achieve a composite material with a reasonable price and performance ratio. Hybrid composite properties are determined by fiber content, length, matrix type, orientation, the intermingling of fiber, bonding between fiber and matrix, fiber and matrix arrangement, and the strain at which individual fibers fail (Balasubramanian, Loganathan, and Srimath et al. 2021b).

According to many researchers, incorporating fibers into a polymer matrix has enhanced the characteristics of hybrid materials in comparison to composites consisting of only one type of fiber. Adding natural or synthetic fibers to a polymer matrix significantly changes the composites' mechanical properties. Blending various fibers can enhance modulus, strength, moisture resistance, thermal stabilization, stiffness, and durability. Blending natural fibers with glass fibers is a technique to improve the mechanical characteristics of natural fibers, enabling their use in non-structural and semi-structural car parts (Sanjay and Yogesha et al. 2017a).

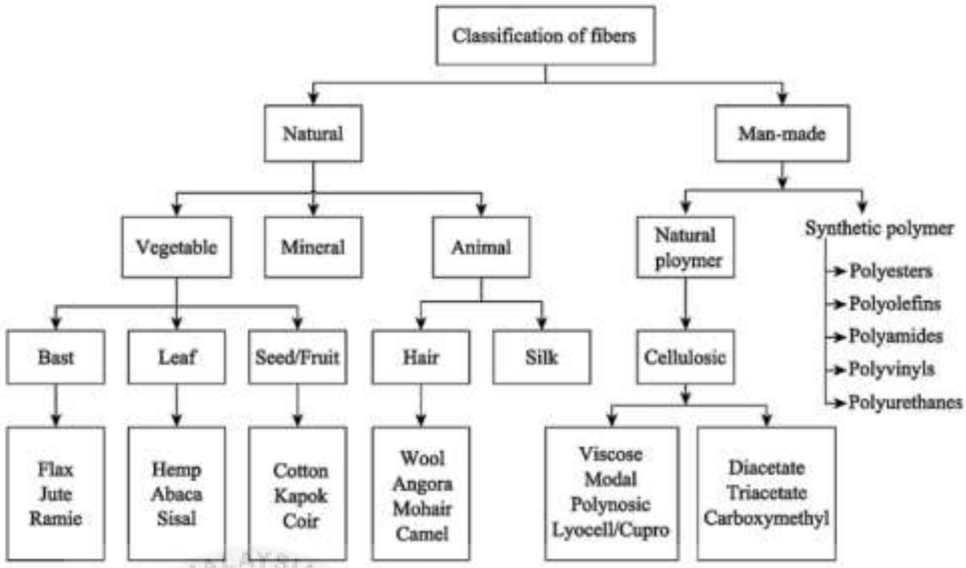

Figure 2.2 Classification of fibers

2.4 Fiber

The adhesion between fibers and matrices is established during the production stage of the composite material. These dramatically affect the mechanical characteristics of the composite material. Synthetic and organic fibers are the two most common types. Organic fibers can typically be categorized based on their source, including vegetables, animals, or minerals, and artificial fibers can be classified based on their basis; natural polymer or synthetic polymers, as depicted in Figure 2.2.

Textile fibers comprise many filaments, each with a 5-15 µm diameter. Because of this, they can be processed using various textile machines. Glass fibers produce two semi-finished fiber products, as illustrated in Figure 3. These fibers are marketed in the following forms such as:

- Tiny fibers, ranging from a fraction of a millimeter to a few centimeters in length.

These materials are utilized in injection molding and include felts, mats, and short fibers.

- The composite material utilizes long fibers that are either used as they are or woven, which are cut during fabrication.

2.4.1 Main Types of Fiber Materials

The main types of fiber materials include:

- High-density polyethylene.
- Silicon carbide (high temperature resistant).
- Boron (high modulus or high strength).
- Carbon (high modulus or high strength).
- Glass.
- Natural fibers (flax, hemp, sisal, etc.)

When creating fiber reinforcement, fibers can be assembled in various ways to form fiber shapes for making composite materials:

- One-dimensional: tows, yarns, or tapes that run in just one way
- Two-dimensional: Felts, mats, and other non-crimp textiles
- Fabrics having fibers orientated in more than two dimensions (termed "tridimensional fabrics")

2.5 Natural Fiber

Lately, there has been a growing utilization of plant fibers in the production of biofuels and biological substances and as a strengthening component in composite materials. Natural fibers possess various physical and mechanical properties and are a sustainable resource that can biodegrade. Additionally, due to the rise in global population, the amount of agricultural waste is also increasing. This waste pertains to all plant crops such as bananas, flax, coconut, pineapple, cotton, hemp, etc. Nowadays, synthetic fibers have been replaced by natural fibers due to their high cost, environmental pollution, and limited biodegradability. Natural fibers are light, strong, and resistant to shrinkage (1.3 g/cm3), making them biodegradable and superior to synthetic fibers (2.5 g/cm3) in terms of stiffness-to-weight ratio (Naveen Kumar et al. 2023).

Natural fibers come from a non-man-made source, such as plants, animals, or minerals. Animal fibers like hair, silk, and wool are all proteins, whereas every plant fiber is formed of cellulose. There are many different kinds of plant fibers. Some examples of bast or stem fibers are flax, hemp, jute, kenaf, roselle, ramie, and sisal. Other examples include cotton, coir, kapok, oil palm, sponge gourd, fruit, wood, cereal straw, and other grass fibers like bagasse and bamboo. (Sanjay and Yogesha et al. 2017).

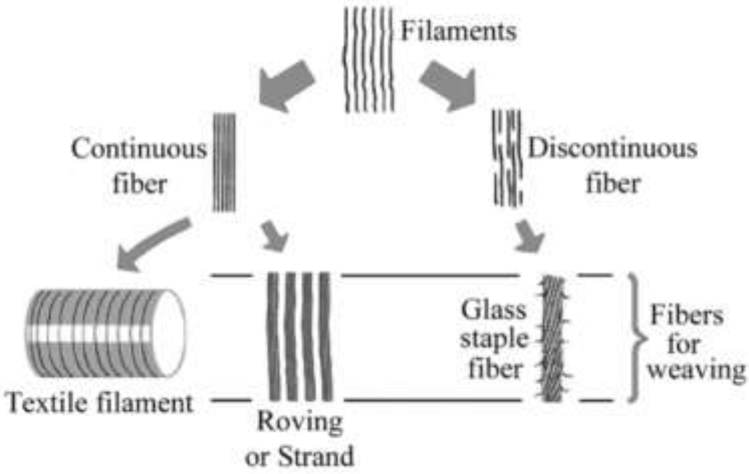

Figure 2.3 Difference fiber form

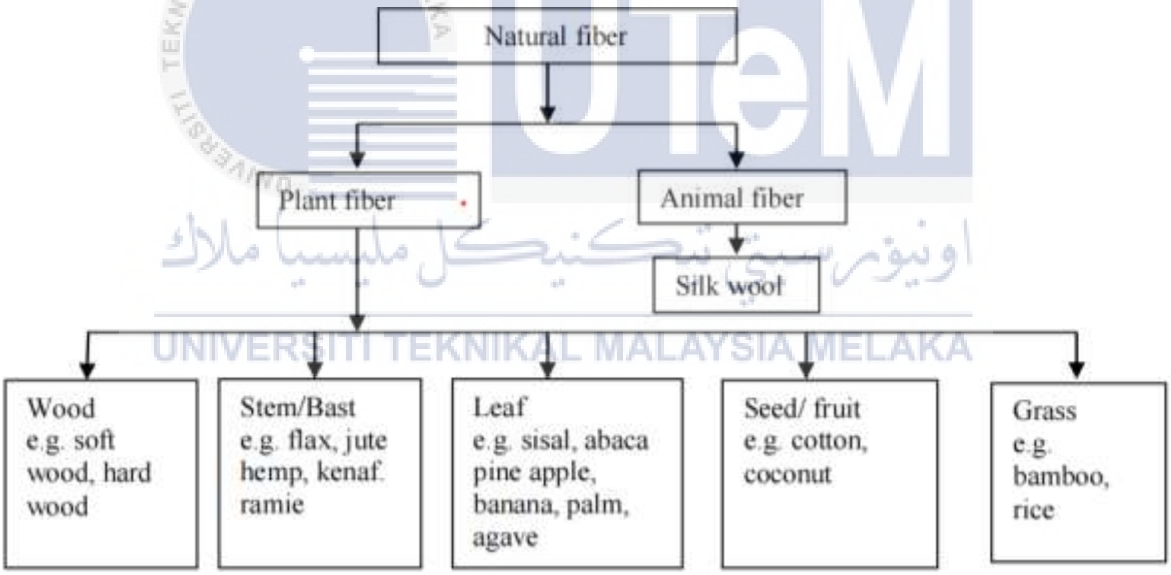

Figure 2.4 Examples of Natural Fibres Used in Composites (Parbin et al. 2019)

Most plant fibers contain lignin, cellulose, hemicellulose, wax, and various inorganic and water-soluble substances in their chemical composition. Cellulose is the main component of organic fibers, and anhydrous-D-glucose, which contains three hydroxyls

(OH) groups, is the major building block of cellulose macromolecules. The hydroxyl groups create hydrogen bonds within the macromolecule and other cellulose macromolecules. Thus, all fibers that are found in nature tend to attract and absorb water molecules. Natural fibers exhibit a wide range of properties, unlike conventional fibers such as glass, aramid, and carbon, which have a fixed range of properties. Natural fibers' cellulose comprises natural substances like waxes and lignin. The filters consist of lignin-bonded cellulose microfibrils. The chemical structure of natural fibers affects their physical properties, including cellulose content, degree of polymerization, orientation, and crystallinity. Nanocellulose fibrils that are homogeneous and extracted from different lignocellulosic fibers have the potential as a reinforcing component in polymer matrix composites(Parbin et al. 2019).

Plant growth conditions and extraction methods influence these factors. The characteristics of fibers differ significantly based on their source within a plant, the quality of the plant, and its geographical location. Fibers exhibit variations in their length, cross-sectional area, and structural imperfections such as micro compressions, pits, or cracks. Table 2.2 shows the chemical composition of the natural fibers.

Table 2.2 Chemical composite of natural fiber

Fibers	Cellulose (wt.%)	Hemicellulose (wt.%)	Lignin (wt.%)	Waxes (wt.%)
Abaca	56–63	20–25	12–131	-
Bagasse	55.2	16.8	25.3	-
Bamboo	26–43	30	21–31	-
Banana	63–64	-	5–11	-
Coir	32–43	0.15–0.25	40–45	-
Cotton	85–90	5.7	-	0.6
Curaua	7.36	9.9	7.5	-
Flax	71	18.6–20.6	2.2–20.6	1.5–1.7
Hemp	68–74	15–22.4	3.5–10	0.8
Jute	61–71.5	13.6–20.4	12–13	0.5
Kenaf	45–72	20.3–21.5	8–13	-
Pineapple	80.5	17.5	8.3	-
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Sisal	65–78	10–14	9.9–14	2

The superior characteristics of natural fibers, including their low density, high specific strength, and cost-effectiveness, have been widely recognized. (Bhuyan and Gogoi et al. 2020).Natural fiber composites are utilized to construct various building products, including panels, door shutters, and roofing sheets. These composites may be used either independently or in conjunction with other materials. The utilization of bagasse for the production of particle boards. The utilization of Thai wood fiber in hardboard production has been reported. According to this research, the Philippians utilize coir and banana stalks to produce particle boards. Several automotive companies, including Audi, BMW, Fiat, Ford, Mitsubishi, Renault, and Volvo, have incorporated natural fibers into their parts.

The packaging industry employs natural fibers due to their degradability. The utilization of natural fibers in various applications, such as composites, is restricted to non-structural and interior applications owing to their inadequate moisture resistance and inferior mechanical properties. Natural fibers produce multiple items, such as ropes, dusters, and seed pots. There are several reasons to favor natural fibers over synthetic ones, including their low price, low density, abundance, eco-friendliness, nontoxicity, high degree of flexibility, renewability, biodegradability, minimal environmental impact, high specific strength and modulus, and straightforward processing. In addition, contemporary industrial globalization has made plant fiber a crucial contributor to sustainable development. Plants used to produce natural fibers help the planet organically recycle carbon dioxide from the air.

2.6 Work Material

In engineering manufacture, "work material" refers to the necessary materials, tools, machinery, parts, facilities, resources, and supplies needed to complete the work that is not used up or included in the work. The study will examine the mechanical properties of a glass fiber-reinforced polyester hybrid composite filled with pineapple leaf. The research will employ materials such as fiber extraction equipment, mold materials, manufacturing equipment, testing equipment, and safety gear.

2.6.1 Pineapple Leaf

The fruit of pineapple is typically grown for consumption. Pineapple bran, the remaining pulp after juicing pineapple, is high in vitamin A and is sometimes used as animal feed. The pineapple plant's leaves are the source of PALF. Tropical nations are the primary cultivators of this plant. India has significant cultivation, around 91,000 hectares, and is continuously growing. The pineapple harvest features a short stem that initially generates a cluster of stringy foliage. The foliage measures approximately 91 cm in length, with a width ranging from 5 to 7.5 cm. They have a sword-like shape and are colored in a dark shade of green. The edges of the leaves are adorned with spiny claws. They are capable of yielding fibers that are robust, white, and silky in appearance. Pineapple leaves are predominantly discarded due to insufficient awareness about their potential economic applications. Throughout history, PALF yarns have been used to produce mops, curtains, rugs, and textiles.

PALF is a kind of fiber made up of many plant cells, including cellulose (70-82%), polysaccharides, and lignin. These components are all present in PALF fiber. Pineapple leaf fiber contains 78% cellulose, lignin – 10%, and Moisture Content – 12%(Cheirmakani, Subburaj, and Balasubramanian 2022). PALF contains significant amounts of lignin and other waxy substances, which lead to quicker fading of dyes in comparison to cotton. The coarseness of PALF makes it challenging for the stain to penetrate. The fibers possess a flat shape and comprise a bundle of vessels grouped in clusters of fibrous cells. These cells are acquired through the mechanical elimination of all the outer layers of the tissue. PALF is a high-quality material that doesn't have a mesh-like structure, unlike jute. The fiber has a high capacity for absorbing moisture. PALF exceptional mechanical characteristics are linked to its elevated cellulose levels and relatively low microfibrillar angle of 14°. PALF and jute fibers have similar flexural and torsional rigidity. PALF has a distinctive quality: when it becomes wet, the strength of its fiber bundles drops by about half, yet the strength of the yarn goes up by around 13 percent.

