Experimental Investigation of Physical and Mechanical Behavior of Moringa-Bamboo Fiber Reinforced Epoxy Hybrid Composite

Mohamed Yassin Mohamed

A Thesis submitted to the Department of Mechanical Engineering,

School of Mechanical, Chemical and Material Engineering

Presented in Partial Fulfillment of the Requirement for the degree of

Master of Science in Manufacturing Engineering

Office of Graduate Studies

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

September, 2022 G.C

Adama, Ethiopia

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Advisor: Dr. Venkatesh Chenrayan

Co-Advisor: Dr. Kiran Shahapurkar

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Candidate's Declaration

I hereby declare that this master's thesis entitled "**Experimental Investigation of Physical and Mechanical Behavior of Moringa-Bamboo Fiber Reinforced Epoxy Hybrid Composite**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mohamed Yassin Mohamed

Signature: ______________________ Date: ______________________

Recommendation of Advisor

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "**Experimental Investigation of Physical and Mechanical Behavior of Moringa-Bamboo Fiber Reinforced Epoxy Hybrid Composite**" prepared under our guidance by **Mohamed Yassin Mohamed** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Advisor: Dr. C. Venkatesh Chenrayan ______________________ ____________________

Signature Date

Co-Advisor: Dr. Kiran Shahapurkar ______________________ ____________________

Signature Date

Approval of Advisor

We, the advisor of the thesis entitled "**Experimental Investigation of Physical and Mechanical Behavior of Moringa-Bamboo Fiber Reinforced Epoxy Hybrid Composite**" developed by **Mohamed Yassin Mohamed,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Advisor: Dr. C. Venkatesh Chenrayan ______________________ ____________________

Signature Date

Co-Advisor: Dr. Kiran Shahapurkar ______________________ ____________________

Signature Date

Approval by Board of Examiners

We, the undersigned, members of the Board of Examiners of the thesis by **Mohamed Yassin Mohamed** have read and evaluated the thesis entitled "**Experimental Investigation of Physical and Mechanical Behavior of Moringa-Bamboo Fiber Reinforced Epoxy Hybrid Composite**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	America Society for Testing and Material
BB-60	Bamboo-Bamboo composite
BM-30/30	Bamboo-Moringa hybrid composite
BF	Bamboo Fiber
BFEC	Bamboo Fiber Eco-Composites
CMCs	Ceramic Matrix Composites
ER	Pure Epoxy Resin
FRCs	Fiber Reinforced Composites
IJERT	International Journal of Engineering Research and Technology
MOPH	Moringa Oleifera Pod Husks
MM-60	Moringa-Moringa composite
MMCs	Metal Matrix Composites
NaOH	Sodium hydroxide
SEM	Scanning Electron Microscope
NFRPc	Natural Fiber-Reinforced Polymer Composite
PMCs	Polymer Matrix Composites
RIM	Resin Infusion Molding
RTM	Resin Transfer Molding
NFC	Natural Fiber Composite
UTM	Universal Testing Machine
S	Specimens

NOMENCLATURE

M_c	Mass of composite
M_f	Mass of fiber
Me	Mass of epoxy
V_f	Volume fraction of fiber
V_m	Volume fraction of matrix
V_c	Volume of composite
V_f	Volume of fiber
V_m	Volume of matrix
vol.%	Volume percentage
wt.%	Weight percentage
ρ_c	Density of composite
ρ_f	Density of fiber
ρ_m	Density of matrix
M_m	Mass of moringa
ρ_m	Density moringa

ABSTRACT

Nowadays, synthetic fiber composites are currently in decline because of their high initial cost and detrimental impact on the environment. In this research, natural composites from moringa, bamboo, and their combinations were developed and their mechanical and physical properties were extensively studied by comparing them with pure epoxy resin samples (ER). The natural composites were also compared with their hybrid composites. These composites were represented as MM-60, BB-60, and BM-30/30. The samples were fabricated using a hand lay-up technique with slight pressure exerted for better compactness and to minimize the void content. The mechanical properties such as tensile, compression, flexural, hardness, and impact properties of the synthesized composites were investigated. In the preparation of all samples, a constant proportion of epoxy resin was used (40 vol.%). The flexural and tensile properties of epoxy composites with moringa and bamboo fiber reinforcement are highly impacted by the fiber content (60 vol.%) incorporated in the epoxy matrix. When compared to neat epoxy, all bamboo/moringa sample composites show superior mechanical strength. The tensile strength increases ranged from 5.8 to 70.53%, with BB-60 showing the greatest improvement. From 5.79 to 59.87% more flexural strength was recorded compared to pure epoxy. The maximum flexural strength was recorded by BB-60. The biggest boost in compressive strength was seen in BB-60, with improvements ranging from 13.06 to 68.43%. In terms of impact strength, which is related to flexibility and absorption energy, the maximum rise in impact strength was recorded by BM-30/30 at 210 (kJ/m^2). In addition to this, BM-30/30 exhibits superior tensile modulus, flexural modulus, and compressive modulus. From the hardness test, the highest hardness value observed by moringa reinforced composites (MM-60) was 40.83HV. The greatest water absorption (%) was also recorded near to saturation point by MM-30/30, and was 7.604%. Therefore, in terms of strength BB-60 and in terms modulus and impact BM-30/30 best and recommended for automotive interior door parts and packaging application as lightweight materials.

Keywords: Moringa, Hybrid composite, Bamboo, light weight, Mechanical strength.

CHAPTER ONE

1. INTRODUCTION

1.1. Background of study

The advent of composite materials dates back to the beginning of human creation. The concept of composites is therefore not new. Bone and wood are the two most ancient and well-known natural composites. These organic materials serve a variety of functions, such as the usage of natural bone as a knife in times prior to 10,000 BC. (Varvani-Farahani., 2009). The strongest and longest-lasting constructions were created by the Egyptians and Mesopotamians in antiquity utilizing mud and straw (Varvani-Farahani., 2009; J S., 2018). In addition to these fundamental natural composites, engineering composites have also been in use for a very long time. Black carbon in rubber, glass fiber in resin, Portland cement mixed with sand, and asphalt mixed with sand are some of these that are frequently used (Krishan., 2012).

The need for materials with good stiffness, strength, and low density grew in the middle of the 20th century (Rajak, et al., 2019). The composites industry started to mature in the 1970s. During this period, plastic resin and reinforcing fibers are being created. Today's modern technology demands a material to have very particular qualities in order to satisfy the needs of diverse applications. Composite materials are wise to obtain optimal qualities in this way. This is due to the fact that a composite is a combination of two or more macroscopic phases with optimal mechanical, physical, and chemical properties as compared to the components of composites functioning separately (Khan., 2018).

Materials with very different qualities are combined to create composite materials, which have their own unique features. Properties or a group of properties that could not have been reached separately can be attained in composites There are various classifications of composite materials, from them polymer-based matrix composites are frequently employed in a variety of engineering applications such as aerospace, chemical, automotive, medical, electrical, sport equipment, packaging (Vijaya et al., 2016) , different structural and load bearing applications (Jani et al., 2021; Sampath and Kumar., 2020; Kumar et al., 2021). Composite materials have two categories according to the constituent reinforcements, these are synthetic and natural composites (Xu et al, 2019, Ogin et al., 2016). Synthetic composites, also called man-made composites, include Kevlar, glass, aramid, carbon (Delgado et al., 2012, Ogin et al., 2016) and others. Natural composites, on the other hand, are derived from natural resources (animals, plants, and minerals) such as sisal, bamboo, banana, jute, kenaf, and flax (Kumar et al., 2021, Ogin et al., 2016).

Due to the shifting of views toward environmental issues and growing legislative pressure, eco-friendly, green, and sustainable materials have received a lot of attention in the last ten years (Hu et al., 2017). The environmental friendliness of natural composites has attracted as a potential reinforcement sources for bio-composites. In addition, natural fibers are ideal for use in lightweight applications (Bharath et al., 2020). Therefore, natural composites are increasingly becoming a potential option to replace synthetic composites in engineering composites (Athijayamani et al., 2009). Furthermore, natural composites have the following superior advantage over synthetic composites such as biodegradability, non-toxicity (Das., 2021; Venkatesha., 2021), reusability (Das., 2021; Loganathan et al., 2019; Venkatesha., 2021), availability, low cost (Das., 2021; Athijayamani et al., 2009; Venkatesha., 2021). Even though, its advantage, natural composite has some limitations which include inconsistency in physical and mechanical characteristics, low moisture resistance (Loganathan et al., 2019), hydrophilic behavior (Loganathan et al., 2019; Athijayamani et al., 2009), lower impact strength (Athijayamani et al., 2009). To overcome these drawbacks, natural hybrid composites have been introduced to mitigate the weaknesses of their components and complement each other, resulting in a decisive impact on engineering and technology applications (Loganathan et al., 2019). The recent structural and natural hybrid composites are usually referred to as advanced materials, which are different from conventional composites (Jani et al., 2021).

The parameter that determines the characteristics of composites

Composites are materials that are designed for a specific application area. The properties of

composites can be controlled by controlling parameters that affect the properties of composites. The major parameters in composite preparation include nature of fibers, fiber orientation, fiber hybridization, fiber surface treatment, moisture uptake behavior of fiber, matrix material properties, and adhesion at the interfacial and fabrication method, which strongly affect the characteristics of natural fibers.