Table 2.3 Comparison of the mechanical and physical characteristics of pineapple fiber and fruit (Yves et al. 2018)

Fibers	Young modulus E (GPa)	Tensile strength Rm (MPa)	Density d(g/cm³)	Ratio Rm /density
Abaca	72	850-1400	1.4	803.6
Bagasse	31.96	729.48	1.91	381.9
Banana	27-32	529-914	0.31-1.02	1136.4
Cotton	5.5-12.6	264-800	1.5-1.6	285.2
Hemp	30-70	310-900	1.07	363.6
Flax	27-32	300-1500	1.54	1688.3
Jute	10-55	200-800	1.44	404.9
Coconut	0.4-6	131-175	1.15	133.0
Palm	3.58	130-248	0.27	351.9
Ramie	44-128	348-938	1.56	428.8
Sisal	9.-38	80-840	1.45	362.1
Pineapple leaf	34.5-82.51	413-1627	1.52	1070.39
Pineapple leaf	43	1244.3	0.95	1309.8
Pineapple steam	33.6	1072	0.9	1191.1
Pineapple root	44.5	1533.5	1.01	1518.3

2.6.2 Glassfiber

Polymeric matrix composites (PMC) usually use glass fibers as their primary reinforcing fibers. Glass fibers are advantageous because of their outstanding insulating characteristics, excellent tensile strength, good chemical resistance, and inexpensive nature. The cons include a comparatively high density and low tensile modulus compared to other typical fibers. It is also susceptible to abrasion during the handling process, which might reduce its tensile strength. In addition, it has a somewhat poor resistance to fatigue and high hardness, both of which contribute to excessive wear on cutting tools and molding dies.

Glass fibers known as E-glass and S-glass are the two types that are used most commonly in the fiber-reinforced plastics (FRP) industry. C-glass is a distinct kind of glass that differs from E-glass in that it is used in chemical applications that need greater resistance to acids. E-glass is used extensively in the FRP sector because of its inexpensive cost compared to the cost of other reinforcing fibers currently available on the market. S-glass, first developed for use in aircraft components and missile casings, boasts the highest tensile strength of any fiber now in use. However, because of the differences in composition and the additional costs of manufacture, the price is much more than that of E-glass. In comparison to S-glass, the cost of S-2-glass is much lower. The tensile strength and modulus of S-2 glass are equivalent to those of S glass, although S-2 glass is manufactured to non-military criteria that are less stringent.

Like regular soda-lime glass used for windows and containers, glass fibers also contain SiO2 as the main component. To enhance its workability and modify the network structure of SiO, other oxides like B023. E- and S-glass fibers have superior resistance to water corrosion and higher surface resistivity than soda-lime glass content. They have a disordered, three-dimensional network of silicon, oxygen, and other atoms within their internal structure. Glass fibers are non-crystalline and have equal properties in all directions, which means they are isotropic.

Uses of Glass fibers are the primary type of reinforcing fiber used in polymers due to their cost-effectiveness and high efficiency. Glass fibers are the ideal reinforcement for polymers or plastics due to their superior strength and modulus, which surpasses that of polymers. Fiber-reinforced glass plastics are widely utilized in various industries such as automotive, construction, marine, corrosion, electrical, and aerospace. These items are available in many different kinds of goods, such as water slides, bathtubs, swimming pools, storage containers, instrument enclosures, pipes, pressure vessels, furniture, railings, roofing, siding, doors, windows, structural shapes, aircraft flooring, and automotive parts. The utilization of glass-fiber composites has been steadily rising.

Table 2.4 Properties of fibers

Fibers	Tensile modulus (GPa)	Tensile strength (GPa)	Density (g/cm^3)
E-glass	72.4	3.5[a]	2.54
S-glass	85.5	4.6[a]	2.48

Silica	72.4	58	2.19
Tungsten	414.0	4.2	19.30

2.6.3 Polyester

Polyester resin is an artificial substance that falls under the category of thermosetting polymers. Polyester resins typically undergo a heating process and can be melted again without losing their inherent properties. Thermoplastics are distinct from thermosets as they do not change permanently after hardening. Due to this reason, thermoplastics can usually be recycled. Certain polyester resins are thermosetting, similar to those used in fiberglass. Polyesters are significant polymers that contain an ester functional group in their backbone. Polyesters can be either naturally occurring or artificially produced. Polyesters that occur naturally can decompose, but most synthetic polyesters cannot. Polyesters, whether thermoplastic or thermoset, depend on their chemical composition. Polyesters can have different leading chains, which can make them aliphatic, aromatic, or semi-aromatic.

Polyesters with aromaticity typically have increased glass transition temperature, thermal stability, mechanical strength, and chemical stability (Kausar et al. 2019). A few typical instances are polycaprolactone, polylactic acid, polyhydroxyalkanoate, polyethylene adipate, polyethylene terephthalate, polybutylene terephthalate, and polyethylene naphthalate. Polyesters artificially exhibit excellent characteristics such as resistance to moisture and fire, mechanical and thermal properties, liquid crystal properties, and environmental stability (Hofmann et al. 2022). Polyester resin is commonly used in different applications because of its exceptional mechanical characteristics, affordability, and simple processing. Utilizing continuous fibers such as glass or carbon fibers to strengthen polymers creates fresh opportunities for implementation in the automotive, aerospace, and construction industries.

To put it differently, using fiber reinforcements has made it possible for polymeric materials to substitute conventional materials such as aluminium, steel, and concrete in high-performance engineering structures. The growing usage of fiber-reinforced polymer (FRP) composites can be attributed to their lightweight, design flexibility, and high specific strength and stiffness (Ramadan et al. 2021). FRP is used to manufacture 80-90% of the interior furnishings in commercial aeroplanes. Lately, the utilization of FRP has become prevalent in the building and restoration of metal frameworks. When building an FRP bridge, the weight is usually 75% less than a steel bridge, which is advantageous if the ground condition is not good.

Polyesters have various applications, such as creating films, capacitor components, liquid crystal displays, automotive interiors, holograms, wire insulation, jet engine seals, tapes, and textiles. Polyester resin and glass fiber composites are commonly used to manufacture car body parts and watercraft. Further exploration of polyester combined with nanodiamonds, fullerenes, graphene, GO, and CNTs could uncover significant uses for these materials in fields like solar energy, ballistic protection, and aerospace and defense technology (Kausar et al. 2019).

Table 2.5 The properties of thermoset matrix (Yashas Gowda et al. 2018)

Thermoset	Density (g/cm3)	Tensile modulus (GPa)	Tensile Strength (Mpa)	Compression Strength (Mpa)
Polyester	1.0-1.5	2.0-4.5	40-90	90-250
Epoxy	1.1-1.6	3.0-6.0	28-100	100-200
Vinyl ester	1.2-1.4	3.1-3.8	69-86	86
Phenolic	1.29	2.8-4.8	35-62	210-360

2.7 Cutting Process Machine

The CNC router machine will be utilized to cut fabricated materials into test specimens as part of the project. The samples are cut based on specific size ranges and parameters, using the appropriate tool eye speed. This literature review will encompass researchers using the machine above to section specimens.

2.7.1 CNC Router Machine

A Computer Numerical Controlled (CNC) router machine is a machine that uses computer programming to control a high-speed rotating cutter for cutting and shaping operations. These machines can cut many materials, such as plastics, wood, carbon fiber, and light metals like aluminium. They are commonly utilized for cutting two-dimensional shapes on level surfaces. Using pre-set toolpaths from a vector drawing, a controller guides the machine to move the tool head horizontally and vertically. Yet, equipped with a programmable Z-axis and appropriate design file and controller, they possess the same ability to carve intricate 3D shapes and patterns into a diverse array of materials.

Their capacity to make precise cuts is one of their most significant advantages. Compared to the more traditional method of cutting things by hand, using a CNC router machine, driven by CAD software, has considerably simplified the process of cutting complex and precise materials. Cutting with precision has the additional advantage of reducing the amount of wasted material, resulting in more significant cost reductions and increased profit margins, eliminating human and machine errors to increase product accuracy. CNC machines streamline and reduce errors compared to conventional manufacturing systems with several stations and operator setups. Traditional techniques set up and operate each machine individually for various components, increasing mistakes. The CNC router machine cut all parts, including odd-shaped ones, continuously. CNC router machines can use machine boards accurately if the codes are programmed. The machining process is highly accurate if the regulations are coded correctly.

Some CNC router machines can cut up to 30 different materials, including but not limited to wood, steel, foam, plastic, acrylic, and many others. These machines can manage the operation of cutting a single design repeatedly with ease and may be left unattended to keep the production line moving. Those who need a single method to be cut repeatedly should consider using these machines. CNC router machines are much safer than traditional routers since they do not rely on human control and are equipped with safety features that limit the likelihood of accidents. Since the programming and power can be learned digitally, this eliminates the need for first-hand training, lessening the strain on human resources. This technology offers another significant advantage. Most significantly, workshops may make use of the natural adaptability and flexibility that these devices possess. The operators can update and modify the product to meet the demands and requirements of various business sectors. It is simple and convenient to update a CNC router machine because all that is required is a software upgrade, and there is no need to acquire a prototype. In addition, due to the rising demand for this equipment, manufacturers have responded by making a diverse selection of systems available at competitive costs.

2.8 Machine Testing

Mechanical testing is a fundamental component of materials science and engineering, which encompasses assessing materials' mechanical characteristics and performance in diverse settings. Investigating the mechanical properties of glass fiber pineapple leaf reinforced polyester hybrid composite requires automated testing. This project involves testing the mechanical properties of the specimen through tensile, flexural, and impact tests. The process enables the assessment and measurement of mechanical attributes, the choice of materials, optimization, and adherence to quality control and standards.

Furthermore, it aids in identifying the optimal pairing for particular use cases. Mechanical testing is a technique employed to predict the performance and simulate the behavior of glass fiber reinforced with polyester hybrid composites. It is also used for research and development purposes and safety assessment. The simulation of composite material behavior under varying loading conditions aids in the optimization of design and ensures dependable performance in practical applications. This study aims to analyze the impact of various factors on the mechanical properties of glass fiber-reinforced polyester hybrid composites reinforced with pineapple leaf fibers.

2.8.1 Tensile Test (ASTM D3039)

The ASTM D3039 standard is used for composites of highly oriented polymers and fibers with a high tensile modulus. The tensile characteristics refer to how materials respond to resist forces applied in tension. Assessing the tensile factors is essential as it details the elasticity modulus, elastic threshold, elongation, and proportionality (R. Rahman and Putra et al. 2018). Constraints, decrease in surface, pulling ability, breaking point, strength at breaking point, and additional pulling characteristics. The tensile factors differ depending on the material and are established by conducting a tensile test. This test generates a curve that shows the relationship between the load and elongation, which is then transformed into a curve that displays the correlation between stress and strain. Tensile testing specimens are commonly shaped like a dumbbell or dog bone and a rectangular bar, as shown in Figure 2.5.

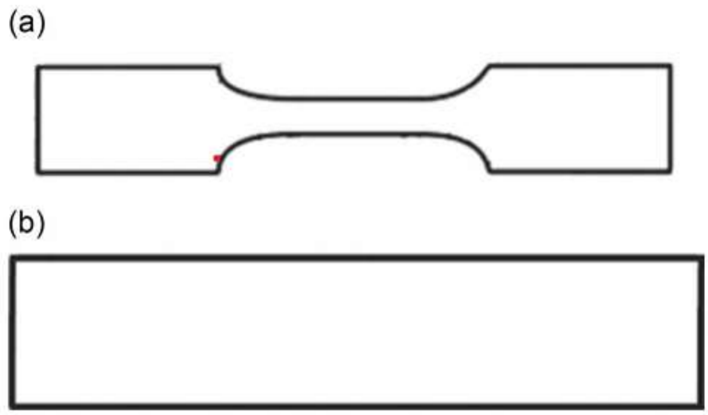

Figure 2.5 Example shape of specimen for tensile testing:

(a) dumbbell or dog bone, and (b) rectangular bar

The instrument was utilized with a crosshead velocity of 2 mm/min at a temperature of 26 3°C and relative humidity of 55 2%. Six specimens with dimensions of 150 x 20 x 3 mm (length x width x thickness) were subjected to the tensile test. The mean values were stated along with their corresponding standard deviations. Every specimen was loaded until it failed. The tensile test outcomes were used to measure the tensile potency, Young's modulus, and elongation percentage. Tensile strength, Young's modulus, and elongation percentage directly apply to prosthetic sockets(Odusote and Kumar et al. 2016). Tensile strength, Young's modulus, and percent elongation of composites increased with fiber loading, as seen in Tables 6 and 7. 50 wt. percent fiber loading gave epoxy and polyester composites the maximum tensile strength.

Tensile characteristics, particularly Young's modulus, increased between 40 and 50 percent. 40–50 percent fiber loading did not raise the modulus of elasticity. Percentage elongation results differed from tensile strength and Young's modulus, which rose with fiber loading. The pineapple leaf epoxy composite had a 12.6 percent difference between 30 and 40% fiber loading and a dramatic drop from 8.93 to 8.15 percent from 40 to 50 percent fiber loading. Glass fiber polyester composite samples had more important mechanical qualities than all pineapple leaf polyester mixed ratios except at 50 wt. percent fiber, whereas pineapple leaf epoxy composite at 40 and 50 wt.% had higher mechanical values than glass fiber polyester composite. Overall, pineapple leaf epoxy composites exhibit the most strength compared to those of the pineapple leaf polyester composite and glass fiber polyester composite.

Table 2.6 The tensile strength of glass fibre and pineapple leaf fibre reinforced polyester composite

Composite	Parameter	Fiber loadings (wt.%)				
		0	20	30	40	50
Pineapple	UTS	10.22±1.93	30.15±3.03	48.78±3.90	62.09±4.87	69.12±5.20
	Y Modulus	1.12±0.02	2.43± 0.07	3.46±0.05	4.81± 0.11	5.03± 0.10
	Elongation	0.98 ± 0.01	2.79± 1.10	3.11 ± 0.06	4.99 ± 0.13	5.44± 0.11
Glass fiber	UTS	65.72 ± 3.30				
	Y Modulus	7.33 ± 3.22				
	Elongation	7.76 ± 1.10				

s

Table 2.7 Pineapple leaf fibre reinforced epoxy composites' tensile characteristics

Composite	Parameter	Fiber loadings (wt.%)				
		0	20	30	40	50
Pineapple	UTS	14.30±2.21	35.88±0.90	62.75±2.10	76.47±3.85	80.12±2.23
	Y Modulus	2.43 ±0.19	5.42 ± 0.10	7.80 ± 0.08	8.93± 0. 11	8.15± 0 .22
	Elongation	2.56 ± 0.13	5.88 ± 0.20	6.92± 0.17	7.55± 0.31	8.24 ± 0.24

2.8.2 Flexural Test (ASTM D790)

A flexural test, also known as a bending test or a 3 point bend testing, is a mechanical test used to determine a material's strength and stiffness when subjected to a bending force. Other names for this test include a bending test and a flexure test. It considers the material's ability to withstand loads without cracking when bending or flexing, as well as its resistance to bending or flexure, and it does so. Figure 2.6 the flexural strength of epoxy and polyester composites reinforced with pineapple leaf fibers. The test of flexural was conducted with a length: 150 mm, width: 20 mm, and thickness: 3 mm. Fibre content boosted all composites' flexural strength. However, pineapple leaf polyester composite flexural strength varied little. From 0 to 20% fiber loading, flexural strength dropped 3.5% before rising again.