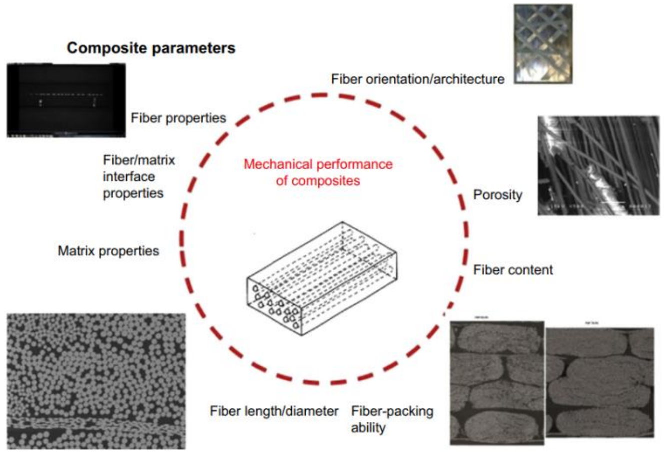


Figure 1.1: Parameter which affects the properties of composite (Ogin et al., 2018).

This work is mainly intended to develop a plant-based natural fiber composite made from bamboo and moringa that reinforce an epoxy matrix for engineering applications.

1.2. Problem of statement

Ethiopia's natural bamboo forest covers 86% of African bamboo (Tolessa et al., 2017). This resource has to be utilized properly. At the same time, moringa oleifera is also the most denied plant as reinforcement for composite materials. Especially in Ethiopia, the fibers found in the cover of moringa pods have no function and can be considered waste. As much as previous investigattion, scientists also don't recognize the potential uses of fibers in moringa pods. Furthermore, it is rich in fiber and wasted from commercial industries after yielding its economic value. Up until this point, there hasn't been any research in the scientific community on hybrid composites made of moringa and bamboo fibers. Synthetic composites' impact on the environment is currently a problem that requires a proper solution. E-glass synthetic fiber, accounts for more than 95% of current usage, in fiber applications. Furthermore, existing synthetic composites are high raw material costs, poor machinability, limited resources, and maintenance complexity. Natural fiber reinforced composites, in contrast, are lightweight, low cost, have a relatively high elastic modulus and strength, and have less processing energy consumption. The above constraints motivate become a reason to develop a fully biodegradable composite material exploiting Ethiopia's properly underutilized natural fiber resources. Therefore, the composite material was developed from moringa and bamboo to compensate the shortage of synthetic materials and its environmental problems as a universal concern. This composite is mainly recommended for packaging application.

1.3. Research question

- What are the characteristics and chemical composition of bamboo and moringa bio-fibers?
- What is the mechanical behavior of the natural composites and hybrid composites that are reinforced with bamboo, moringa, and bamboo/moringa fiber?
- Is it possible to develop a natural composite from long bamboo/moringa fibers that is woven $90^0/0^0$ orientation manually using the hand lay-up method?
- Which fiber-epoxy blend offers more mechanical strength?

1.4. General and Specific Objective

1.4.1. General Objective

The main objective of this work is to develop natural fiber composite materials that made from moringa/bamboo fibers by hand lay-up method and studying their mechanical properties.

1.4.2. Specific Objective

The research has the following specific objectives these are:

- Studying the effect of the addition of reinforcements and its change on the characteristics of natural fiber reinforced composites.
- To examine the mechanical properties such as tensile, compression, flexural, impact, and hardness testing of the sample specimen materials.
- To determine water absorption properties, density, and void content of the composites.
- To perform microstructural characterization using a Scanning Electron Microscope for flexural sample composites.
- To evaluate experimental results.
- To interpret test results and recommend the ideal application domain.

1.5. Scope

The investigation of local highland bamboo from hawassa city, and moringa oleifera plant fibers from adama city, is the main subject of this work. Following preparations of the samples for testing, tensile, compression, flexural, impact, and hardness tests were carried out on all samples. Additionally, analysis of density, void content, water absorption, and SEM results were carried out.

The physical and mechanical characteristics of four samples—pure epoxy (ER), bamboo-bamboo (BB-60), moringa-moringa (MM-60), and bamboo/moringa (BM-30/30)—were essentially designed for this investigation. With a fixed 0/90 woven fiber configuration, the processing parameters for this study involved modifying (changing) the reinforcements.

1.6. Significance of the study

Many sectors will benefit from this work, particularly the advanced materials industries, which have recently experienced a material shortage that compromised the green environment. The major significances are:

- It is possible to create distinctive forms of environmentally friendly composite materials from naturally occurring resources like bamboo and moringa.
- Composites have a great role in decreasing pollution because the reinforcements are completely biodegradable.
- Present the scientific community with the new understanding of hybrid Moringa/bamboo composites as a prospective candidate for the creation of novel composites that satisfy emerging new technology.
- This work will also become the benchmark for those who want to study this topic further.
- Bio-composite can be used for various applications, such as semi-structure, automotive parts, and industrial lightweight packaging applications.

1.7. Limitation of the study

There were many challenges in completing this thesis work. These difficulties have an impact on the work's output result. There is neither an adequate laboratory setup for testing natural fiber reinforced composites nor a completely functional workshop for the production of composite materials. Even the testing facility that was available produced occasionally erroneous and irrelevant results. Finding commonplace, straightforward equipment for experimental work is another challenge. Another difficulty was the lack of effective methods for fiber extraction. As a result, only the mechanical extraction approach was used to extract the fibers. Furthermore, no machine existed to prepare the weave. As a result, the weaving was made by hand. Because of this, it is challenging to weave fibers precisely and compactly, which reduces the strength of the output composites. The hand lay-up approach was utilized to create the sample composites, although this method has many shortcomings that degrade the quality of the composites, such as excessive void content and porosity during the fabrication process. Vacuum infusion fabrication was strongly advised for this work in order to reduce void content and improve mechanical strength.

1.8. Organization of the study

The work is comprising of five chapters:

Chapter one: Introduction - In the first chapter background, problem statement, objectives, significance, scope, research question, and limitation of the study were stated.

Chapter two: Literature review - All relevant research papers such as Journals, articles, and publications regarding natural fiber composite materials and synthetic composites reviewed. Additionally, Moringa, bamboo, and hybrid composites were widely and deeply reviewed and summarized. Finally, research gap was stated.

Chapter three: Materials and methods - Materials used for this work and their background information, Sample fabrication process, and methods of testing were discussed.

Chapter four: Results and discussion- density, tensile, flexural, compression, impact, hardness testing, and SEM microstructure results are shown and a detailed discussion was done.

Chapter five: Conclusion, recommendation, and future work of the research were stated.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

In some related research areas, various relevant literature reviews on natural composite materials with different fibers and matrix materials have been conducted so far. The researchers also tried to do a little research on moringa and most on bamboo fibers as separate reinforcing fibers. In general, this section provides and refers to a large number of previous works, the majority of which are related to composite materials and their types; general information about natural fibers, such as moringa and bamboo fibers; fabrication methods; fiber treatment; and other topics were covered in this chapter. Modern advanced technology heavily relies on composite materials. Sometimes advanced composites are called "design materials" that possess the required optimum properties. Composites are used to join two or more components, and the resulting assembly has superior qualities to the parts alone (Hsissou et al., 2021). Polymer composites are currently one of the top materials in today's advanced material technology, offering performance and an affordable price, particularly in industries with high demand, like the aviation industry. Modern composites use fibers that are significantly stronger and more rigid than traditional materials (Roylance., 2000). Generally, composites can be classified as the following:

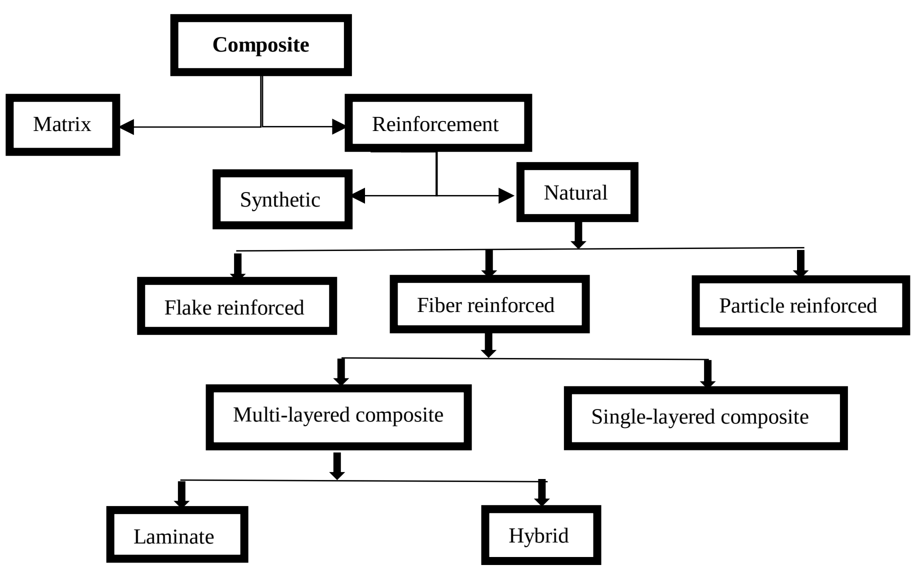


Figure 2.1: Classification of composite material (Gupta and Srivastava, 2021).

In synthesizing composite, reinforcement such as natural or artificial and matrix from the fundamental material types metals, ceramics, and polymers (thermoset, thermoplastic or elastomer) are required. Therefore, manipulating these parameters will give a possibility to acquire particular features.

Matrix material

In composite materials, the matrix is the main component of the newly developed materials. As a result, the matrix component makes up the majority of composites. The matrix could be made of an elastomer, thermosetting, or thermoplastic material. The presence of matrix material always helps to hold the fibers in place, connect the fibers, and convey force to the fibers. In addition to these, they give the structure stiffness, shape, and protection from corrosion and chemical impacts on the fiber. Depending on the specific requirements, various types of matrix materials may be offered (Hsissou et al., 2021). The thermosetting and thermoplastic matrix types, which are frequently employed in polymer composites, are two well-known matrix types.

Thermosetting matrix

They are typically liquid at room temperature, but during the application, under the influence of heat and a substance called a hardener, they solidify. It's a polymer that can never revert to its initial state after being solidified by curing. To make them firm, hardeners must be included. In general, thermoset composites are rigid, brittle, and have low impact strength, but they are strong and have good cyclic strength. It is excellent for synthesizing big parts with long, short, or woven fibers since it has good creep resistance. Epoxy resins, polyesters, polyurethanes, polyimides, and phenoplasts are a few examples of thermosetting materials (Hsissou et al., 2021; Saheb and Jog., 1999). The common feature that shared by all thermoset materials is dangerous in case of body contact (Ogin et al., 2016).

Thermoplastic matrix

It's made of polymer materials that can be remolded, reversible, and recycled to their original form without changing the physical properties. In product manufacturing, the thermoplastic matrices are heated to make them ready for forming processes such as extrusion, molding, and injection before curing, to create end products with the required structural shapes. Thermoplastic materials possess a variety of unique properties that are needed for today's technology. Thermoplastic composites are known for being relatively tougher, less brittle, corrosion resistant, excellent electrical and thermal insulators, improved impact resistance, and damage tolerance. They do not oxidize and have high corrosion resistance. High mechanical strength and lightness are two further defining qualities of these matrices, which make thermoplastic a viable material for a variety of applications (Hsissou et al., 2021). To enhance the mechanical performance of thermoplastic materials, several compatibilizers or coupling agents are used in addition to chemical treatment (Saheb and Jog., 1999).

Reinforcement

The matrix, reinforcement, and additive are the three primary components of composite materials. As a result, reinforcement is a crucial component of composite materials that distributes and supports the majority of the load during the course of their lifetime. Reinforcements are material that added in composite to strength the composite with required properties. It is either anisotropic (in the form of continuous or long fiber composites), which is reliant on the orientation of the fibers, or isotropic (in the form of particulate fiber composites, short fiber composites, and metal structure) which is independent on the orientation of fibers (Hsissou et al., 2021).

2.1.1. Classification of reinforcements

Reinforcements are filiform skeletons that excel in the mechanical strength of the composites. As we are aware, reinforcement can consist of both organic and inorganic fibers that range in size from small particles to continuous threads. (Hsissou et al., 2021). It is classified based on its shapes. These appearances have effects on the properties of manufactured composites. Even though the ultimate strength of composites is a synergy of matrix and reinforcement, the performance and properties of composites strongly depend on reinforcement materials. The common types of reinforcement classification based on shapes are shown in the following figure 2.2.

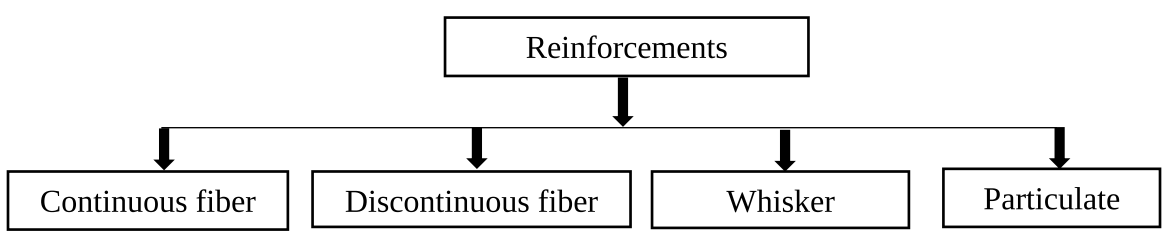


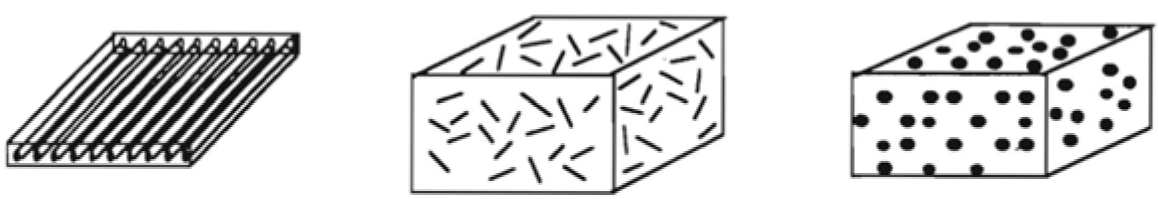
Figure 2.2: Reinforcement Classifications

Continuous fibers are those that have long strands and a small cross-sectional area. They mostly appear as circular and rectangular shapes with various diameter ranges (0.0025 mm to 0.13 mm). Due to its small cross-section, it has a strong ability to bear the load that is transferred from the matrix. As shown in the figure 2.3, it is oriented in a specific direction. Fiber-reinforced composites are anisotropic materials that have different properties in different directions (Djafari., 2022).

Discontinuous (short) fibers are the chopped form of filamentary fibers used as reinforcing agents in given composites. Short fibers are between 1 and 5 mm in length. They are mostly recognized for their in-plane isotropic characteristics, which means that their organization in composites is random (Djafari., 2022). Discontinuous fibers have the advantage of being more isotropic than continuous fibers and being simpler to fabricate.

Whiskers are made of very fine crystal fibers. They are quite small less than 1 mm in length. It is well recognized for its use in ceramic composites as a crack protector. Additionally, it improves the strength and flexibility of metal composites (Sampath and Kumar., 2020).

Particulates are incredibly tiny, three-dimensional particles with a variety of regular and irregular shapes. When there is a need to maximize strength while reducing ductility, it is preferred. Force transfer is higher in particle fibers due to a larger surface area of exposure to the matrix. When high-temperature performance is needed, it is mostly necessary. Its advantage, when particulates are embedded in composites the stiffness of composites will be boost (Sampath and Kumar., 2020).



a) Continuous fibers b) Discontinues (short)/ whiskers fibers c) Particulates

Figure 2.3: Reinforcement classification based on the shape (Sampath and Kumar., 2020).

2.1.2. Overview of Natural fibers

The cellulose fibers found in natural plant materials are made up of a few helically wrapped cellulose microfibrils and are held together by an amorphous lignin matrix. Water is kept in the fibers longer thanks to lignin. It serves as a defense against biological attack and gives to stem a strength to withstand wind and gravity pressures. A thin primary wall—the initial layer to form during cell growth—encircles a secondary wall in the intricate, layered structure that makes up a fiber's cell wall. Three layers make up the secondary wall, and the thick middle layer determines the fiber's mechanical characteristics. Long-chain cellulose molecules are used to create a series of helically wound cellular micro-fibrils in the intermediate layer. The microfibrillar angle is the angle created between the fiber axis and the micro-fibrils, and it differs from one fiber to another in value (Gupta et al., 2015).

Natural composites are created by using reinforcement from the natural world. These natural composites are made from natural materials and have unique qualities that provide them with exceptional advantages, including low density, biodegradability, accessibility, non-abrasiveness, good mechanical performance, and absence of toxicity (Abera Betelie et al., 2019). Currently, bio-organic particles made from agricultural and plant waste are the most acceptable, affordable, and environmentally benign material for creating innovative composite materials (Sampath and Santhanam., 2019). Hemicelluloses are branching polymers of carbon sugars with a variety of chemical configurations, and they are mostly found in the primary cell wall. Lignin has an aromatic structure and is amorphous. Pectin has intricate side chains that are frequently cross-linked by calcium ions and arabinose sugars. The unique cell shape of cellulose is what determines the mechanical characteristics of plant fibers. The major cell wall is the main location for hemicelluloses, which have branching polymers of carbon sugars with a range of chemical configurations. The aromatic nature of lignin makes it amorphous. Pectin side chains frequently cross-link with calcium ions and arabinose sugars, making for complex pectin structures. The cellulose framework structure of the fiber is held together by the adhesive provided by the lignin, hemicelluloses, and pectin (Kabir et al., 2011).

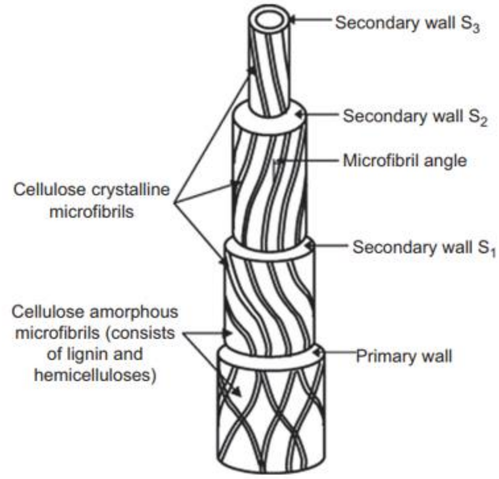


Figure 2.4: General structure of natural fibers (Dhakal et al., 2018).

Characteristics of bamboo

From a large-scale perspective, bamboo is made up of a hollow portion and a thin wall with a specific sloping shape. Bamboo is made of unidirectional fibers that are reinforced by parenchymatous ground tissue, which serves as a matrix at the tissue level. The characteristic of functionally graded materials for bamboo is indicated by the non-uniform distribution of vascular tissue in the radius direction. The bamboo fibers are more numerous and denser in nature towards the outer periphery than they are in the interior zone. Greater and sparser bamboo matrix volume percent can be found near the inner zone (Raya et al., 2004). It has more than ten cellular layers, with thick layers and thin layers arranged alternately on the cell wall of bamboo fibers for each different microfibril orientation (Wang and Chen., 2022).