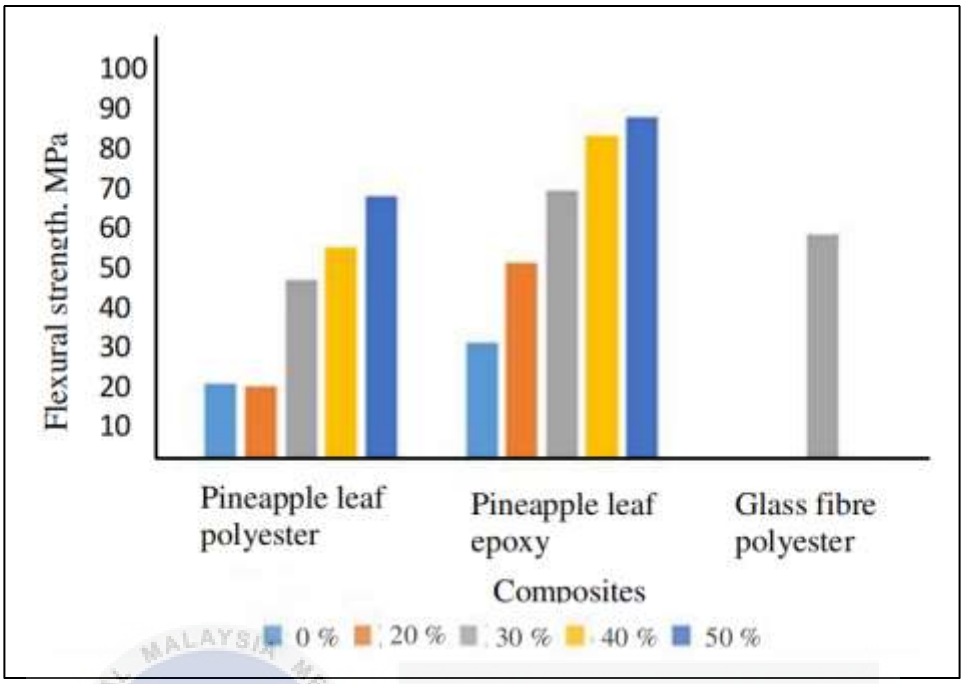

Figure 2.6 The Flexural Strength of Epoxy and Polyester Composites Reinforced with Pineapple Leaf Fibres

Evaluating a material's strength and elasticity is crucial, and flexural properties play a significant role. These properties enable the material to withstand dynamic loads, such as those encountered in the gaiting system (Odusote and Kumar et al. 2016). Except for the 20 percent of pineapple fibre epoxy composite, the flexural strength of all other composite samples rose with increasing fibre loading. This outlier can be due to insufficient fiber loading. After fibers were impregnated, an increase in fiber-to-fiber contact led to increased flexural modulus and strength. The pineapple leaf fiber-reinforced epoxy composites have higher power than the glass fiber and pineapple polyester composites. They are better at withstanding bending forces because they can withstand more flex than strain or modulus than tensile strength. Many crystals in a pineapple leaf allow it to distribute applied loads in a matrix effectively. Additionally, it can withstand bending with different fiber loadings thanks to its crystalline fibril.

2.8.3 Impact test (ASTM D6110)

Plastics with notches in them may have their Charpy impact resistance measured using the ASTM D6110 standard test procedure. The test technique is utilized to assess the durability of plastics against fracture caused by bending shock, as shown by the energy taken out from standardized test samples of a particular size under predetermined sample preparation, notching, and testing conditions. Adding fibers one at a time also increased impact strength in the impact test samples shown in Figure 2.7. Impact strength ratings for glass fibre polyester were greater than those for pineapple leaf polyester and epoxy, especially at 30% fibre loading. Pineapple epoxy and polyester derived from pineapple leaves follow soon after.

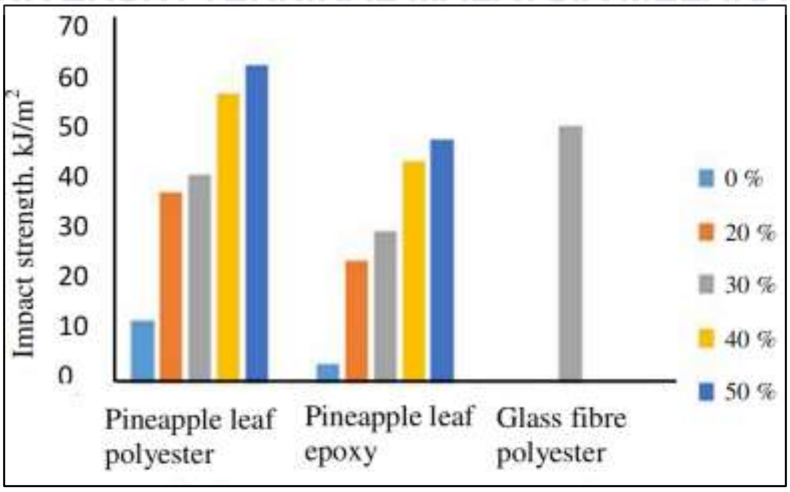

Figure 2.7 The impact testing of glass fiber, epoxy, and polyester reinforcing pineapple leaf composite

Overall, pineapple leaf polyester's ability to absorb energy when subjected to a force is known as impact strength than pineapple leaf reinforced epoxy and glass fiber reinforced polyester at 50%. This quality is closely linked to the toughness of materials. The toughness of a material is directly related to the area beneath its stress-strain curve. However, toughness can be measured by impact strength. Some products necessitate impact resistance. The products' durability also relies upon their ability to withstand impact and prevent damage from impact loads, ensuring safety (Odusote and Kumar et al. 2016).

2.8.4 Water Absorption Test (ASTM D570)

ASTM D570 is a technique used to measure the quantity of water a substance absorbs in particular circumstances. These circumstances include the plastic type, any additives utilized, the temperature, and the duration of exposure. The information illuminates how the materials perform in wet or moist conditions. The sample is submerged in water for a set period. This process was frequently done for 24 hours, 48 hours, 98 hours, 196 hours, and 312 hours. The percentage of water absorption testing is determined using the equation in Figure 2.8.

$$\text{Water absorption (\%)} = \frac{m_2 - m_1}{m_1} \times 100$$

Figure 2.8 Equation of water absorption

m1 = the weight before being submerged in water in grams,

m2 = the weight after being submerged in water in grams.

Figure 2.9 shows a positive association between the percentage of water absorbed during testing and the square root of the time in hours for unidirectional, angle-ply, and cross-ply hybrid composites. Based on Figure 2.9, it is clear that the mixed composite samples quickly absorb water initially, but then the absorption rate decreases until it reaches saturation. S1 showed the highest water absorption in the unidirectional hybrid composite after reaching the saturation point, followed by S2, S3, and S4 (as shown in Figure 2.9a). The S4 sample of the unidirectional composite laminates had the lowest water absorption percentage of any hybrid composite laminates tested, at 3.80%. As seen in S5 and S9, the hybrid angle-ply and cross-ply composite absorbed the most water (6.16% and 5.9%, respectively).

Since angle-ply composites have more fiber and matrix contacts than unidirectional and cross-ply hybrid samples, they absorb more water. Water molecules have less resistance and more channels to move through in materials with angle ply. Thus, increased moisture absorption has been seen in the case of angle ply composite. Water molecules face increased resistance and fewer channels for flow in unidirectional and cross-ply samples. This results in less water being absorbed. C2J6C2 has the lowest water absorption of the four layering sequences because the carbon fiber layers are on the exterior of the composite. Carbon fibers substantially reduce the quantity of water a composite absorbs.

Due to the diffusion of water molecules from the jute fiber, the C2J3C2J3 stacking sequence exhibited moderate water absorption. Two carbon layers are located at the bottom, followed by three jute layers, two carbon fiber layers, and three jute layers at the top. Due to jute fiber layers on both surfaces of the hybrid composite J3C4J3, it exhibited weak water resistance. They allowed water molecules to permeate the layers, rapidly absorbing large quantities of water. They observed composites that were unidirectional, angle-ply, and cross-ply. The S4 sample with the C2J6C2 stacking sequence exhibited the least water absorption, measuring 3.8%. Although there was a minor difference in water absorption between layering sequences, there was no significant difference between fiber orientations in hybrid composites.

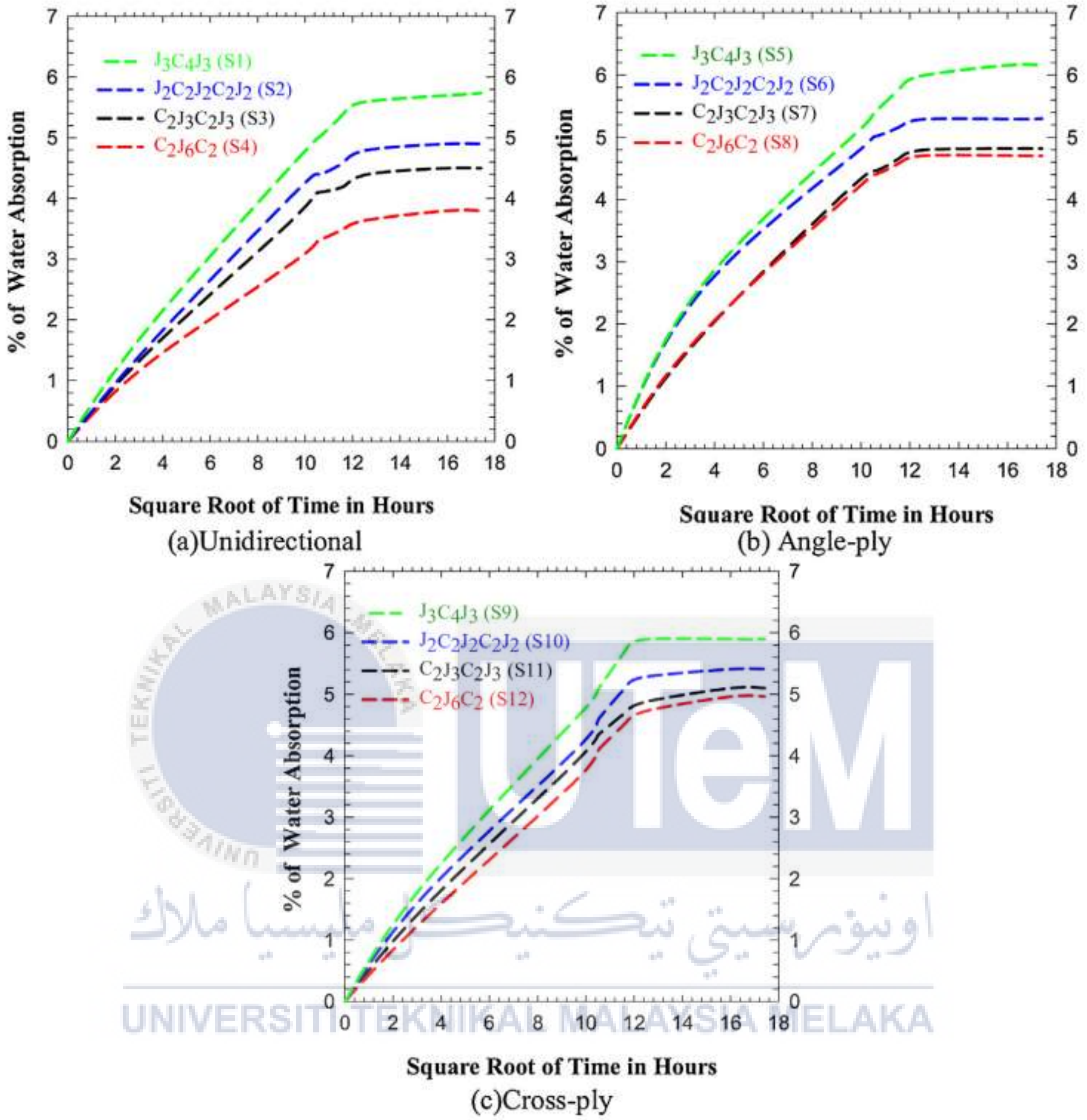

Figure 2.9 Unidirectional (a), Angle-ply (b), and Cross-ply (c) water absorption curve (Abu Shaid Sujon, Habib, and Abedin 2020)

2.9 Summary

Table 2.8 Summary of previous research

No.	Literature Title	Materials	Result	Testing	References
1.	Comparative studies and mechanical properties on the different volume fractions of pineapple leaf fiber and jute fiber reinforced epoxy resin composites	- Pineapple fiber + jute Fiber + epoxy resin	- 20% pineapple leaf fiber+80% epoxy resin has a hardness value of 80.67 N/mm2. - The pineapple leaf fiber (20% and +80% Epoxy resin) has high ultimate, flexural, and elongation values. - Compared to jute fiber (10% pineapple leaf fiber +10% jute fiber and Epoxy Resin). - Pineapple has around 80% cellulose content. PALF has the highest Young's modulus, density, and tensile strength of related natural fibers. It's perfect	- Tensile test - Flexural test - Hardness test	(Nirmaladevi et al. 2022)

			for building materials, vehicle parts, and furniture.		
2.	Mechanical behavior of glass fiber polyester hybrid composite filled with natural fillers	- Glass fiber + polyester resin - Glass fiber + banana chopped filler + polyester resin - Glass fiber + rice husk filler + polyester resin	- Banana chopped filler boosts tensile strength. Tensile strength rises with rice husk filler loading (5–10wt%) but decreases at 15wt%. 15wt% banana chopped filler yields the highest tensile strength, while rice husk yields the lowest. - Flexural strength increases with rice husk filler loading (5–10wt%) but decreases at 15wt%. Regardless of fiber orientation, 15wt% chopped banana filler loading yields the highest flexural strength, while rice husk yields the lowest. - Banana chopped filler improves impact strength. Rice husk filler addition enhances impact strength (5–10wt%) but decreases (15wt%) regardless of fiber orientation. 10wt%	- Tensile test - Flexural test - Hardness test	(Gupta et al. 2016)

			rice husk filler loading maximizes impact strength. - Rice husk filler hardens. Banana chopped fillers enhance hardness (5wt% to 10wt%) but reduce at 15wt%. Regardless of fiber orientation, 10% chopped banana filler loading (C3) yields the highest hardness, whereas 5wt% rice husk yields the lowest.		
3.	Green composites of natural fiber bamboo/pineapple leaf/coconut husk as hybrid materials	- Bamboo + Pineapple leaf + polyester resin - Coconut husk Fibers + Pineapple leaf + polyester resin - Bamboo + Pineapple leaf + Coconut husk +	- The bamboo pineapple-coconut husk fiber composite material had a 366 MPa maximum tensile strength. - The bamboo-pineapple-coconut husk mixture can produce a bending strength of 0.302 kN. - Flat surface and matrix-filler interface interlocking affect the composite's mechanical characteristics. - Fiber cellulose affects composite tensile and compound properties.	- Tensile test - Flexure test - Scanning electron microscopy test	(Suryani et al. 2020)

		polyester resin			
4.	Effects of fiber loading on mechanical characterization of pineapple leaf and sisal fibers reinforced polyester composites for various applications	- Pineapple leaf fiber + polyester resin - Sisal fibers + polyester resin	- Polyester composite specimens with 50% natural fiber had 207.5 MPa, 4078 MPa, and 13.8% maximum tensile strength, modulus, and elongation. - 50% natural fiber specimen had maximum flexural strength and modulus of 90.3 MPa and 3478, respectively. - In specimens with 50% natural fiber, impact strength reaches 29 J/m2 and hardness 83.7. - Adhesion between natural fibers and polyester matrix may improve mechanical properties. Industrial, automotive, and construction industries can employ this composite material.	- Tensile test - Flexure test - Imapact test	(Sathees Kumar, Muthalagu, and Nithin Chakravarthy et al. 2021)