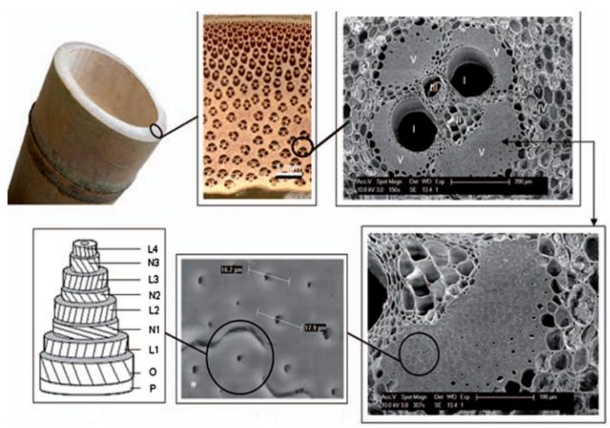


Figure 2.5: Internal structure of bamboo **(**Abdul Khalil et al., 2022)

Characteristics of moringa tree and its fruits

The tree grows a tuberous tap root and is between 5 and 12 meters tall with an open, umbrella-shaped crown, a straight trunk, and corky, whitish bark. Depending on the climate, the foliage is either evergreen or deciduous and contains leaflets that are 1 to 2 cm in diameter. The flowers are white or cream in color. Depending on the variety, the fruits (pods) start out light green, thin, and sensitive and eventually turn dark green, hard, and up to 120 cm long (BA et al., 2013). The fruit's exterior is exceedingly rough and hard, making it a waste product that is discarded. Long capsules and oilseeds can be found in some moringa fruits. In maturity stage, they range in length from 20 to 40 cm, and each fruit has 12 to 35 seeds. In the early stage, they are white, but when they reach maturity, they turn brown (Trigo et al., 2020). Environmental conditions may have an impact on moringa plants' chemical makeup (Melesse et al., 2012). Fast-growing moringa trees produce long, green pods after 6 to 8 months, and they can keep producing for another 30 to 40 years. It produces a lot of feed, up to 120 metric tons of dry matter (Madalla et al.,2013).

2.1.3. Chemical composition of natural fiber

Natural composites are composed of various chemical compositions. These chemical composition percentages depend upon the types of natural fibers. Natural fibers mostly consist of cellulose, hemicellulose, pectin, and lignin. The mechanical and physical characteristics of composite materials are impacted by these mixtures. For instance, cellulose, which primarily contains fibers, is in charge of strength and flexibility. Recyclability, thermal deterioration, and moisture absorption are all caused by hemicellulose. Lignin is responsible for thermally ultraviolet degradation. For various fibers, the percentage content of each of these components are varies. Plant based fibers are lignocellulosic in nature and made up of waxy compounds, cellulose, hemicelluloses, lignin and pectin proportion of natural fiber's structural content (Kabir et al 2011).

Table 2.1: Chemical composition of bamboo and moringa fiber reported in previous literature

Fibers	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Others (%)	References
Bamboo	26-43	30	21-31	-	Jahan and Son.,2021.
	60–80	5–20	-	20	Saheb and Jog., 1999.
	26-43	30	21-31	8.9	J S., 2018.
	60.8	32.2	-	7	Shah et al., 2016.
	74.36	25.29	0.08	0.27	Wang et al., 2022.
	60	-	32	-	Okubo et al., 2004.
	34.5	20.5	26	8	Harikumar and Devaraju., 2021.
Moringa	33.4±1.32	32.06±1.2	20.14±1.59	-	Lehman et al., 2017.
	43.44	0.25	45.84	10.47	Nayak and Khuntia 2019.
	65.5	-	20.5	5.15	Sharma et al., 2021.
	13.7	9.6	4.3	10.52	Mishra and Sinha., 2020.
	51.33	14.31	23.39	9.82	J S., 2018.

2.1.4. Physical and Mechanical properties of natural fibers

Mechanical analysis is the study of how a material responds to loads. The cellulose content is primarily responsible for the mechanical properties, which are regulated by a number of variables (Rassiah et al., 2013). Furthermore, aspect ratio, fiber-matrix bonding, fiber arrangement, load transfer at the interface, and volume fraction of the fibers are controlling factors in natural fiber composites that influence the overall properties of composites (Saheb and Jog., 1999).

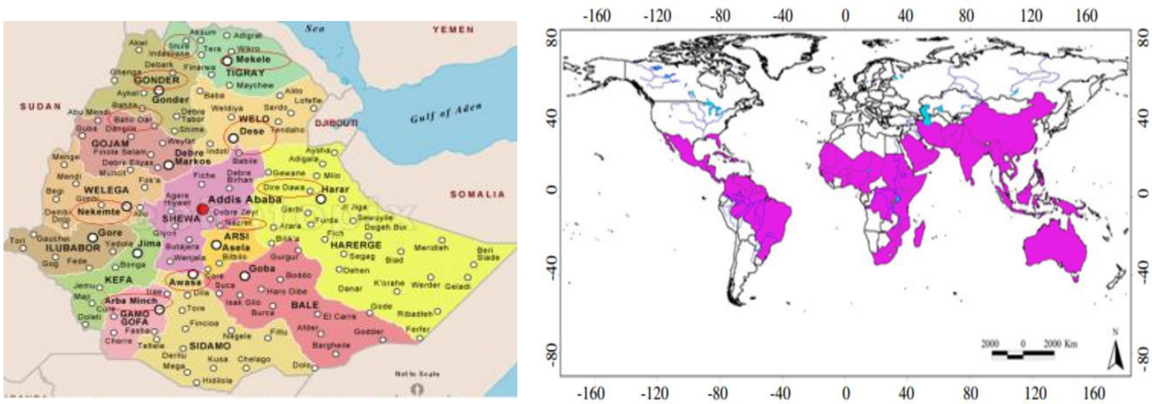
The mechanical properties of plant fibers are determined by cellulose, which has its unique cell geometry.The major structural elements of the fiber, including its strength, stiffness, and structura -l stability, are all provided by cellulose (Kabir et al., 2011). Natural fiber composites were created with special qualities for certain uses. For this reason, properly examining and comprehending the constraint factors is vital. The most typical natural composites' fundamental physical and mechanical characteristics are listed in the table below. These mechanical and physical characteristics of natural fibers are average values collected from a variety of sources.

Table 2.2: Natural fibers versus their properties

Fiber properties	Abaca	Bamboo	Banana	Coir	Cotton	Flax	Hemp	Jute	Kenaf	Pineapple	Ramie	Sisal
Density(g/cc)	1.5	0.85	1.35	1.2	1.21	1.38	1.47	1.23	1.2	1.5	1.44	1.2
Diameter(μm)	20	56.5	21	18.5	23.5	21.5	30.5	15	24	24.5	49	27
Length(mm)	4.9	2.75	0.65	1.65	35.5	37.5	30	3.4	6.2	5.5	145	4.4
Tensile strength(MPa)	621.5	566	721.5	175	442	689	845	480	612.5	898.5	669	681
Young's modulus(GPa)	32.35	53	29.5	6	8	60	45	37.5	41	71	94.7	15.5
Elongation at break (%)	2.9	4.65	5.5	20	6	2.1	3.05	2.3	4.8	2	3	2.45
Moisture content (%)	14	14	10.5	10	33.5	7	8	12	9.1	14	14.5	11

Moringa oleifera Plant

Moringa oleifera plant is a tree in the Moringaceae family that thrives in tropical and subtropical climates and is quick to grow, adaptable, and well known as drought-resistant. It has 14 species in a single genus family (Sharma et al., 2021; Saa et al., 2019). This plant can survive drought and can grow in harsh climates, infertile soil, and even barren ground with a wide pH range, i.e., 4.5 pH 9 (Ezekiel et al., 2014). It is a versatile tree where almost all parts of the tree can be used for various purposes, among which are food, medicine, fertilizer, honey cleanser, pulp, pollution control, and reinforcement for composite materials, among its application areas. For this reason, it is also called the miracle tree. The moringa tree, known locally as Shiferaw or aleko, enjoys great popularity in Ethiopia and also worldwide. The southern and western parts of the country are particularly suitable for this tree. Moringa production in Ethiopia is mainly in the following specific zones and special districts such as South Omo, Gamo Gofa, Kaffa, Sheka, Bench Maji, Wolaita, Dawaro, Bale, Borena, Sidama, Burji, Amaro, Konso and Derashe between 500 and 1800 meters above sea level in the low to medium highland agro-climate, according to the flora of Ethiopia (Edwards et al., 2000; Yisehak et al., 2011).



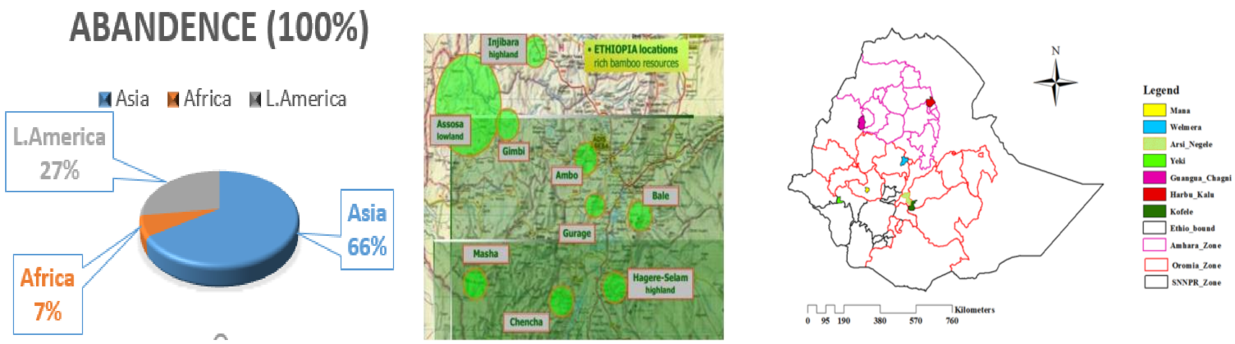
(a) (b)

Figure 2.6: Moringa oleifera distribution: a) Though out Ethiopia (Edwards et al., 2000) and b) though out the world (Gandji et al., 2022).