5.	Mechanical Properties of Pineapple Leaf Fiber-reinforced Polyester Composites	- Pineapple leaf fiber + polyester resin	- PALF polyester composites' tensile strength and Young's modulus rose linearly with fiber weight fraction. - Flexural strength above 30%. Fiber weight fraction increased impact strength linearly. - 30 wt% fiber composites have 24 kJ/m2 impact strength.	- Tensile test - Flexure test - Impact test	(Devi, Bhagawan, and Thomas et al. 1997)
6.	Mechanical properties of pineapple leaf fiber reinforced Polymer composites for application as a prosthetic socket	- Pineapple leaf fiber + polyester resin - Pineapple leaf fiber + epoxy resin - Glass fiber + polyester resin	- Glass fiber and pineapple fiber-reinforced polyester composites have poorer flexural, impact, and tensile characteristics than epoxy composites. - Pineapple leaf fiber-reinforced epoxy resin - could replace fiberglass polyester prosthetic sockets, especially above-knee ones that need more strength. - Pineapple leaf fiber is biomechanically adequate, lightweight, pleasant, and psychosocially acceptable.	- Tensile test - Flexure test - Impact test	(Odusote and Kumar et al. 2016)

7.	Mechanical properties of waste natural fibers/fillers reinforced epoxy hybrid composites for automotive applications	- Sample 1 = Epoxy Matrix (50) + jute fiber (25) + sugarcane bagasse (15) + coconut coir (5) +neem wood (5) - Sample 2 = Epoxy Matrix (50) + jute fiber (25) + sugarcane bagasse (5) + coconut coir (15) +neem wood (5) - Sample 3 = Epoxy Matrix (50) + jute fiber (25) + sugarcane bagasse (5) + coconut coir (5) +neem wood (15)	- Sample 3 increased tensile strength to 9.178 MPa. Compared to sample 1, composite samples 2 and 3 had 48.1 and 28.8% tensile values. - Sample 3 achieved maximum flexural (9.6 MPa) and impact energy (2 J). The percentage of flexural values (sample 2–84.15, sample 3–44.3) - Impact values (sample 2–40 J, sample 3–15 J) compared to sample 1. Due to fiber and powder dispersion in a jute/epoxy matrix, - Sample 3 shows good tensile, flexural, and impact properties. - Dashboards, door panel upholstery, and bumpers can benefit from this material.	- Tensile test - Flexure test - Impact test	(Dattatreya et al. 2023)

8.	Development of glass/jute fibers reinforced polyester composite	- Jute fiber + polyester resin - Glass fiber + polyester resin - Jute fiber + polyester resin + glass fibers	- 25%–35% natural fiber content is allowed for 30% and 40% reinforcement. - Natural fibers can replace 50% of glass fibers for 10% of support. - Chemically treated jute fibers have higher fiber/matrix interfacial strength than glass fibers, increasing mechanical characteristics. - Glass fiber + jute fiber-reinforced polyester composites have better characteristics than others.	- Tensile test - Flexure test - Impact test - Water Absorption Test	(Bindal et al. 2013)
9.	The effect of different fiber loading on flexural and thermal properties of banana/pineapple leaf (PALF)/glass hybrid composite	- Glass fiber - Banana - Pineapple leaf fiber	- Banana and PALF hybrid composites should have 40 wt% fiber volume. At 40 wt%, banana glass hybrid composite had 90.951 MPa flexural strength and PALF glass hybrid 105.087 MPa. - TGA showed that banana-glass and PALF-glass hybrid composites had	- Flexure test - Thermogravimetric analysis (TGA) - Dynamic mechanical analysis	(Zin, Abdan, and Norizan 2018)

			the best onset degradation temperature at 40 wt%. - DMA investigation demonstrated a shift in the Tg for banana-glass hybrid composite from 30 to 40 wt%, indicating optimum conditions for composite sample molecular structure stability.		
10.	Investigation of mechanical testing on hybrid composite materials	- Glass fiber + epoxy resin - Kenaf/ glass + epoxy resin - jute/glass + epoxy resin	- Tensile experiments demonstrate that kenaf hybrid composites are stronger than jute hybrid composites but weaker than glass fiber composites. – - Kenaf hybrid composites last longer before failing the other two varieties. - Kenaf hybrid composites have the highest compressive strength to tensile strength ratio of 47.48%.	- Tensile test - Compress test	(Hamidon, Sultan, and Ariffin et al. 2018)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section provides comprehensive details about particular procedures or methods for identifying, selecting, and analyzing data related to this experiment. The methodology section of this chapter enables the reader to critically assess the entire process and rehabilitation. This researcher utilizes the process flow to achieve the current work goal and objective. The investigation will be carried out in three phases. The initial step involves manually soaking, drying, and blending the materials to become fiber for the experiment. The next step is to cut the fabricated material using the CNC router machine into experiment specimens.

Then, four types of testing are conducted to assess the material's strength: tensile testing, flexural testing, impact testing, and water absorption testing. The last stage involves examining the experimental material. The analysis will focus on data obtained from tests such as tensile testing, flexural testing, impact testing, and water absorption. This experiment aims to find out which of the four testing methods will produce better results for the quality and mechanical properties of the specimen material. This chapter will briefly summarise the experiment and methodology employed to obtain an accurate and consistent outcome. This section established the details of the investigation.

3.2 Project Experiment Process

Composite slabs are fabricated using the traditional method of hand lay-up. Pineapple leaf is combined with polyester resin to serve as the matrix material, while glass fiber is utilized as a reinforcement. The polyester resin, hardener, and accelerator are mixed in different ratios of 20:80, 40:60, 50:50, 60:40, and 80:20 for curing at room temperature. Composite fabrication utilizes a silicon mold with dimensions of (300 ×200× 10) mm^3. By stirring, the natural fillers are combined with polyester resin. Then, the resulting mixture is poured into molds that meet the standards for different testing conditions and characterization. Once the composite mix is ready, it is poured into a mold to produce sheets with the desired thickness.

The composite is permitted to solidify or set. After the composite sheets are treated, they are cut to the necessary dimensions for examination. The layered sheets are placed onto the CNC router machine to specify the cutting and molding procedures. The software determines the tool's path, the cut's depths, and the shapes needed for the specimens. The CNC router machine executes the instructions, leading to the precise cutting and shaping of composite samples. Any leftover material or rough edges produced during cutting are eliminated to maintain consistency and avoid stress concentration points. The specimens are meticulously purified to eliminate any fragments or impurities that could impact subsequent analysis.

The specimens composite that were made were tested mechanically to assess their performance. The assessments comprise tensile strength, flexural strength, impact strength, and water absorption measures. These examinations offer an understanding of the hybrid composite's physical performance and structural integrity. Data gathered from mechanical tests are collected and documented for experimentation purposes. Conducting statistical analysis is necessary to determine the importance of the findings. The mechanical characteristics of the hybrid composite, including its strength, stiffness, and toughness, are examined to obtain the best ratio preparation of glass fiber pineapple leaf-reinforced polyester hybrid composite.

3.2.1 Process flowchart

A process flowchart illustrates the steps in accomplishing a task or reaching an objective. It's a potent instrument that assists people and groups in comprehending, examining, and enhancing their procedures. A flowchart is a visual diagram that shows the order of actions or tasks in a process. It employs uniform symbols and connectors to illustrate the movement of data, substances, or activities. Flowcharts are mainly used to improve a process's comprehension, communication, and analysis. Stakeholders help pinpoint improvement areas, simplify workflows, and increase overall efficiency.

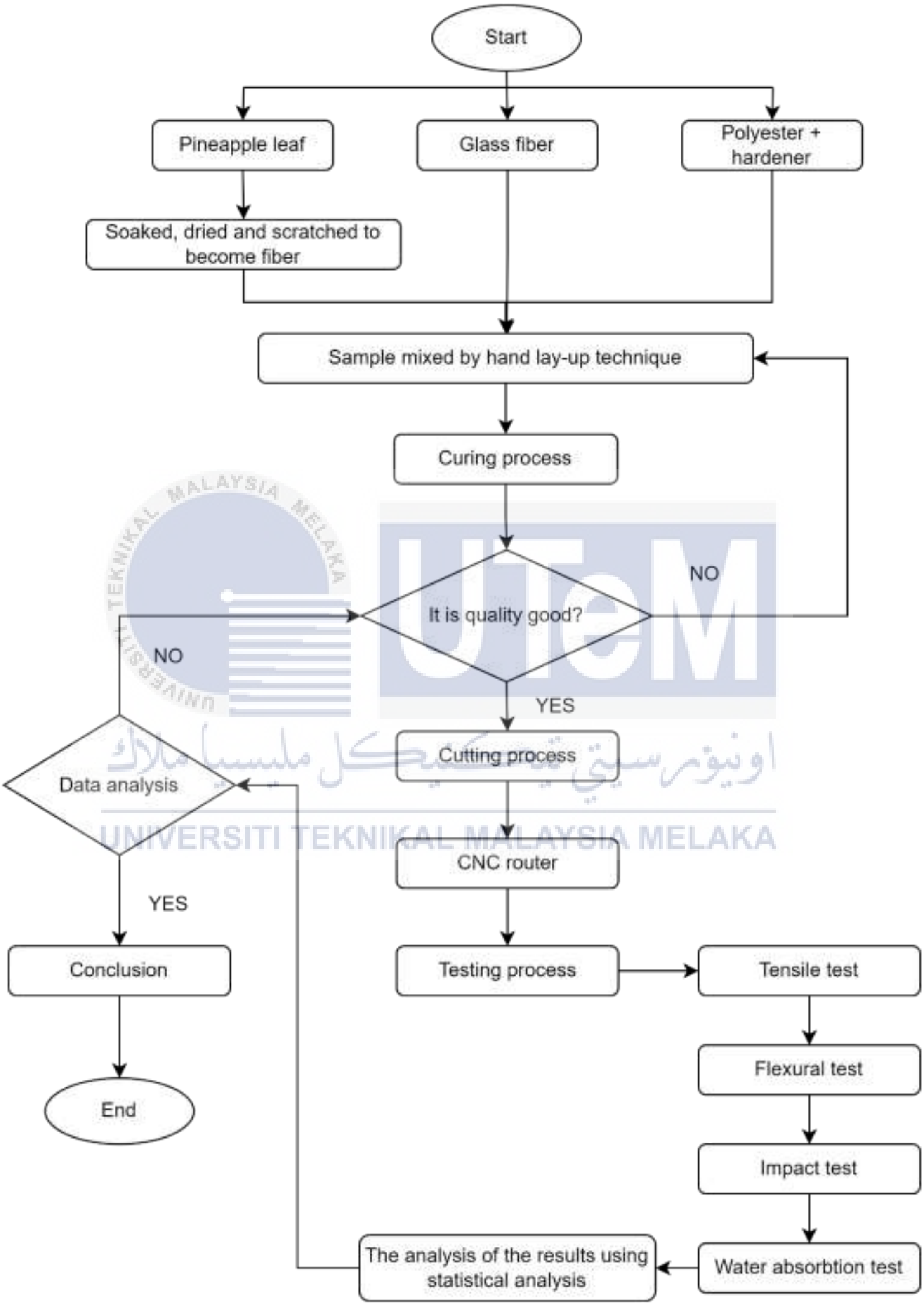

Figure 3.1 Process Flowchart

The process in this study is illustrated in Figure 3.1, covering all stages from beginning to end. Firstly, the experimental research process will create the sample by using a mixture of glass fiber pineapple leaf-reinforced polyester hybrid composite. The model will then be cut to a particular size. The piece will be readied using a compression device to enhance its strength for acquiring reliable information. Once the materials are flawless, the process of cutting can commence. Next, the CNC router machine is utilized to cut the sample. Once the specimen is prepared, it will be cut using these devices. The CNC router machine will slice the specimen into four parts for conducting tensile, flexural, impact, and water absorption tests. The dimensions for the tensile testing are 250mm in length and 25mm in width. The size of the tensile test is predetermined. Consequently, the samples must be cut based on pre-established measurements. The examination procedure includes flexure, impact, and water absorption testing. Collect and analyze the information after performing the cutting process on the sample. Insufficient data will lead to slicing the specimen and collecting more information to achieve better results.

3.3 Design of trial sample material specimen

The sample size will be 300mm x 200mm, as shown in Figure 3.2. After the specimen is developed, it will be trimmed to a specific size and tested for tensile strength, flexural strength, impact resistance, and water absorption. These samples are designed to comply with testing criteria to determine superior material characteristics post-cutting. The models come in three sizes: 250mm x 25mm for the tensile and flexural tests, 100mm x 15mm for the impact test, and the remaining size for the water absorption test.

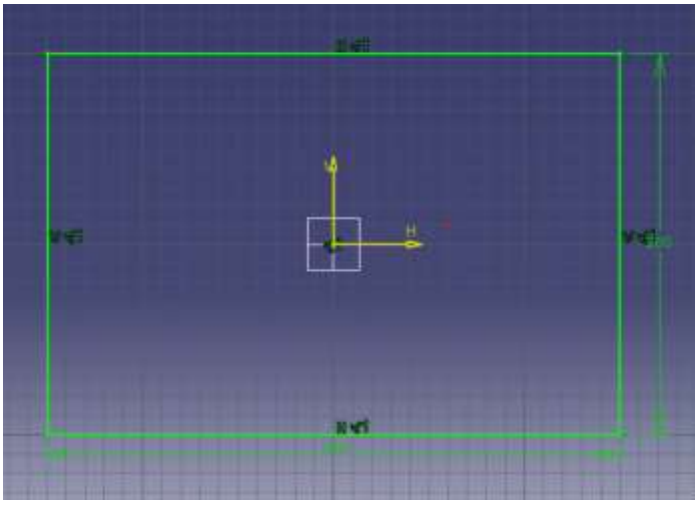

Figure 3.2 The dimension of specimen

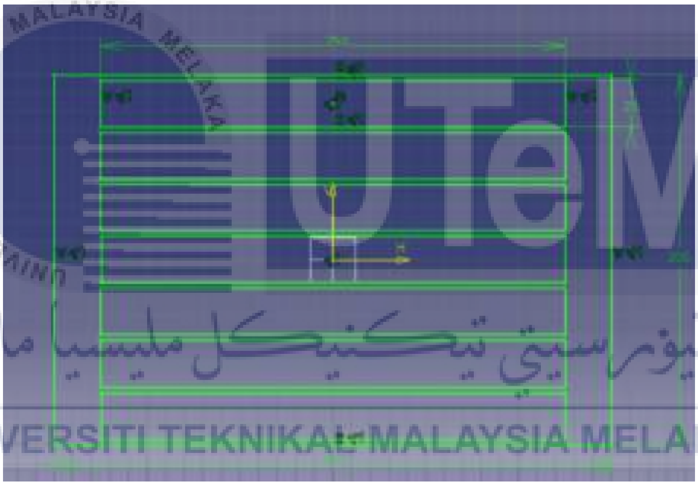

Figure 3.3 Dimension Size of Specimen Tensile and Flexural Testing

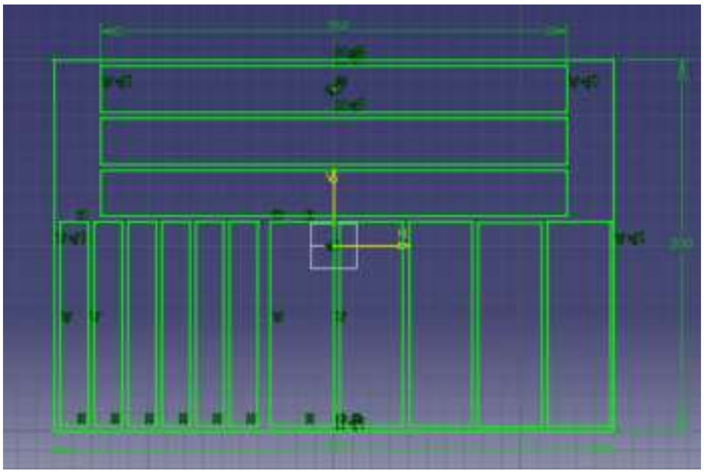

Figure 3.4 Dimension Size of Specimen Flexural, Impact, and Water Absorption Testing

3.4 Experimental Procedure

The experimental method used in this study is a systematic procedure for each category. Every technique or operation in this research has its individual Standard Operating Procedure (SOP). These procedures are essential to guarantee the smooth running of operations and processes. For every approach to yield accurate and satisfactory outcomes, it is necessary to have a focal point. This part will explore different stages, such as the evaluation phase. After that, this chapter will cover some significant procedures or steps. The process involves testing for tensile strength, flexural strength, impact resistance, and water absorption.

3.4.1 Fabrication Material

Pineapple leaves in Malaysia are commonly wasted due to insufficient awareness of their economic potential. Typically, farmers discard or incinerate most of the pineapple plant's leaves once they have harvested the fruit. Burning pineapple leaves openly can also cause environmental problems. The leaf of the pineapple was obtained from Batu Pahat, Johor. For the first process, all the leaves are taken off from the pineapple. After that, to create pineapple leaf powder the pineapple leaves need to be soaked in water for 24 hours. The pineapple leaves are washed and dried in the sun for several months until all the moisture is removed. Next, cut the dehydrated pineapple foliage into tiny bits using scissors for effortless blending. Crush the small fragments using a mixer and crusher machine and store them in a moisture-free receptacle to prevent exposure to liquid. Dried pineapple leaves that have become powder are depicted in Figure 3.5

Figure 3.5 a) Grinding Machine, b) Pineapple leaf powder

For the testing, you need two composite sheets of silicon mold for each ratio. There are two types of mold used for this experiment. The size of each silicon mold is 312mm x 212mm x 10mm. After the pineapple leaf, and the polyester resin is ready to be weighed. They mix it. After that, the hand layup technique is used to saturate the glass fibers and pineapple leaf fibers with polyester resin. The hand layup process are depicted in Figure 3.6. Before doing the hand layup, it is important to ensure that the silicon mold is clean and dry. Additionally, the composite is then cured. Typically, the composite is left at room temperature for 48 hours to allow the polyester resin to harden and create a sturdy and long-lasting material. This process will continue until all combinations of the composites 20:80, 40:60, 50:50, 60:40, and 80:20 are finished.

Figure 3.6 Hand layup process

3.4.2 CNC Router Machine Process

It must be positioned on the vice's top surface to secure the material. It must be set to zero to reset the position or coordinate axis on the computer control panel. The cutting instrument must remain in the identical place once the coordinates have been verified in the NC code format. Spindle velocities of 100 rotations per minute, 200 cycles per minute, and 300 rotations per minute are employed.

Figure 3.7 CNC Router Machine

3.4.3 Tensile Testing Process

Once the pineapple leaf laminate is cut, tensile test was on the specimen material using a universal testing machine. The ASTM D3039 test standard was utilized to determine the ultimate tensile strength, the strain to failure, and Young's modulus of the produced composites. The specimens for the test were sliced into strips that were 250 millimeters in length and 25 millimeters wide. The SHIMADZU universal testing machine model can be found in the FTK laboratory. The next thing that needs to be done is to enter all the data into the computer. The dimension of all specimens was 250 mm x 25 mm x 1 mm (length width thickness) as shown in Fig. 3.8 shows the realistic picture of static tensile test specimen. Each kind of composite was tested five times. After completing the tensile operation, the tensile test results will be shown on the computer.

Figure 3.8 Tensile test specimen

3.4.5 Flexural Testing

During the flexural test, a sample of composite material made of glass fiber and polyester is filled with pineapple leaf and loaded horizontally using a three-point loading configuration. The static three-point bending test was performed at the FTK laboratory with a universal testing machine of the SHIMADZU model. The dimension of all specimens was 250 mm x 25 mm x 1 mm (length width thickness) as shown in Fig. 3.9 shows the realistic picture of a static flexural test specimen. Each kind of composite ratio was tested five times. In a 3-point bend test, the tensioned side of the sheet or plate is convex, causing the outer fibers to experience the highest levels of stress and strain. Failure happens when the material's limits are surpassed by strain or elongation. Typically, a support span upholds the specimen while the loading nose applies a load to the center, causing three-point bending at a fixed speed. The test parameters include the support span, loading velocity, and maximum deflection. The definition of these characteristics varies according to the thickness of the sample being tested, as per ASTM and ISO. The ASTM D790 examination concludes when the model deflects by 5% or fractures before this stage. Once this testing is completed, the computer will display the flexural test results. For the flexural test, we will require data such as flexural stress and strain at yield and break, among others. Additionally, stress and strain graphs and unprocessed data may be available.

Figure 3.9 Flexural test specimen

3.4.6 Impact Testing Process

Testing the impact is essential to assess substances' mechanical characteristics and efficiency when exposed to high-velocity impact or shock-loading circumstances. The process includes applying a controlled impact force on a material sample and analyzing its reaction to determine its durability, resilience, and energy absorption capacity. It involves rapidly loading a model to evaluate its impact strength. Determining the impact value of materials is carried out by conducting various experiments. Impact testing commonly consists of the use of Charpy impact testers. Charpy technique, the model remains horizontal as it is upheld on both ends. Once the procedure is completed, the impact test outcome will be accurately documented. Finally, move on to the next stage of the process once all the testing has been finished.

Figure 3.10 Impact test machine

3.4.7 Water Absorption Testing Process

Assessing the moisture resistance and durability of composite materials is crucially done through water absorption testing. Water absorption can cause composite materials to degrade, change dimensions, lose mechanical properties, or experience other harmful effects. Comprehending their ability to resist moisture is essential in forecasting their durability in practical settings. Precisely weigh and document the starting weight of every composite sample using an accurate scale. Keep the composite samples submerged in water for a set amount, around 25 days. Once the assigned testing time is over, remove the combined samples from the water and softly dab away any remaining water on the surface. The formula for calculating water absorption is:

Water Absorption (%) = [(Final Weight - Initial Weight) / Initial Weight] x 100

A higher water absorption rate implies a higher tendency to absorb moisture, which may result in reduced durability, changes in size, or possible deterioration over time.

Figure 3.11 Water absorption process

3.5 Summary

Each of these processes and preparations must be carried out correctly and by the process planning for the project to achieve its goals. By the time we reach the end of this chapter, we will have understood how critical methods, planning, and preparation are to achieving desired results and performance. In conclusion, to get reliable results from these examinations, each process must be carried out precisely and without making any mistakes.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter contains a detailed explanation of the outcomes that were achieved based on the analysis and results, along with the calculations that were utilized. To evaluate the PLRP composite, there are four types of testing will be carried out specifically, tensile testing, flexural testing, impact testing, and water absorption testing. The results of the study are based on the data that was collected from these experiments. In all testing procedures, the ASTM Standard is applied as a guide for specimen dimensions for the objectives of this investigation.

4.2 Result and Analysis of Tensile Test

Testing for tensile strength is an essential technique for determining the mechanical properties of materials. It provides significant data on the materials' overall performance, as well as their stiffness and elasticity. Specifically focused on the ratio of PL20P80, PL40P60, PL50P50, PL60P40, and PL80P20, the findings and analysis of the tensile strength and elasticity tests that were performed on PLRP composites are displayed in Figures 4.1 and 4.2. Because the testing procedure was carried out by the ASTM D3039 standard, the results that were produced were guaranteed to be accurate and reliable. Figure 4.1 shows that the tensile strength of PL40P60 was found to be higher than other ratios. This indicates that it can endure loads that are applied to it before it fails. On the other hand, PL80P20 demonstrated a lower tensile strength, which indicates that it has a weaker resistance to forces applied from the outside. Figure 4.2 shows that the PL40P60 material exhibited increased elasticity. In terms of elasticity, PL80P20 demonstrated a lower value, which indicates stiff behavior and less ability to deform and recover. According to these findings, PL40P60, which had a greater percentage of pineapple leaf reinforcement (40%), benefited from an enhanced fiber content, which contributed to an improvement in tensile strength during the process.

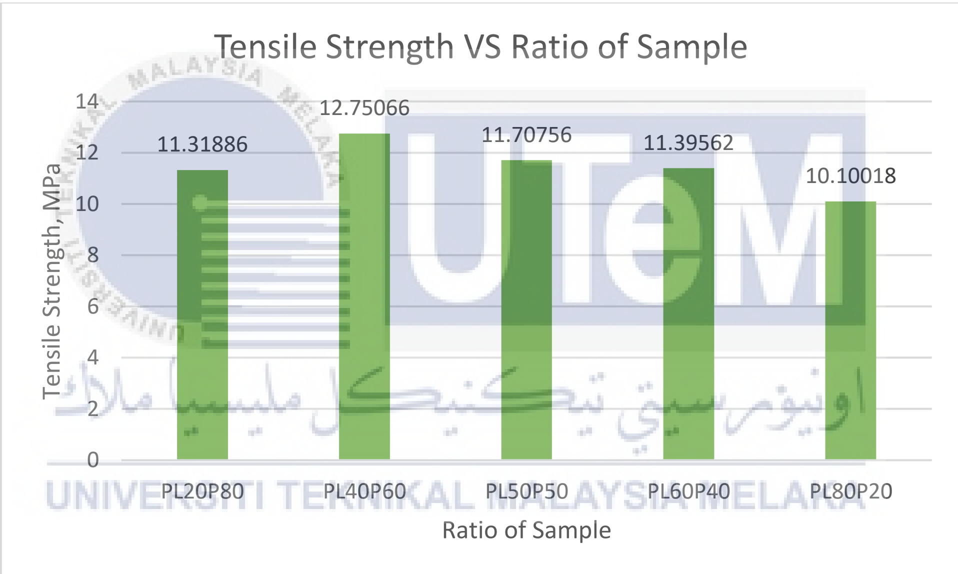

Figure 4.1 Tensile Strength for five ratios of PLRP composite

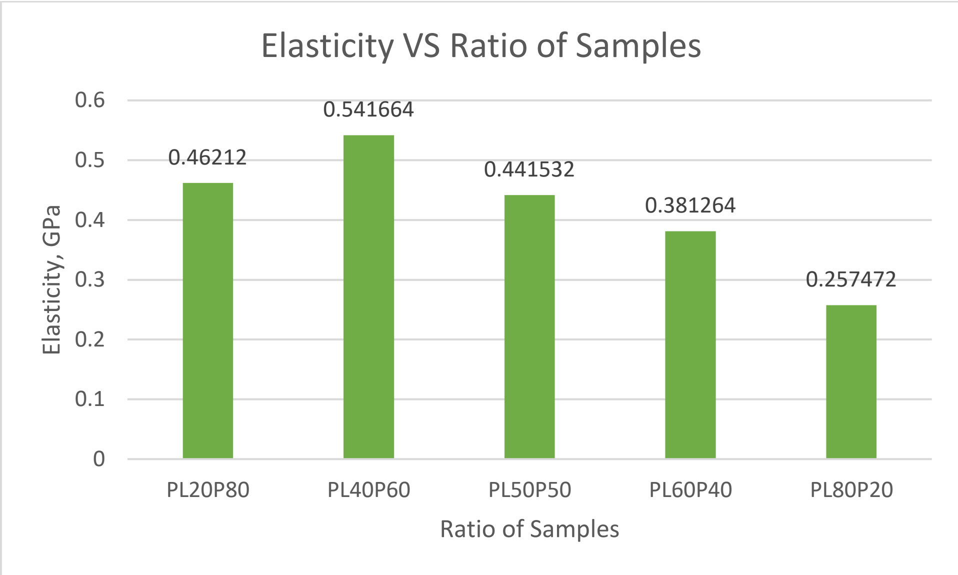

Figure 4.2 Elasticity for five ratios of PLRP composite

Figure 4.3 Tensile test specimen

As given in Tables 4.1 and 4.2, a one-way analysis of variance (ANOVA) was performed to analyze the tensile strength and elasticity of the PLRP composites. The results prove that the tensile strength and elasticity of the PLRP composites remained statistically significant throughout all five ratios. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of tensile strength and elasticity throughout the five ratios of PLRP composites. The highest possible tensile performance is achieved by combining pineapple leaf and polyester resin in a ratio of 40% each.