Bamboo Plant

Bamboo is the most important and abundant plant that mainly grows in sub-tropical and tropical environments (Emamverdian et al., 2020). It is the Poaceae family and the Bambusoideae subfamily that have fast-growing renewable eco-friendly and have a positive impact on the production of clean oxygen. It is a multi-purpose material with countless applications, from construction to fuel (The monthly planet, 2022. Bamboo. p.1). Studies show that on the earth, approximately 1500 bamboo species exist (Kaur et al., 2017; Emamverdian et al., 2020) within 75 genera in the earth (He et al., 2007). Bamboo is a type of grass that needs to mature from 3 years to 5 years. Bamboo's cellulose content rises as it becomes older, but as it gets older, its ash contents fall. Hemicellulose and lignin concentrations are not consistent throughout time. Their content from greatest to lowest are at the ages of 2, 3, and 1 year–old respectively (Desalegn et al., 2022). Africa is home to roughly 43 kinds of bamboo, which occupy over 1.5 million hectares (Kigomo., 1988). In Ethiopia significant amount of bamboo, resources are there. More than one million hector bamboo is found in Ethiopia, which is approximately 86% of African bamboo (Kelbessa et.al., 2000; Saheb and Jog., 1999.).

There are two endemic bamboo species in Ethiopia: the highland bamboo (Arundinaria alpine) and the lowland bamboo (Oxytenantheria Abyssinia). These species are found only in Ethiopia and some parts of Africa. Lowland bamboo is mostly grown in the western region of Ethiopia, between the major river valleys and the border with Sudan, at elevations between 1100 and 1700 meters above sea level. These bamboos are commonly used for house construction, fencing, food, and as a source of energy (Kelbessa et al., 2000). The Ethiopian Forest survey shows that there are about 850,000 hectares of lowland bamboo and 130,000 hectares of highland bamboo in Ethiopia (Saheb and Jog., 1999). The figure 2.7, describe the contribution of world bamboo resources by continent and the main location of lowland and highland bamboo in Ethiopia.



(a) (b) (c)

Figure 2.7: Bamboo distribution: (a) Show global distribution (Kassahun., 2015; Emamverdian et al., 2020) and (b) specific region distribution (Editor: S. George., 2007), and (c) show distribution in Ethiopia (Yigardu et al., 2016).

2.1.5. Moringa and Bamboo applications

Moringa is the most neglected natural plant in Ethiopia. However, it has plenty of applications in different fields. Researchers gave it different names, and "The Miracle Tree" is one of them. Every part is rich in nutritional content and useful for multiple health problems. The Moringa plant has been around since 150 B.C. History demonstrates that ancient kings and queens consumed Moringa fruit and leaves to keep their skin and intellect in good shape (S, G et al., 2015). Moringa oleifera in Ethiopia is used as food and traditional medicine. This undiscovered tree was uncommon to use as reinforcing fiber. Currently, scientists are digging into the amazing use of moringa in different fields. The industry squanders a significant amount of the fiber-rich Moringa oleifera fruit husk (MOFH) after it has produced its economic worth (J S., 2018). The role of moringa in advanced technology materials is not well expressed by literature, especially in hybrid composites. According to earlier research, moringa is among the most significant and effective natural fibers in terms of fiber strength (Nayak and Khuntia., 2019).

Medical, breast-feeding, innovative materials, food, water treatment, and anti-inflammatory are a few uses for moringa. Leprosy and epilepsy treatments also possible using moringa leaves (Yisehak et al., 2011). Researchers are attempting to demonstrate that moringa can treat cancer and diabetes. Because of their high fiber content, moringa oliefera pods (fruits) are also used to alleviate joint pain, liver, diarrhea, and spleen issues (Gopalakrishnan et al., 2022).

Figure 2.8: Moringa oleifera powder, leaves, and capsules (Arnarson., 2018)

Bamboo is a versatile plant that is widely distributed in our nation. In contrast to moringa, bamboo is well known in the scientific community as a material used in advanced composites. In Ethiopia, bamboo is frequently utilized for furniture, musical instruments, and house construction. But generally speaking, it has a wide range of applications, from food to building, all across the world. Due to its qualities as an anti-bacterial, anti-UV, anti-static, absorbent material, and more, bamboo has been used in a variety of industries including textiles, paper, construction, packaging, and healthcare (Jiang et al., 2022; Emamverdian et al., 2020). Numerous researchers have shown bamboo is an effective material in terms of reinforcement material. This work serves as proof of bamboo's appropriateness for use in composite materials.

Figure 2.9: Traditional application of bamboo in Ethiopia (Alene., 2018).

The main focus of this research is on the possible use of entirely biodegradable natural plant fibers, such as moringa and bamboo fibers, in the fabrication of composite materials and the examination of their mechanical properties.

2.1.6. Composite fabrication Techniques

Composites can be developed using various methods in the manufacturing sector. But all composite fabrication methods are not used for all application areas. Selecting appropriate technique is decisive and important for the final composite properties. So, they have a significant effect on the properties of the composite. The choice of manufacturing processes is influenced by the types of polymer matrix, fiber orientation, and fiber types (Ravindran et al.,2021). The fabrication of polymer composites is highlighted here. The most common fabrication techniques are injection molding, hand lay-up, compression molding, extrusion molding, Vacuum assisted resin infusion molding and pultrusion. Some of the techniques are only applicable to polymer composites. Below some of the composite fabrication techniques are stated:

Compression molding

A closed molding method using high pressure is called compression molding. This technique creates composite products using two matching metal molds (Gupta et al., 2015). The compression causes preheated material that is maintained in the mold cavity to deform until the NFC freezes. It provides superb surface polish and very minimal material waste. It is an easy way of fabricating thermoset and thermoplastic composites with fiber reinforcement. Natural fibers and resin are combined during the procedure and added to the mold plate. The preheated fiber-resin mixture is left in the mold while pressure is applied until the desired composite solidifies (Dasore et al., 2022). If the material is continuous fibers, the mold cavity is filled with matrix resin after the fibers have been positioned according to the specifications. Using a hydraulic press, pressure is used to ensure strong adhesion and to reduce the void. Therefore, simple procedures can be used to create products of all types, from the simple to the complicated one. The procedure produces nearly little waste, and the finished product look better (Dasore et al., 2022).

Hand Lay-Up

This method is extremely well known for preparing natural fiber composites. It is one of the oldest composite fabrication methods (Gupta et al 2015). Continuous fiber, short fiber, unidirectional and woven fiber can be synthesized using the hand lay-up method. After resins are distributed throughout the mold by using a simple roller, reinforcements are added layer by layer to achieve the required thickness. At the end, with standard temperature and pressure, the curing process is finished to get the final material. It provides good accuracy with less tooling expense (Dasore et al., 2022).

Vacuum-assisted resin infusion molding (RIM)

It is a closed-mold manufacturing method with a modest tooling investment that can produce high-performance, large-scale products (Abdurohman et.al., 2018). RIM is a dual-mold procedure that begins with laying dry fibers in a flexible metal face that is pressed down over the composite. Finally, it is exposed to a vacuum to ensure the quality of the product. NFC can be obtained in a short time through this method. This technique is suitable for multilayer laminated natural fiber composites. This approach is particularly used to handle woven and non-woven fabrics as well as unidirectional NFC. In this procedure, the resin and hardener are released by a vacuum pump to wet the mat mold. It uses a dual mold process that starts with laying dry natural fiber on a flexible metal surface. The procedure is then carried out in a vacuum to preserve the composite's high quality. The resulting composite can be gained quickly by using vacuum assisted resin infusion molding (Dasore et.al., 2022).

Injection molding

In the injection molding process, raw materials are forced into a mold cavity. By splitting the mold in two and forcing the molten plastic out, products are created. Four steps make up this procedure:

clamping, injection, chilling, and ejection. The reciprocating screw first compresses the thermoplastic pellets, which are subsequently forced into a heating chamber. The next step is to flow the softened material. The required shape is pressed under pressure through a nozzle into a cavity in a cold mold. In these hollow molds, complex shape materials can be created. The molds can be opened to remove the items. It is mostly suited to the accurate dimensional creation of plastic parts. Thermoset and thermoplastic-based fibers (both synthetic and natural) reinforced composites are both acceptable for this method (Gupta and Srivastava., 2015). It is Faster and more suited for high-volume production process. This method can be used to create intricate shapes in a range of sizes. With this method, good dimensional precision can be attained (Asha and Chandra., 2014).

Pultrusion

Pultrusion is a practical method for thermoset resin matrix and natural fiber reinforcing. The resin bath is passed through with rolled roving. The resin bath is changed into the desired shape by the hot die. The formed shape then moves into the drawer for the profile for the last curing step. The steel mold is being produced at a temperature of 150 °C and a pressure of 50 kN. Despite the slow production rate, the finished product has better mechanical performance The curing process needs 1 day at room temperature and by keeping a constant pressure of 10 kN. This method used to create thermoset polymer composites that are reinforced with artificial or natural fibers. The hybrid composites also develop though pultrusion process (Gupta and Srivastava., 2015).

2.1.7. Reinforcement Extraction

Various methods are available to extract the required net fiber reinforcement. However, the dominant methods in these days are mechanical methods, chemical methods, and combinations of mechanical and chemical methods (Zakikhani et al., 2022). These methods each have their own advantages and disadvantages based on the application area. According to environmental concerns, mechanical extraction is preferable in some circumstances, although chemical treatment has the advantage to get better quality fibers, (Zakikhani et al., 2022). To compromise, this combined method of extraction is an ideal one. The three fiber extraction techniques are described in detail below.

Mechanical extraction

As the name suggests, mechanical extraction is the process of extracting fibers using mechanical methods. The most common ones among these methods are rolling, crushing, stream explosion, and grinding. This approach, which is well-known across a variety of industries, makes it possible to remove the fiber without harming the environment (Zakikhani et al., 2022).