Table 4.1 Summary statistics result of Tensile Strength

SUMMARY

Ratio	*Count*	*Sum*	*Average*	*Variance*
PL20P80	5	56.5943	11.31886	0.12096
PL40P60	5	63.7533	12.75066	0.226371
PL50P50	5	58.5378	11.70756	0.552321
PL60P40	5	56.9781	11.39562	0.068956
PL80P20	5	50.5009	10.10018	0.45799

Table 4.2 ANOVA of Tensile Strength for five different ratios of PLRP Composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Ratios	18.00059	4	4.500147	15.77231	5.61E-06	2.866081
Within Ratios	5.706391	20	0.28532			
Total	23.70698	24				

Based on Table 4.3, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with $\alpha = 0.05$ and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}(5,20)$= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5,20)\sqrt{\frac{0.2853}{5}} = 4.24\sqrt{\frac{0.2853}{5}} = 1.0128$$

Thus, any pairs of ratio averages that differ in absolute value by more than 1.0128 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 11.3189$, $\bar{y}_2 = 12.7506$

$\bar{y}_3 = 11.7076$, $\bar{y}_4 = 11.3956$

$\bar{y}_5 = 10.1001$

and the differences in averages are;

$\bar{y}1 - \bar{y}2 = 11.3189 - 12.7506 = -1.4317$

$\bar{y}1 - \bar{y}3 = 11.3189 - 11.7076 = -0.3887$

$\bar{y}1 - \bar{y}4 = 11.3189 - 11.3956 = -0.0767$

$\bar{y}1 - \bar{y}5 = 11.3189 - 10.1001 = 1.2188^*$

$\bar{y}2 - \bar{y}3 = 12.7506 - 11.7076 = 1.0430^*$

$\bar{y}2 - \bar{y}4 = 12.7506 - 11.3956 = 1.3550^*$

$$\bar{y}_2 - \bar{y}_5 = 12.7506 - 10.1001 = 2.6505^*$$

$$\bar{y}_3 - \bar{y}_4 = 11.7076 - 11.3956 = 0.3120$$

$$\bar{y}_3 - \bar{y}_5 = 11.7076 - 10.1001 = 1.6075^*$$

$$\bar{y}_4 - \bar{y}_5 = 11.3956 - 10.1001 = 1.2955^*$$

When there are significant differences between the means of pairs, there are star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

Table 4.3 Summary statistics result of Elasticity

SUMMARY

Ratio	*Count*	*Sum*	*Average*	*Variance*
PL20P80	5	2.3106	0.46212	0.000904
PL40P60	5	2.70832	0.541664	0.004405
PL50P50	5	2.20766	0.441532	0.000604
PL60P40	5	1.90632	0.381264	0.000859
PL80P20	5	1.28736	0.257472	0.001812

Table 4.4 ANOVA Elasticity for five different ratios of PLRP Composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Ratios	0.224524	4	0.056131	32.69883	1.63E-08	2.866081
Within Ratios	0.034332	20	0.001717			
Total	0.258856	24				

Based on Table 4.4, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with $\alpha = 0.05$ and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.0017}{5}} = 4.24\sqrt{\frac{0.0017}{5}} = 0.0782$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.0782 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 0.4621,\ \bar{y}_2 = 0.5417$

$\bar{y}_3 = 0.4415,\ \bar{y}_4 = 0.3812$

$\bar{y}_5 = 0.2574$

and the differences in averages are;

$\bar{y}1 - \bar{y}2 = 0.4621 – 0.5417 = -0.0796$

$\bar{y}1 - \bar{y}3 = 0.4621 – 0.4415 = 0.0206$

$\bar{y}1 - \bar{y}4 = 0.4621 – 0.3812 = 0.0809$*

$\bar{y}1 - \bar{y}5 = 0.4621 – 0.2574 = 0.2047$*

$$\bar{y}_2 - \bar{y}_3 = 0.5417 - 0.4415 = 0.1002^*$$

$$\bar{y}_2 - \bar{y}_4 = 0.5417 - 0.3812 = 0.1605^*$$

$$\bar{y}_2 - \bar{y}_5 = 0.5417 - 0.2574 = 0.2843^*$$

$$\bar{y}_3 - \bar{y}_4 = 0.4415 - 0.3812 = 0.0603$$

$$\bar{y}_3 - \bar{y}_5 = 0.4415 - 0.2574 = 0.1841^*$$

$$\bar{y}_4 - \bar{y}_5 = 0.3812 - 0.2574 = 0.1238^*$$

When there are significant differences between the means of pairs, there are star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

4.3 Result and Analysis of Flexural Test

The experimental bending responses are identified by applying universal testing equipment with a three-point bend test. The tests performed on the specimens were prepared by ASTM D 790 standard. This experiment determines and analyses which of the five different ratios of PL20P80, PL40P60, PL50P50, PL60P40, and PL80P2 can withstand the maximum flexural stress without breaking down. Figure 4.4 shows that the PL40P60 has a higher maximum flexural stress than other ratios. This shows that PL40P60 can withstand a higher bending force before failure compared to other ratios. However, PL80P20 had a lower maximum stress compared to other ratios.

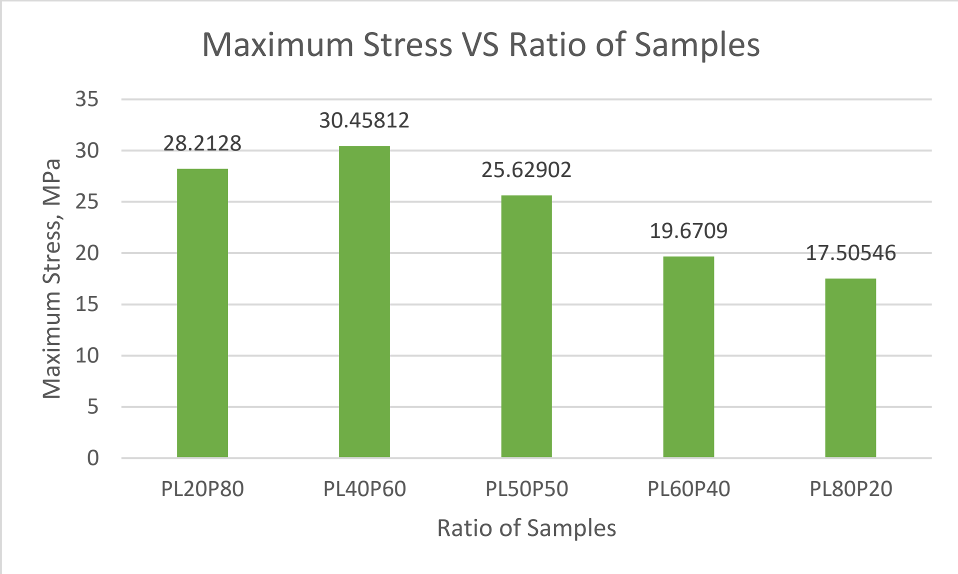

Figure 4.4 Maximum Stress for five ratios of PLRP composite

Figure 4.5 Flexural test specimen

As given in Tables 4.5 and 4.6, a one-way analysis of variance (ANOVA) was performed to analyze the maximum flexural stress of the PLRP composites. The results prove that the maximum flexural stress of the PLRP composites remained statistically significant throughout all five ratios. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of maximum flexural stress throughout the five ratios of PLRP composites. The highest possible flexural stress performance is achieved by combining pineapple leaf and polyester resin in a ratio of 40%.

Table 4.5 Summary statistics result of maximum stress

SUMMARY

Ratio	*Count*	*Sum*	*Average*	*Variance*
PL20P80	5	141.064	28.2128	0.429491
PL40P60	5	152.2906	30.45812	0.110127
PL50P50	5	128.1451	25.62902	0.109635
PL60P40	5	98.3545	19.6709	0.513013
PL80P20	5	87.5273	17.50546	0.351341

Table 4.6 ANOVA of maximum stress for five different ratios of PLRP Composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Ratios	612.9648	4	153.2412	506.2122	8.73E-20	2.866081
Within Ratios	6.054426	20	0.302721			
Total	619.0193	24				

Based on Table 4.6, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.3027}{5}} = 4.24\sqrt{\frac{0.3027}{5}} = 1.0432$$

Thus, any pairs of ratio averages that differ in absolute value by more than 1.0432 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1$= 28.2128, $\bar{y}_2$ = 30.4581

$\bar{y}_3$ = 25.5290, $\bar{y}_4$ = 19.6709

$\bar{y}_5$ = 17.5055

and the differences in averages are;

ȳ1 - ȳ2 = 28.2128 – 30.4581 = -2.2453

ȳ1 - ȳ3 = 28.2128 – 25.5290 = 2.6838*

ȳ1 - ȳ4 = 28.2128 – 19.6709 = 8.5419*

ȳ1 - ȳ5 = 28.2128 – 17.5055 = 10.7073*

ȳ2 - ȳ3 = 30.4581 – 25.5290 = 4.9291*

ȳ2 - ȳ4 = 30.4581 – 19.6709 = 10.7872*

ȳ2 - ȳ5 = 30.4581 – 17.5055 = 12.9526*

$$\bar{y}_3 - \bar{y}_4 = 25.5290 - 19.6709 = 5.8581^*$$

$$\bar{y}_3 - \bar{y}_5 = 25.5290 - 17.5055 = 8.0235^*$$

$$\bar{y}_4 - \bar{y}_5 = 19.6709 - 17.5055 = 2.1654^*$$

When there are significant differences between the means of pairs, there are star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

4.4 Result and Analysis of Impact Test

The purpose of the impact test is to find out the way a composite specimen reacts to a suddenly applied stress. The ratio of PL20P80, PL40P60, PL50P50, PL60P40, and PL80P20 used for impact testing, all one of which has a specific shape called the V-notch. When a V-notched of PLRP breaks under an impact load, the Charpy impact test measures the amount of energy it takes in. For this test, a hammer is used to hit a PLRP that is hanging from a pendulum arm. The composite of PLRP is held firmly at both ends. The exact amount of energy taken by the PLRP can be found by measuring the amount that the pendulum arm slows down. Based on Figure 4.9, the PL40P60 ratio had a higher impact strength, which means it could absorb and release energy more effectively under sudden loading situations than other ratios. On the other hand, a ratio of PL80P20 had a smaller impact strength, which means it could not handle and absorb as many impact forces compared to another ratio.

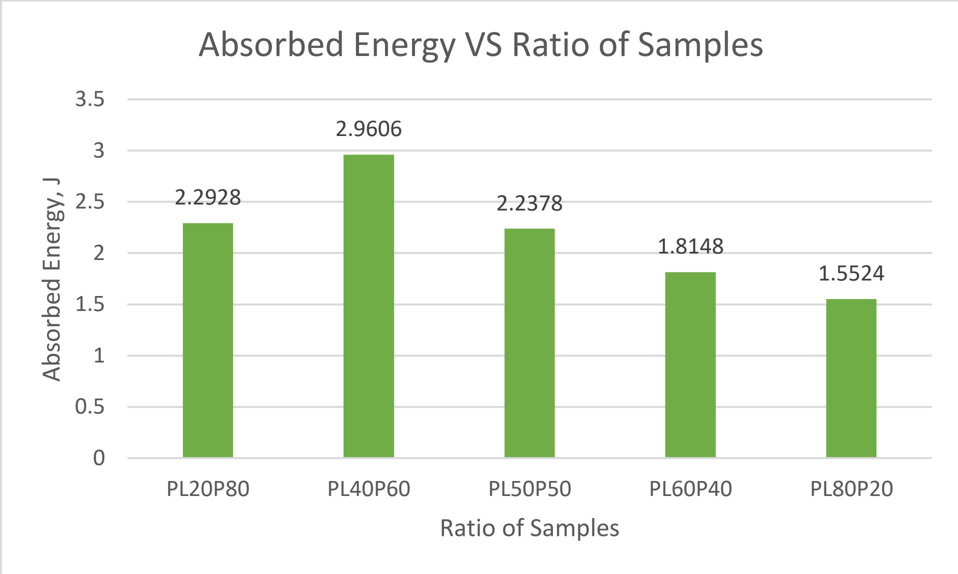

Figure 4.6 Absorbed Energy for five ratios of PLRP Composite

Figure 4.7 Impact test specimen

As given in Tables 4.7 and 4.8, a one-way analysis of variance (ANOVA) was performed to analyze the impact test of the PLRP composites. The results prove that the amount of energy of the PLRP composites remained statistically significant throughout all five ratios. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of the amount of energy throughout the five ratios of PLRP composites. The ratio of PL40P60, which includes 40% pineapple leaf, performs better and it could be used in conditions requiring higher impact resistance.

Table 4.7 Summary statistics result of absorbed energy

SUMMARY

Ratios	*Count*	*Sum*	*Average*	*Variance*
PL20P80	5	11.464	2.2928	0.020331
PL40P60	5	14.803	2.9606	0.155842
PL50P50	5	11.189	2.2378	0.467714
PL60P40	5	9.074	1.8148	0.788665
PL80P20	5	7.762	1.5524	0.06782

Table 4.8 ANOVA of absorbed energy for five different ratios of PLRP Composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Ratios	5.761539	4	1.440385	4.800091	0.007049	2.866081
Within Ratios	6.001489	20	0.300074			
Total	11.76303	24				

Based on Table 4.8, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.3001}{5}} = 4.24\sqrt{\frac{0.3001}{5}} = 1.0388$$

Thus, any pairs of ratio averages that differ in absolute value by more than 1.0388 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 2.2928,\ \bar{y}_2 = 2.9606$

$\bar{y}_3 = 2.2378,\ \bar{y}_4 = 1.8148$

$\bar{y}_5 = 1.5524$

and the differences in averages are;

$\bar{y}1 - \bar{y}2 = 2.2928 – 2.9606 = -0.6678$

$\bar{y}1 - \bar{y}3 = 2.2928 – 2.2378 = 0.0550$

$\bar{y}1 - \bar{y}4 = 2.2928 – 1.8148 = 0.4780$

$\bar{y}1 - \bar{y}5 = 2.2928 – 1.5524 = 0.7404$

$\bar{y}2 - \bar{y}3 = 2.9606 – 2.2378 = 0.7228$

$\bar{y}2 - \bar{y}4 = 2.9606 – 1.8148 = 1.4082$*

$\bar{y}2 - \bar{y}5 = 2.9606 – 1.5524 = 0.4230$

$$\bar{y}3 - \bar{y}4 = 2.2378 - 1.8148 = 0.6854$$

$$\bar{y}3 - \bar{y}5 = 2.2378 - 1.5524 = 0.262$$

$$\bar{y}4 - \bar{y}5 = 1.8148 - 1.5524 = 2.1654^{*}$$

When there are significant differences between the means of pairs, there are star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

4.5 Result and Analysis of Water Absorption Test

The purpose of water absorption testing is to see how easily PLRP composites can absorb water, which can have major impacts on their long-term durability and mechanical properties. This test was used to find out how much water was absorbed after 25 days. From Figure 4.8 until Figure 4.12, the water absorption tests were carried out on PL20P80, PL40P60, PL50P50, PL60P40, and PL80P20 from day 5 to day 25. The results showed that the PL80P20 composite had a greater amount of water absorption, which means that the composite took in more water during the testing time compared to other ratios. Otherwise, the percentage of PL20P80 composite, had less water absorption, which means it let less water through. The larger percentage of fiber content in PL80P20 composite (80% pineapple leaf) could make it easier for water to get into the mixture, which will allow it to absorb more water. PL20P80 composite could have a more compact structure because it has less fiber (20% pineapple leaf). This makes it harder for water to get through.