Steam explosion method

It is the earliest method from the mechanical extraction method. In addition to this, it needs a small amount of energy for the process. It is a popular method in the pulp industry. It primarily serves as a means of separating lignin from the surface of fibers (Martijanti et al., 2020). Figure 2.10 illustrates the extraction process using a steam explosion. However, this approach has the following disadvantages:

- The fibers will be stiff and black after extraction.
- It is impossible to remove all lignin
- The bundle is not broken up into individual fibers.
- To obtain the necessary fiber, a further procedure is required.

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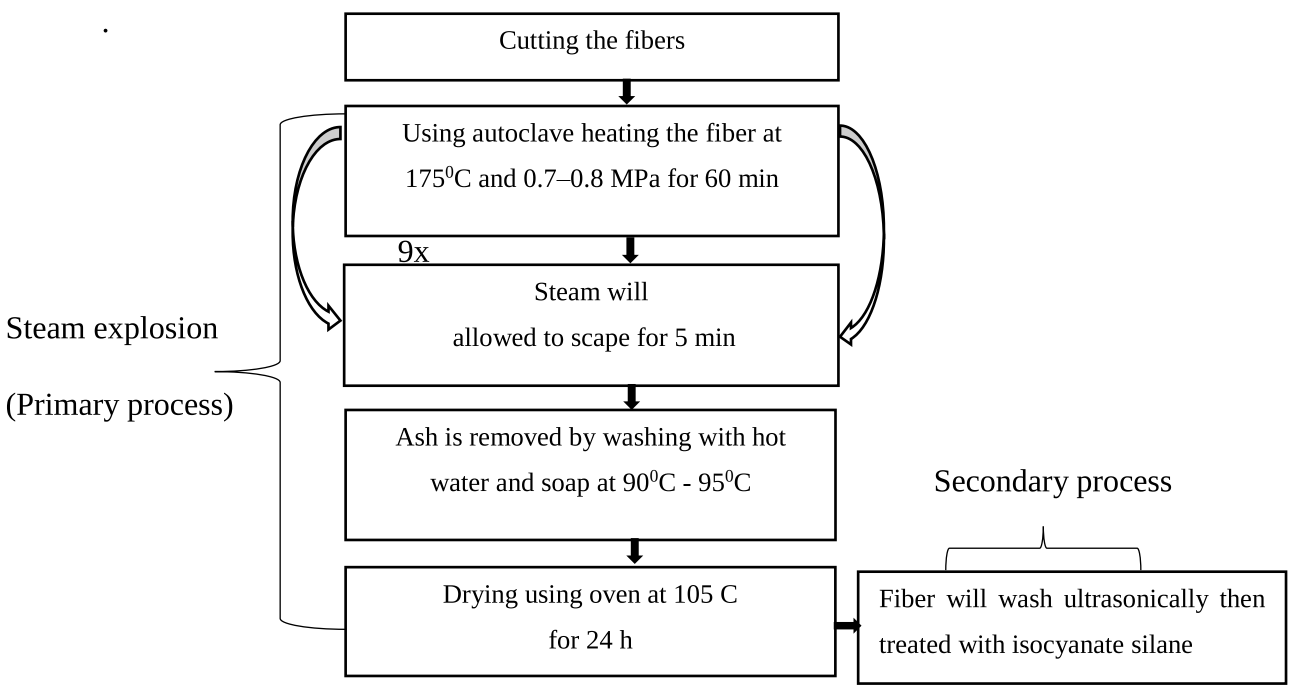


Figure 2.10: Steam explosion process (Martijanti et al., 2020)

Retting method

This is another mechanical extraction method to get the required fibers. Keep the reinforcements submerged in water for three days to obtain the strip of fibers by peeling them. Use a sharp-edged tool to smash and scrape the fibers to further separate them before combing. Due to beating and scraping involved in this technique the quality of fiber is lower (Zakikhani et al., 2022; Martijanti et al., 2020).

Crushing method

The majority of crushing is done with mechanical equipment. It is impossible to obtain long fiber with this procedure. This is a well-known drawback of it. It is only appropriate for powder and short fibers (Zakikhani, et.al., 2022). The steps in the crushing method are as shown:

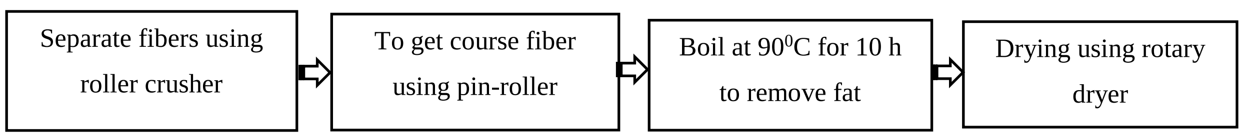


Figure 2.11: Extraction step of fiber using a crushing method (Martijanti et al., 2020).

Grinding method

The qualities of the finished product are significantly impacted by the grinding process. For instance, the material's tensile strength might have reduced, but its tensile modulus might have grown. Initially, the culm is separated into strips and left in water for a day. After 24 hours, a sharp tool is used to manually cut the soaked fibers into smaller pieces, and a broader strip of fiber is then fed through an extruder. Finally, a grinding machine is utilized to attain the desired size (Zakikhani et al., 2022; Martijanti et al., 2020).

Rolling mill method

This process is similar to the grinding method. The culm was cut with a thickness of 1 mm pieces. Then put it into the water for one hour. After that, they move slowly and under low pressure through the rolling mill equipment. Following milling, the strip of fibers was re-soaked for a half-hour in water before being cut into fibers using a razor blade. The fibers are then dried for a day in the sun. The final fiber length is between 220 and 270 millimeters long (Martijanti et al., 2020).

Chemical extraction

It is an easy, cheap, and effective technique as compared to other methods. Chemicals that are utilized to extract the necessary fibers are the major ingredients in this process. For example, if natural fibers are treated with NaOH, the hydroxide groups in the fibers are reduced, which results in boosting of fibers' ability to withstand moisture (Dasore et al., 2022). The fiber gotten from this method is less damaged because there is no direct physical force. The researcher claims that there are several procedures to use with varying chemical concentrations to remove the fiber using this method (Zakikhani et. al., 2022). The process of alkalinization is depicted in figure 2.12 below.

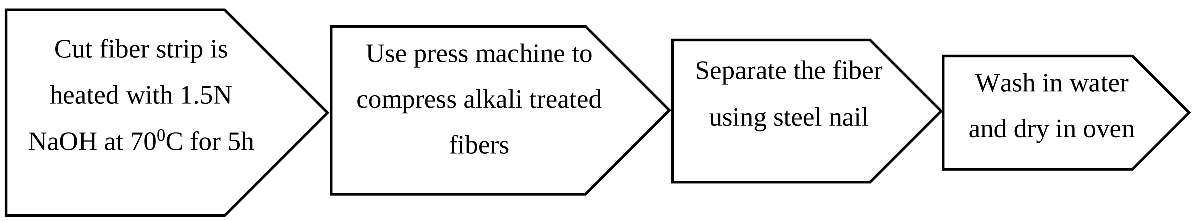


Figure 2.12: Alkalization method process (Martijanti et al., 2020).

Combine extraction

After a chemical treatment to remove the fibers, compression molding and roller mill mechanical techniques are typically used in this procedure. This combined effort of chemical and mechanical processes gives the chance to get net fibers easily (Zakikhani, et.al., 2022). But, the effectiveness of this method depends on constraints, these are:

- Compression mold dimension
- Roller diameter

Step in combine extraction method for roller mill:

1. The culm of the fiber plant is mechanically sliced to obtain the fiber strip.
2. These strips are immersed in NaOH solution at different concentrations at 70^0C for 10 h.
3. Chemically treated fiber strips are rolled by a roller to separate fibers.
4. Use water to wash.
5. Dry it for a day in an oven set at 105°C.

Therefore, the overall properties of natural fibers are affected by the type of extraction method used.

So, selection of the best technique of extraction is the crucial step in the development of cellulosic fiber composites to acquire unique properties.

2.1.8. Chemical treatment and Fiber-Matrix Interface

An interface is a region where a discontinuity in physical, mechanical and chemical properties occur. Due to the difference in properties between the two phases. The fiber-matrix interface, in addition to the primary (matrix) and secondary (reinforcement) phases, can be thought of as the third phase in composites. Lignocellulosic fibers' propensity to absorb moisture is its primary flaw. Dimensional instability results from the interaction between hydrophilic lignocellulosic fibers and hydrophobic matrix. Chemically treating fibers is one of the greatest ways to solve this issue (Dhakal et.al. 2018). The hemicellulose, lignin, wax, and oils that encircle the fiber's shell are eliminated by chemical treatment, which increases surface roughness and enhances interface bonding (Nayak and Khuntia., 2019; Jahan and Soni., 2021; Kaur et al., 2017; Sreenivas et al.,2016). The mechanical characteristics of synthetic composites are influenced by hydrophilic properties. Further, they lead to dimensional instability as well as porous composites. Although it varies from fiber to fiber, the moisture content is often between 5 and 10%. (Saheb, D. and Jog, J., 1999). The fibers must be "moist" by the matrix substance then, surface area of the interface is increased by well-"wetted" fibers (Banga et al., 2015).

2.2. Previous work on natural fibers

The most pertinent prior studies on natural composites including composites made of moringa and bamboo fibers, synthetic/natural hybrid composites, and natural hybrid composites are covered in this section of the chapter.

Natural fiber composites

Okubo et al., (2004) were studied on the development of composites focusing on ecological purposes using bamboo fibers and their basic mechanical properties. The steam explosion method was used to extract the bamboo fiber eco-composites (BFEC). The hot-pressing technique was used to create the composite samples. After fabrication, their internal state and static strength were analyzed.

Wang and Ying., (2014) were investigate effects of bamboo fiber content and the alkali treatment of bamboo fibers on physical properties, mechanical properties as well as water absorption. In order to improve the bamboo fiber reinforced composite's mechanical and physical properties, a novel method of bamboo fiber arrangement modification has been proposed. In this study, composite materials were made from raw and alkali-treated bamboo fiber, and a silane coupling agent was utilized to enhance interfacial interaction. In general, the alkali-treated bamboo fiber's qualities far out performed those of untreated bamboo fiber. The outcomes show that alkali treatment significantly enhanced the adhesive contact between fiber and matrix.

Lehman et al., (2017) were studied on the viability of utilizing natural fibers from the agricultural byproducts of Moringa oleifera pod husks (MOPH) to strengthen and improve the characteristics of composite materials. The chemical and physical properties of the fibers were extensively studied to evaluate their potential as fillers in bio-composites. MOPH proof as a good bio-reinforcing filler for composites.

Tang et al., (2018) were proposed a novel method for extracting BF from bamboo culms by using an eco-friendly solvent extraction technique, and composite samples were fabricated from this fiber by the hot-pressing method. In addition, the obtained BFs have excellent flexibility and are very convenient for use in nonwoven technology. The influence of bamboo fiber concentration on the mechanical and physical properties of the bamboo-reinforced improved Polypropylene composites was investigated.

Ayrilmis et al., (2018) were studies focusing on the extraction of nano-cellulose from M. oleifera and its applications in epoxy resin. Cellulose nano-whiskers were made from Moringa oleifera drumstick fruit fibers by acid hydrolysis techniques. Cellulose nano-whiskers were added to an epoxy matrix at various weight ratios to examine the effects on the mechanical and thermal properties of the finished composite. The thermal stability of composites rose slightly.

Sampath and Santhanam., (2019) were evaluated the effects of moringa and nano-ash filler particles in the combined basalt fiber/epoxy composite on mechanical performance, chemical reaction, and reaction toward moisture. To prepare the composite sample, the hand lay-up approach was applied. In this work, the potential of ash particles from agricultural residue was investigated. Additionally, the impacts of the moringa and bagasse ash filler particles on the mechanical, chemical, and water absorption characteristics of the sample composites were identified.

Mishra and Sinha., (2020) were made an investigation of the use of easily available, reasonably priced moringa leaf powder as reinforcement in epoxy composites for limited structural use. In this instance, various filler concentration ranges were used to manufacture the samples. A hand lay-up approach was used to create these composite examples. Investigations were done into how variations in filler concentration affected morphological, thermal, mechanical, and water absorption characteristics. In comparison to pure epoxy resin, the material's characteristics are thereby improved. In this work, the authors have attempted to produce advanced composites suitable for specific applications.

Sharan et al., (2021) were an attempt to use the finite element analytical method to investigate the effects of fiber arrangement on the mechanical properties of natural fiber reinforced epoxy composite. This work tried to discuss the potential application of plentiful natural fiber reinforced composites such as hemp fiber, banana fiber, kenaf fiber, jute fiber, and pineapple leaf according to their fiber arrangements. Tests for tensile strength, bending, and hardness was completed. Due to the fiber configuration, various outcomes were found based on these testing. The arrangement of zero and ninety degrees of pressure/stress was therefore small based on the results of the tensile and bending tests. However, with a 45-degree setup, excellent results for the hardness test were discovered. This study only focus on the orientation of the different natural fibers.

Natural-Synthetic hybrid composites

Vijaya et al., (2021) were study various combinations of bamboo/glass fibers with thermoplastic matrix hybrid composites were analyzed. Swiping the orientation and composition of the fibers and matrix optimizes the strength of composite specimens. Additionally, a novel method was used in this study to create hybrid composite laminates with various layouts. The process of compression molding was employed to create sample composites. The high-strength sample was discovered through a comparison of the samples. To verify the outcomes, numerical analysis was also carried out using ANSYS software.

Nayak et al., (2021) were studies that concentrated on improving the mechanical properties of the composites by blending natural fibers with glass fibers. Jute (J) fibers were used as reinforcement in this hybrid composite. The impact of water dispersion on the natural fiber composites' mechanical characteristics, hardness, and impact resistance was also assessed. These hybrid composites were created using sample hand lay-up method.

Natural- Natural hybrid composites

Athijayamani et al., (2009) were made an investigation to understand the effects of moisture absorption on the mechanical properties of polyester hybrid composites made of roselle and sisal fibers. In this work, the impact of moisture absorption on the mechanical characteristics of hybrid polyester composites reinforced with short roselle and sisal fibers was examined, and an attempt was made to compare the composites with dry fibers to the composites with moisture absorption. The comparison of experimental findings with theoretical and empirical findings revealed strong agreement.

Nayak et al., (2020) were study, one of excellent type of thermoplastic hybrid polymer composite which is reinforced with natural fibers of areca sheath and Moringa oleifera fruit fibers. To develop this hybrid composite, the injection molding method was applied. The composites produced were different combinations of reinforcement and matrix. For comparison purposes, pure Polyethylene terephthalate (PET) composites were also fabricated. This research has demonstrated the potential use of this hybrid natural composite, particularly for lightweight engineering applications. To determine their appropriate application fields, a thorough examination of the areca/moringa PET hybrid composites' physical properties, mechanical capabilities, and thermal stability was conducted.

Praveena et al., (2021) were investigate the behavior of a hybrid natural fiber-reinforced polyester composite, by changing the concentration of the reinforcements (pineapple fibre and sisal fibre) in the composites. Additionally, this effort attempted to highlight and investigate the sample composites' mechanical and hydrophilic properties. The hand lay-up method was used to prepare this sample. As a result, this experiment demonstrated that increasing the reinforcement content up to half of the composite in weight percent results in base dampness, improving mechanical properties, and fading hydrophilic properties.

Mahesh et al., (2021) were study the influence of hybrid natural fibers (ramie and sisal) on the mechanical properties of composite samples. This study also discusses the unique qualities of sisal and ramie coupled to enhance the mechanical performance of the hybrid natural composites. Two procedures were used to create this composite: melt blending with twin screw extrusion in the first step, and injection molding in the second. The scientists claim that both the agriculture and automobile industries can use this special composite sample.

Ravindran et.al., (2021) were studied the mechanical properties of hybrid natural fiber (banana and jute fibers) reinforced vinyl ester using different layers' orders. Chemically treated and untreated sample composites were contrasted. The procedure for creating samples using vacuum infusion was chosen. Basic testing was undertaken to examine the mechanical properties of the material. The outcomes of the experiment demonstrated that the mechanical characteristics of natural fibers are affected by the variation in the layer order. With natural fibers, the polymer matrix materials can create adequate interfacial connections. As a result, the polymer composite shows good performance in dynamic and high temperatures as well as a high toughening effect.

Summary of relevant previous work on moringa and bamboo.

Table 2.3: Summary of literature

Author and Year	Reinforcement	Matrix	Fiber extraction	Manufacturing Process	Results
Nayak et al., 2021	Bamboo, jute, and glass fiber	Polypropylene	Purchased	Hand lay-up	Hardness: 52 BHN, Impact strength: 250 kJ/m^2
Vijaya et al., (2021)	Bamboo fiber and glass fiber	Epoxy	Manually extract	Compression molding	Tensile strength: 95.98 MPa, Flexural strength: 119.34 MPa, Impact strength: 764.5 J/m^2
Mishra and Sinha, (2020)	Moringa oleifera filler	Epoxy	Washing, Grinding then sieving	Hand layup	Tensile strength: 38 MPa, Tensile Modulus: 1.45 GPa, flexural

					strength: 57 MPa , and flexural modulus: 2.09 GPa
Nayak et al., 2020	Moringa fiber and Areca fiber	Polyethylene terephtalate	Retting process	Injection molding	Hardness: 33.88 VHN, tensile strength: 185.9 MPa, flexural strength: 98.5MPa, Impact strength: 35.2 kJ/m^2
Sampath and Santhanam,, (2019)	Basalt Fiber, Moringa & bagasse ash filler particles	Epoxy	hydrochloric acid, sodium hydroxide and ethanol	Hand lay-up	Tensile strength:138.6 MPa, Elongation (%): 2.66, Impact energy: 24 J
Ayrilmis et al., (2018)	Moringa oleifera fiber	Epoxy	Acid hydrolysis with 40% H_2SO_4	Open molding	Tensile strength: 38.6 MPa, Tensile modulus: 1.68 GPa, bending strength: 104.5 MPa and Bending modulus: 3.14 GPa
Tang et.al., (2018)	Bamboo fiber	Polypropylene	Digestion by butanediol water solution	Hot pressing	Flexural strength: 52.8 MPa, Flexural modulus: 2.8 GPa and Impact strength: 12.5 kJ/m^2

Lehman et al., (2017)	Moringa oleifera fiber	Gelatin	Cutting mill , grinding miller then sieving	Casting method	Tensile strength: 7 MPa, Young's modulus: 250 MPa, and elongation at break (%): 3.80
Wang and Ying, (2014)	Bamboo Fiber	polypropylene	Purchased	Injection molding.	Tensile strength: 50 MPa, Young's modulus: 2.5 GPa, Flexural strength: 75 MPa, and Flexural modulus: 4.5 GPa
Okubo et.al., (2004)	Bamboo fiber	Polypropylene	Steam explosion technique	Molding process using hot-press	Tensile strength: 35.1 MPa, Young's modulus: 17.6 MPa, and Failure strain (%): 1.21

2.3. Research Gap

This work focuses on developing natural composites of moringa (MM-60) and bamboo (BB-60) as well as hybrid natural composites from their combination (BM-30/30) for specific applications. To the best of my knowledge, no work has done before that combines moringa pod fibers and bamboo fibers to create a hybrid composite, which is a novel idea that supports the field of advanced material. The gap found in the literature is that a ton of research has been done on a range of natural fibers for polymer composites, but very little has been documented on the reinforcing of fibers from moringa pod fibers. Therefore, the purpose of this study is to close the gap that our literature evaluation revealed and develop the natural composite material that is used to advance the packaging by developing the light and environmental friendly materials.