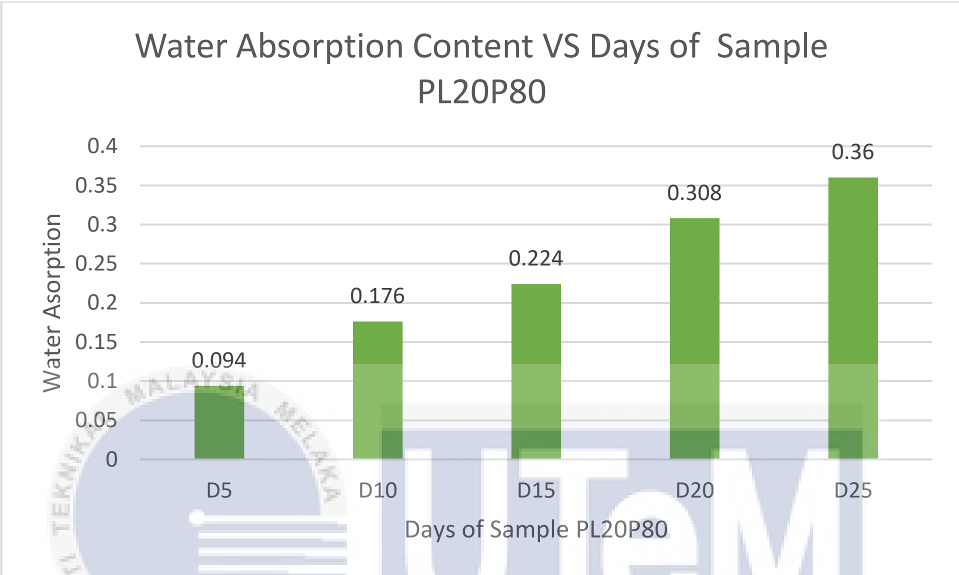

Figure 4.8 Water Absorbed for ratios of PL20P80 Composite

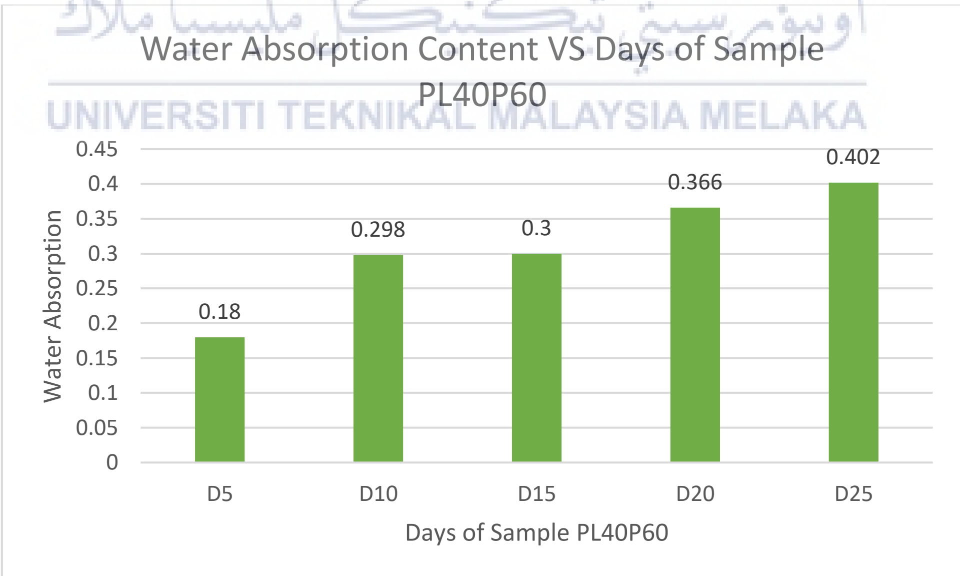

Figure 4.9 Water Absorbed for ratios of PL40P60 Composite

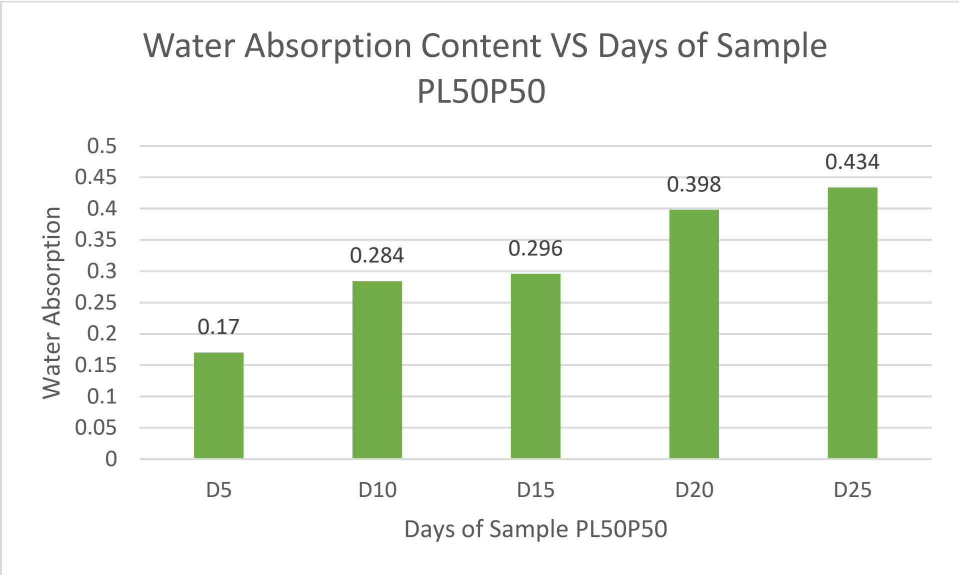

Figure 4.10 Water Absorbed for ratios of PL50P50 Composite

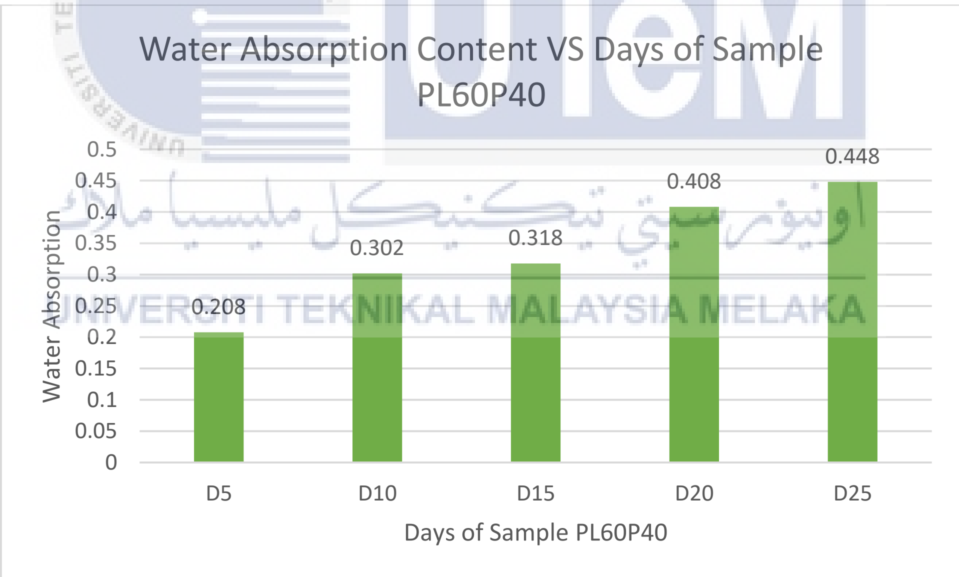

Figure 4.11 Water Absorbed for ratios of PL60P40 Composite

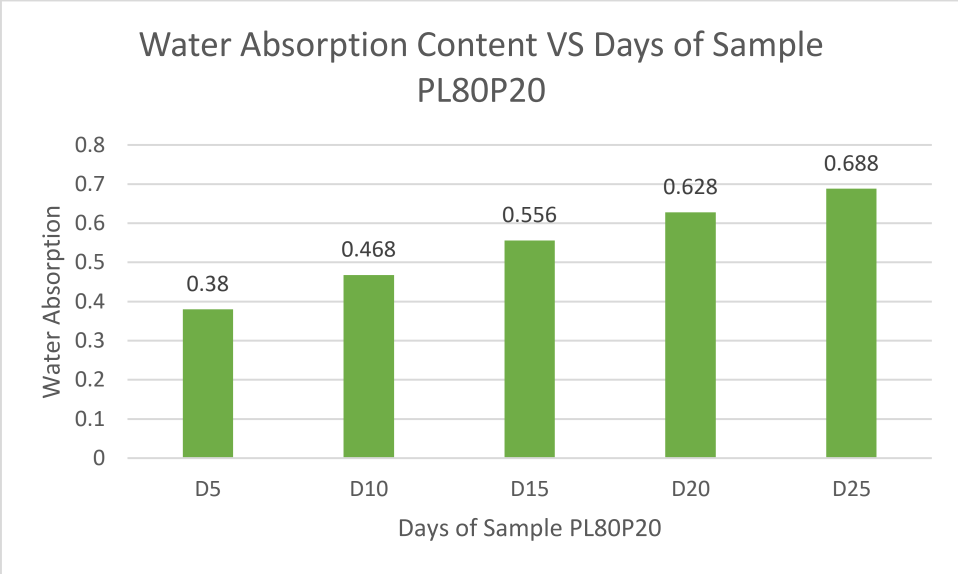

Figure 4.12 Water Absorbed for ratios of PL80P20 Composite

Figure 4.13 Water absorption test specimen

As given in Tables 4.9 and 4.10, a one-way analysis of variance (ANOVA) was performed to analyze the water absorption of the PL20P80 composite. The results prove that the water absorption of the PL20P80 composite remained statistically significant. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of the water absorption of the PL20P80 composite after 25 days.

Table 4.9 Summary statistics result of water absorbed of PL20P80 composite

SUMMARY

Days	*Count*	*Sum*	*Average*	*Variance*
D5	5	0.47	0.094	0.00023
D10	5	0.88	0.176	0.00293
D15	5	1.12	0.224	0.00113
D20	5	1.54	0.308	0.00107
D25	5	1.8	0.36	0.00055

Table 4.10 ANOVA of water absorbed of PL20P80 composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Days	0.222016	4	0.055504	46.9577	6.84E-10	2.866081
Within Days	0.02364	20	0.001182			
Total	0.245656	24				

Based on Table 4.10, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test in order to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a,\ f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}(5,20)$= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5,20)\sqrt{\frac{0.0011}{5}} = 4.24\sqrt{\frac{0.0011}{5}} = 0.0629$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.0629 would imply that the corresponding pair of population means are significantly different. The 25 day averages are;

$$\bar{y}_1 = 0.0940,\ \bar{y}_2 = 0.1760$$

$$\bar{y}_3 = 0.2240,\ \bar{y}_4 = 0.3080$$

$$\bar{y}_5 = 0.3600$$

and the differences in averages are;

$$\bar{y}1 - \bar{y}2 = 0.0940 - 0.1760 = -0.0820$$

$$\bar{y}1 - \bar{y}3 = 0.0940 - 0.2240 = -0.1300$$

$$\bar{y}1 - \bar{y}4 = 0.0940 - 0.3080 = -0.2140$$

$$\bar{y}1 - \bar{y}5 = 0.0940 - 0.3600 = -0.2660$$

$$\bar{y}2 - \bar{y}3 = 0.1760 - 0.2240 = -0.0480$$

$$\bar{y}2 - \bar{y}4 = 0.1760 - 0.3080 = -0.1320$$

$$\bar{y}2 - \bar{y}5 = 0.1760 - 0.3600 = -0.1840$$

$$\bar{y}3 - \bar{y}4 = 0.2240 - 0.3080 = -0.0840$$

$$\bar{y}3 - \bar{y}5 = 0.2240 - 0.3600 = -0.1360$$

$$\bar{y}4 - \bar{y}5 = 0.3080 - 0.3600 = -0.0520$$

When there are significant differences between the means of pairs, there are no star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

As given in Tables 4.11 and 4.12, a one-way analysis of variance (ANOVA) was performed in order to analyze the water absorption of the PL40P60 composite. The results prove that the water absorption of the PL40P60 composite remained statistically significant. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of the water absorption of the PL40P60 composite after 25 days.

Table 4.11 Summary statistics result of water absorbed of PL40P60 composite

SUMMARY

Days	*Count*	*Sum*	*Average*	*Variance*
D5	5	0.9	0.18	0.00245
D10	5	1.49	0.298	0.00182
D15	5	1.5	0.3	0.002
D20	5	1.83	0.366	0.00213
D25	5	2.01	0.402	0.00277

Table 4.12 ANOVA of water absorbed of PL40P60 composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Days	0.143704	4	0.035926	16.08147	4.86E-06	2.866081
Within Days	0.04468	20	0.002234			
Total	0.188384	24				

Based on Table 4.12, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test in order to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a,\ f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f =20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.0022}{5}} = 4.24\sqrt{\frac{0.0022}{5}} = 0.0889$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.0889 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 0.1800,\ \bar{y}_2 = 0.2980$

$\bar{y}_3 = 0.3000,\ \bar{y}_4 = 0.3660$

$\bar{y}_5 = 0.4020$

and the differences in averages are;

$\bar{y}1 - \bar{y}2 = 0.1800 – 0.2980 = -0.0820$

$\bar{y}1 - \bar{y}3 = 0.1800 – 0.2240 = -0.1300$

$\bar{y}1 - \bar{y}4 = 0.1800 – 0.3080 = -0.2140$

$\bar{y}1 - \bar{y}5 = 0.1800 – 0.3600 = -0.2660$

$$\bar{y}2 - \bar{y}3 = 0.2980 - 0.2240 = -0.0480$$

$$\bar{y}2 - \bar{y}4 = 0.2980 - 0.3080 = -0.1320$$

$$\bar{y}2 - \bar{y}5 = 0.2980 - 0.3600 = -0.1840$$

$$\bar{y}3 - \bar{y}4 = 0.2240 - 0.3080 = -0.0840$$

$$\bar{y}3 - \bar{y}5 = 0.2240 - 0.3600 = -0.1360$$

$$\bar{y}4 - \bar{y}5 = 0.3080 - 0.3600 = -0.0520$$

When there are significant differences between the means of pairs, there are no star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

As given in Tables 4.13 and 4.14, a one-way analysis of variance (ANOVA) was performed in order to analyze the water absorption of the PL50P50 composite. The results prove that the water absorption of the PL50P50 composite remained statistically significant. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of the water absorption of the PL50P50 composite after 25 days.

Table 4.13 Summary statistics result of water absorbed of PL50P50 composite

SUMMARY

Days	*Count*	*Sum*	*Average*	*Variance*
D5	5	0.85	0.17	0.0009
D10	5	1.42	0.284	0.00053
D15	5	1.48	0.296	0.00178
D20	5	1.99	0.398	0.00107
D25	5	2.17	0.434	0.00193

Table 4.14 ANOVA of water absorbed of PL50P50 composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Days	0.216936	4	0.054234	43.66667	1.31E-09	2.866081
Within Days	0.02484	20	0.001242			
Total	0.241776	24				

Based on Table 4.14, shows that the P-value was lower than the significant cut-off level which is $\alpha = 0.05$, it is necessary to conduct Tukey's test in order to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a,\ f)\sqrt{\frac{MS\varepsilon}{n}}$$

with $\alpha = 0.05$ and $f = 20$ degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}(5,20) = 4.24$. Therefore,

$$T_{0.05} = q_{0.05}(5,20)\sqrt{\frac{0.0012}{5}} = 4.24\sqrt{\frac{0.0012}{5}} = 0.0657$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.0657 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 0.1700,\ \bar{y}_2 = 0.284$

$\bar{y}_3 = 0.2960,\ \bar{y}_4 = 0.3980$

$\bar{y}_5 = 0.4340$

and the differences in averages are;

$$\bar{y}1 - \bar{y}2 = 0.1700 – 0.2840 = -0.114$$

$$\bar{y}1 - \bar{y}3 = 0.1700 – 0.2960 = -0.1260$$

$$\bar{y}1 - \bar{y}4 = 0.1700 – 0.3980 = -0.2280$$

$$\bar{y}1 - \bar{y}5 = 0.1700 – 0.4340 = -0.2640$$

$$\bar{y}2 - \bar{y}3 = 0.2840 – 0.2960 = -0.0120$$

$$\bar{y}2 - \bar{y}4 = 0.2840 – 0.3980 = -0.1140$$

$$\bar{y}2 - \bar{y}5 = 0.2840 – 0.4340 = -0.0150$$

$$\bar{y}3 - \bar{y}4 = 0.2960 – 0.3980 = -0.1020$$

$$\bar{y}3 - \bar{y}5 = 0.2960 – 0.4340 = -0.1380$$

$$\bar{y}4 - \bar{y}5 = 0.3980 – 0.4340 = -0.0360$$

When there are significant differences between the means of pairs, there are no star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

As given in Tables 4.15 and 4.16, a one-way analysis of variance (ANOVA) was performed in order to analyze the water absorption of the PL60P40 composite. The results prove that the water absorption of the PL60P40 composite remained statistically significant. This is supported by the P-value being below the initial significant level of α

= 0.05. Hence, the results prove that there were variations in the average values of the water absorption of the PL60P40 composite after 25 days.

Table 4.15 Summary statistics result of water absorbed of PL60P40 composite

SUMMARY

Days	*Count*	*Sum*	*Average*	*Variance*
D5	5	1.04	0.208	0.00067
D10	5	1.51	0.302	0.00077
D15	5	1.59	0.318	0.00337
D20	5	2.04	0.408	0.00157
D25	5	2.24	0.448	0.00267

Table 4.16 ANOVA of water absorbed of PL60P40 composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Days	0.177944	4	0.044486	24.5779	1.77E-07	2.866081
Within Days	0.0362	20	0.00181			
Total	0.214144	24				

Based on Table 4.16, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f=20 degrees of freedom for error, the table of percentage points of the studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.0018}{5}} = 4.24\sqrt{\frac{0.0018}{5}} = 0.0804$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.0804 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$$\bar{y}_1 = 0.2080,\ \bar{y}_2 = 0.3020$$

$$\bar{y}_3 = 0.3180,\ \bar{y}_4 = 0.4080$$

$$\bar{y}_5 = 0.4480$$

and the differences in averages are;

$$\bar{y}1 - \bar{y}2 = 0.2080 - 0.3020 = -0.0940$$

$$\bar{y}1 - \bar{y}3 = 0.2080 - 0.3180 = -0.1100$$

$$\bar{y}1 - \bar{y}4 = 0.2080 - 0.4080 = -0.2000$$

$$\bar{y}1 - \bar{y}5 = 0.2080 - 0.4480 = -0.2400$$

$$\bar{y}2 - \bar{y}3 = 0.3020 - 0.3180 = -0.0160$$

$$\bar{y}2 - \bar{y}4 = 0.3020 - 0.4080 = -0.1060$$

$$\bar{y}2 - \bar{y}5 = 0.3020 - 0.4480 = -0.1460$$

$$\bar{y}3 - \bar{y}4 = 0.3180 - 0.4080 = -0.2700$$

$$\bar{y}3 - \bar{y}5 = 0.3180 - 0.4480 = -0.1300$$

$$\bar{y}4 - \bar{y}5 = 0.4080 - 0.4480 = -0.0400$$

When there are significant differences between the means of pairs, there are no star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

As given in Tables 4.17 and 4.18, a one-way analysis of variance (ANOVA) was performed to analyze the water absorption of the PL80P20 composite. The results prove that the water absorption of the PL80P20 composite remained statistically significant. This is supported by the P-value being below the initial significant level of $\alpha = 0.05$. Hence, the results prove that there were variations in the average values of the water absorption of the PL80P20 composite after 25 days.

Table 4.17 Summary statistics result of water absorbed of PL80P20 composite

SUMMARY

Days	*Count*	*Sum*	*Average*	*Variance*
D5	5	1.9	0.38	0.00045
D10	5	2.34	0.468	0.00687
D15	5	2.78	0.556	0.00243
D20	5	3.14	0.628	0.00172
D25	5	3.44	0.688	0.00567

Table 4.18 ANOVA of water absorbed of PL80P20 composite

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Days	0.30304	4	0.07576	22.10035	4.18E-07	2.866081
Within Days	0.06856	20	0.003428			
Total	0.3716	24				

Based on Table 4.18, shows that the P-value was lower than the significant cut-off level which is α = 0.05, it is necessary to conduct Tukey's test to identify any statistically significant differences between the means. The following is the formula for Tukey's test

$$T\alpha = q\alpha\ (a, f)\sqrt{\frac{MS\varepsilon}{n}}$$

with α = 0.05 and f =20 degrees of freedom for error, the table of percentage points of the

studentized range statistic gives $q_{0.05}$(5,20)= 4.24. Therefore,

$$T_{0.05} = q_{0.05}(5{,}20)\sqrt{\frac{0.0034}{5}} = 4.24\sqrt{\frac{0.034}{5}} = 0.1106$$

Thus, any pairs of ratio averages that differ in absolute value by more than 0.1106 would imply that the corresponding pair of population means are significantly different. The five ratio averages are;

$\bar{y}_1 = 0.38000$, $\bar{y}_2 = 0.4680$

$\bar{y}_3 = 0.5560$, $\bar{y}_4 = 0.6280$

$\bar{y}_5 = 0.6880$

and the differences in averages are;

$\bar{y}1 - \bar{y}2$ = 0.38000– 0.4680= -0.0880

$\bar{y}1 - \bar{y}3$ = 0.38000– 0.5560= -0.1760

$\bar{y}1 - \bar{y}4$ = 0.38000– 0.6280= -0.2480

$\bar{y}1 - \bar{y}5$ = 0.38000– 0.6880= -0.3080

$$\bar{y}_2 - \bar{y}_3 = 0.4680 – 0.5560 = -0.0880$$

$$\bar{y}_2 - \bar{y}_4 = 0.4680 – 0.6280 = -0.1600$$

$$\bar{y}_2 - \bar{y}_5 = 0.4680 – 0.6880 = -0.2200$$

$$\bar{y}_3 - \bar{y}_4 = 0.5560 – 0.6280 = -0.0720$$

$$\bar{y}_3 - \bar{y}_5 = 0.5560 – 0.6880 = -0.1320$$

$$\bar{y}_4 - \bar{y}_5 = 0.6280 – 0.6880 = -0.0600$$

When there are significant differences between the means of pairs, there are no star values to indicate this. The Tukey procedure demonstrates that all pairs of means are different. So, the average etch rate will depend on the power setting used.

4.6 Summary

The tensile testing findings indicated that PL40P60 presented superior elasticity and tensile strength as compared to the alternative ratios. This implies that enhanced tensile properties can be achieved with an optimal proportion of 40% pineapple leaf reinforcement and 60% polyester matrix components. Likewise, PL40P60 exhibited higher maximum stress during the flexural testing phase, proving the ideal effect of increased fiber content on flexural strength. The strength of the bond between the fibers and the matrix affects how well loads are transferred in the composite material. A strong bond between the matrix and the reinforcing fibers helps to evenly distribute stress and transfer loads efficiently in the material. This new load transfer mechanism can make the composite material stronger when it is pulled apart, which means it can withstand more force. The results of the impact testing demonstrated that PL40P60 had an excellent impact strength, showing that it's suitable for use in applications that require resistance to sudden forces.

In contrast, PL80P20 demonstrated a higher capacity for water absorption during the water absorption test, indicating a greater sensitivity to moisture. In the PL80P20 ratio, having more fiber can cause the structure to have more holes or weaker bonding at the surface, which makes it more likely to absorb moisture. Pineapple leaf fiber can absorb moisture from the air because they have a hygroscopic nature. The natural characteristics of the fibers can help increase the composite's ability to absorb water, especially when there is a lot of fiber present.

Due to the combination of these findings, an ideal formulation for PLRP composites has been developed, with PL40P60 exhibiting superior tensile and flexural capabilities, in addition to providing superior impact resistance. It would appear that a composition consisting of around 40% pineapple leaf and 60% polyester matrix has the potential to achieve a comprehensive collection of mechanical capabilities. It is important to note that the formulation that is selected is dependent on the specific application's requirements.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The mechanical characteristics of the PLRP were investigated in this study using five distinct ratios, including 20PL80P, 40PL60P, 50PL50P, 60PL40P, and 80PL20P. These ratios were among those that were investigated. The statistical analysis of the experiment material has also been explored utilizing Turkey's techniques and analysis of variance (ANOVA). Both of these methods have been used. The following conclusions can be reached based on the findings that were acquired from the laboratory analysis and the experimental data:

i When it comes to tensile testing, the PL40P60 composite showed higher tensile strength and elasticity in comparison to the other ratios.

ii Within the flexural testing, it was observed that PL40P60 exhibited a higher maximum stress, showing that a higher fiber content has a positive effect on flexural strength.

iii The results of the impact testing showed that PL40P60 proved better impact strength, suggesting its suitability for applications that need to withstand sudden forces.

iv During the water absorption testing, it was observed that PL80P20 showed higher water absorption levels, indicating that it may be more sensitive to moisture.

v Additionally, the ANOVA results indicated that the P-value for each test was shown to be lower than the predetermined significance level of $\alpha = 0.05$.

vi Therefore, it is necessary to conduct the Tukey test to determine which means are significantly distinct from each other.

Achieving the right balance between the reinforcement of pineapple leaf and the matrix of polyester is crucial when formulating PLRP composites. A composition consisting of approximately 40% pineapple leaf and 60% polyester matrix shows the potential to achieve a balanced range of mechanical properties.

5.2 Recommendation

The PL40P60 composition is an effective ratio of pineapple leaf reinforcement and polyester matrix. This combination gives it a balanced set of mechanical properties. This formulation is suggested for situations where it requires a combination of tensile strength, flexural strength, impact resistance, and moderate water resistance is desired. Although conducting additional research and studying for this experiment will result in achieving the highest possible mechanical properties for tensile, flexural, and impact testing. For instance, when considering pineapple, the ratios of 30% to 45% are worth exploring to determine whether they will result in the highest possible mechanical properties or if they will cause a decrease in value. However, the decision on which ratio to choose should ultimately be based on the specific needs of the intended use. This includes considering factors like the environment it will be used in, how much weight it needs to handle, and how long it needs to last.

5.3 Project Potential

The fiber ratio will be dependent on the method of fiber extraction and processing. However, it presents significant opportunities for development and various chances. Applying PALF to create natural fiber composites provides a significant opportunity to enhance the value of pineapple-producing countries, especially countries with large agricultural potential and under development. The PALF-reinforced composites have applications in various automotive components, both on the inside and outside of the vehicle. These include door panels (side and back), headliner panels, seat backs, boot lining, hat racks, spare tire lining, noise insulation panels, molded foot well linings, door trim, windshield, dashboard, business table, pillar cowl panel, door protective cover, seatback linings, floor panels, seat bottoms, back cushions, head restraints, below floor body panels, B-pillar, sliding door inserts, speed indicator gears, steering column bush, front fork bush, internal engine cover, engine insulation, oil filter housing, electrical junction box, bumper, wheel box, roof cover, packing trays, door panel inserts, sun visor, interior insulation, insulation, rear storage shelf/panel, seat cushioning, natural foams, lading floor tray, boot lid finish panel and plenty of different components.

In conclusion, composites reinforced with pineapple leaf fibers (PALFs) contain a variety of desirable features and benefits, including eco-friendly, biodegradability in nature, low cost, tenuity, and easy mouldability. The outcomes from this experiment prove that the addition of a legitimate amount of ratio of pineapple leaf fibers with polymers can improve the mechanical, physical, and thermal properties of the composites.

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APPENDIX

APPENDIX A Gantt Chart PSM 1

ACTIVITIES	STATUS	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Supervisor Selection And Registered Title	Plan														
	Actual														
Brief And Project Explanation By Supervisor	Plan														
	Actual														
Chapter 1: Research Design And Planning	Plan														
	Actual														
Discuss the Problem Statement And Objective For Chapter 1	Plan														
	Actual														
Drafting And Writing Up Chapter 1	Plan														
	Actual														
Brief Methodology	Plan														
	Actual														
Chapter 2: Final Year Project Literature Review	Plan														
	Actual														
Drafting And Writing Up Chapter 2	Plan														
	Actual														
Chapter 3: Research Methodology	Plan														
	Actual														
Drafting And Writing Up Chapter 3	Plan														
	Actual														
Chapter 4: Expected Result	Plan														
	Actual														
Drafting And Writing Up Chapter 4	Plan														
	Actual														
Recheck Chapters 1,2, 3 And 4	Plan														
	Actual														
Recheck Chapter 1,2,3 And 4	Plan														
	Actual														

APPENDIX B Gantt Chart PSM 2

ACTIVITIES	STATUS	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Brief And Project Explanation By Supervisor	Plan														
	Actual														
Purchase the essential raw materials and equipment needed	Plan														
	Actual														
Fabrication process	Plan														
	Actual														
Update and Discuss the Problem of the Fabrication process with the Supervisor	Plan														
	Actual														
Testing process	Plan														
	Actual														
Update and Discuss the Problem of the Fabrication process with the Supervisor	Plan														
	Actual														
Collect the data analysis	Plan														
	Actual														
Drafting And Writing Up Chapter 4	Plan														
	Actual														
Chapter 4: Result and Discussion	Plan														
	Actual														
Drafting And Writing Up Chapter 5	Plan														
	Actual														
Chapter 5: Conclusion and Recommendation	Plan														
	Actual														
Drafting And Writing Up Summary and Poster	Plan														
	Actual														
Preparation and submission of Report PSM 2	Plan														
	Actual														

APPENDIX C Turnitin Summary

Pineapple leaf

ORIGINALITY REPORT

18%	9%	14%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to CSU, San Jose State University Student Paper	1%
2	journal.utem.edu.my Internet Source	1%
3	link.springer.com Internet Source	1%
4	Olembe Roland Yves, Fokam Bopda Christian, Oru Benson Akum, Tchotang Theodore, Kenmeugne Bienvenu. "Physical and Mechanical Properties of Pineapple Fibers (Leaves, Stems and Roots) from Awae Cameroon for the Improvement of Composite Materials", Journal of Fiber Science and Technology, 2020 Publication	1%
5	"Handbook of Epoxy/Fiber Composites", Springer Science and Business Media LLC, 2022 Publication	1%