CHAPTER THREE

3. MATERIALS AND METHODS

This chapter illustrates and explains the systematic approach, materials, chemical treatment, and development of composites reinforced with moringa/bamboo by the hand lay-up method.

Structure of Methodology

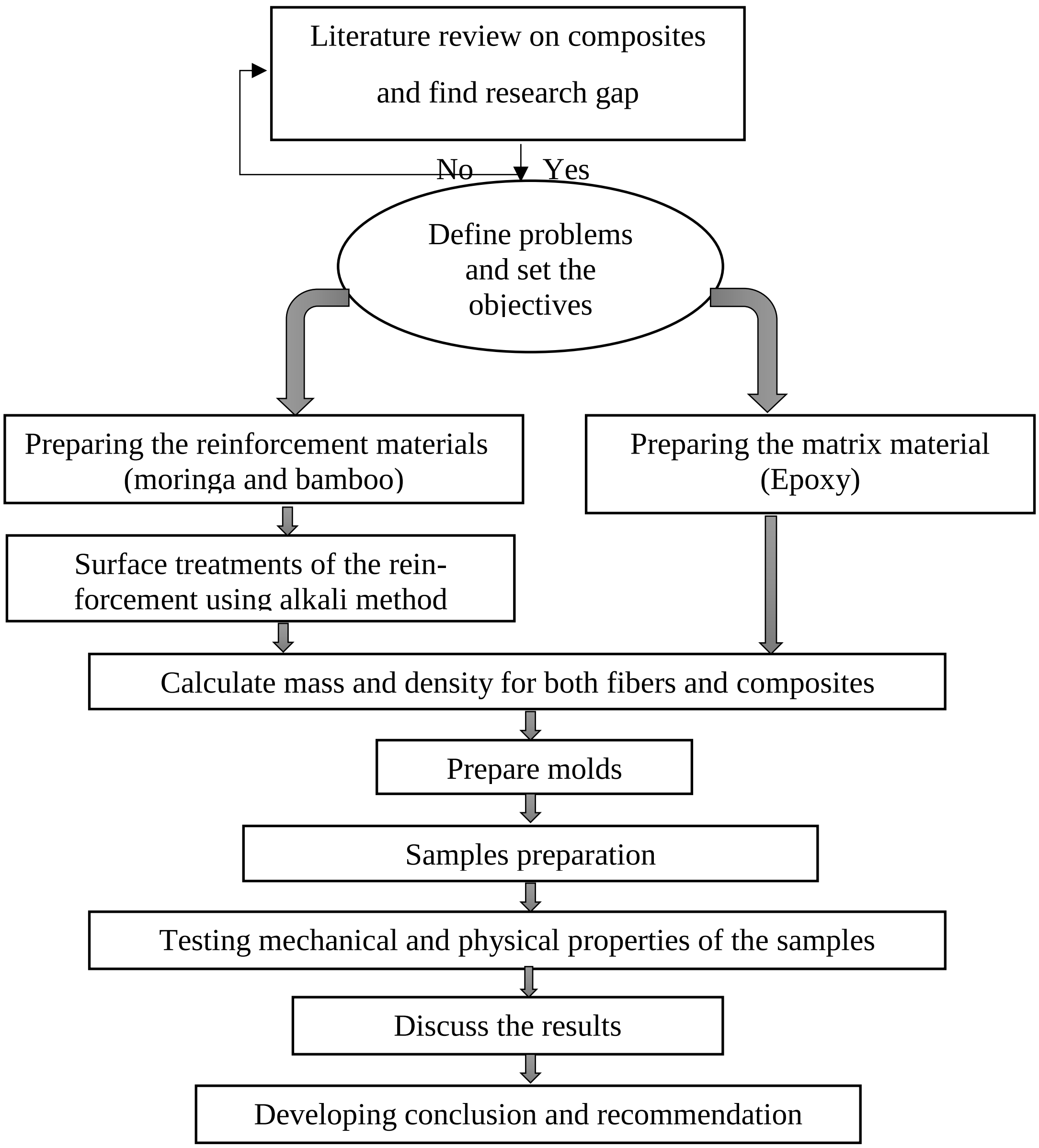


Figure 3.15: Methodology Summary.

3.1. Materials

A lot of materials and tools were required to develop the samples of composites. In this work, bamboo/moringa was used as reinforcement, and epoxy was used as the matrix. Finding the matrix and reinforcing components is the initial stage in creating composite materials. The basic materials used for the fabrication of the samples are as follows:

3.1.1. Collection of moringa pod

The moringa pod was collected from Adama, Ethiopia because this work focuses on studying Ethiopian moringa oleifera. These moringa pods were manually collected from the moringa trees.

Moringa tree Required pod Collected pod

Figure 3.1: Collection of Moringa

3.1.2. Collection of bamboo

For this research, highland bamboo was purchased from the local market in Hawassa city, in the southern part of Ethiopia, employed as a secondary reinforcement for these natural composites. Local people have skill to prepare bamboo mats that are utilized for different purpose, this include creating conventional doors, protecting plants from animal, and building home roof. The key component of natural fiber that gives exceptional strength and flexibility for this bamboo fibers is cellulose, which is found in large concentrations in this weave. The outermost layer of the bamboo plant was used to make the bamboo that was weaved for the neighborhood market. This indicates that the local peoples are generally aware of the parts of bamboo that are flexible and have good mechanical qualities. The bamboo weaving was divided into long and single pieces for this work. The bamboo strip was then manually woven into the mat by hand after being cut to fit the mold cavity.

(a) (b) (c)

Figure 3.2: Bamboo: (a) bamboo plant (b) bamboo woven in the local market (c) cut strips of bamboo.

3.1.3. Fiber extraction and treatment

Fiber extraction came next, after the bamboo and moringa were collected. For bamboo extraction, a mechanical technique was used. With the help of a sharp cutter, the collected bamboo fiber strips were further reduced to the mold cavity's needed dimensions (length, width, and thickness). In figure 3.3a below, bamboo fibers were prepared for chemical treatment. The fiber from moringa pods was extracted using a roller milling machine. At this point, the pods have had the majority of their oil removed. To get rid of moisture, the sun was shone on the crushed moringa pod. This made it easier to remove the fibers. Then, as seen in Figure 3.3b, fibers were removed using a needle. Chemical treatment is then applied to eliminate debris and improve adherence in the interphase.

(a) (b)

Figure 3.3: Fiber extraction: a) extracted bamboo fibers, b) extracted fiber of moringa.

In the development of composite materials, materials must have a strong adhesion force between the reinforcement and the matrix. Natural fibers can be treated using different techniques to remove unnecessary parts of fiber component. The ultimate goal of fiber treatment is to increase the adhesion between the interphases. As we know, composites have three phases: the primary phase (matrix), the secondary phase (reinforcement), and the interphase (the intersection between primary and secondary). So, fiber treatment improves the bonding between matrix and reinforcement in given composites.

In this work, the chemical treatment method of fibers was preferred because, as compared to the mechanical and mixed methods, it has relatively better fiber quality and easy availability of chemicals. The chemical treatment isn't only used to improve bonding but also to remove unwanted material from the surface of fibers. Furthermore, researchers also highly recommend this method for natural fiber treatment. There are a lot of chemicals used to treat fibers, such as alkaline (NaOH), silane (Si), alkali–silane, and maleic anhydride (MA). Alkaline (NaOH) was preferred as the treating chemical agent. According to researchers, bamboo and moringa fibers were treated with 10% NaOH. But the extraction methods for moringa and bamboo fibers were different.

Sodium Hydroxide

Composites made of natural fibers are treated with sodium hydroxide. It can be applied to change hydrophilic characteristics, enhancing composites' dimensional stability. The hydroxyl group's ionization into an alkoxide is facilitated by the existence of aqueous sodium hydroxide (Hamidon et al., 2019).

Fibre–OH + NaOH → Fibre–O–Na + H_2O …………………………………………………………………….. (3.1)

Figure 3.4: Sodium hydroxide used for fibers treatment.

3.1.4. Extraction and Chemical treatment of Moringa fibers

After collecting the moringa pods, the first step was to crush these moringa pods for easy extraction of the fibers because the fibers are found in the interior cover of the pods. For this purpose, a roller milling machine was used to crush the pods. After this, crushed pods were exposed to the sun for 24 hours because there is oily fluid inside the pods. In order to extract fibers, the next step was to use a sharp tool. In our case, a needle was used for extraction of fibers. Finally, clean the fibers using a brush to remove lignin and unwanted waste. Now the fibers are ready for chemical treatment. According to most of the previous work, the moringa fibers were treated with a 10% NaOH solution for 48 hours at room temperature. After two days, the fibers were soaked in distilled water to neutralize the NaOH. Then, fibers were exposed to the sun to dry for one day and become ready as bio-cellulosic reinforcement.

3.1.5. Extraction and Chemical treatment of Bamboo fibers

The collected bamboo from the local market was made into a long single strip of bamboo, which was cut into 30cm lengths using a scissor. Finally, it was cut with a 2.5 mm width and a 0.5 mm thickness for better flexibility. The next step was just to treat the fibers in the same way as moringa with a 10% NaOH solution for 2 days. After 2 days, the fibers were soaked in distilled water to neutralize the NaOH. Finally, these fibers were exposed to the sun to dry for one day. The NaOH for treating both fibers were purchased from a chemical shop. Surface bonding between the fiber and the polymer has a great impact on the performance of the composites (Saheb and Jog., 1999).

(a) (b)

Figure 3.5: Fiber treatment: a) moringa fiber and, b) bamboo fiber immersed in 10 vol.% NaOH.

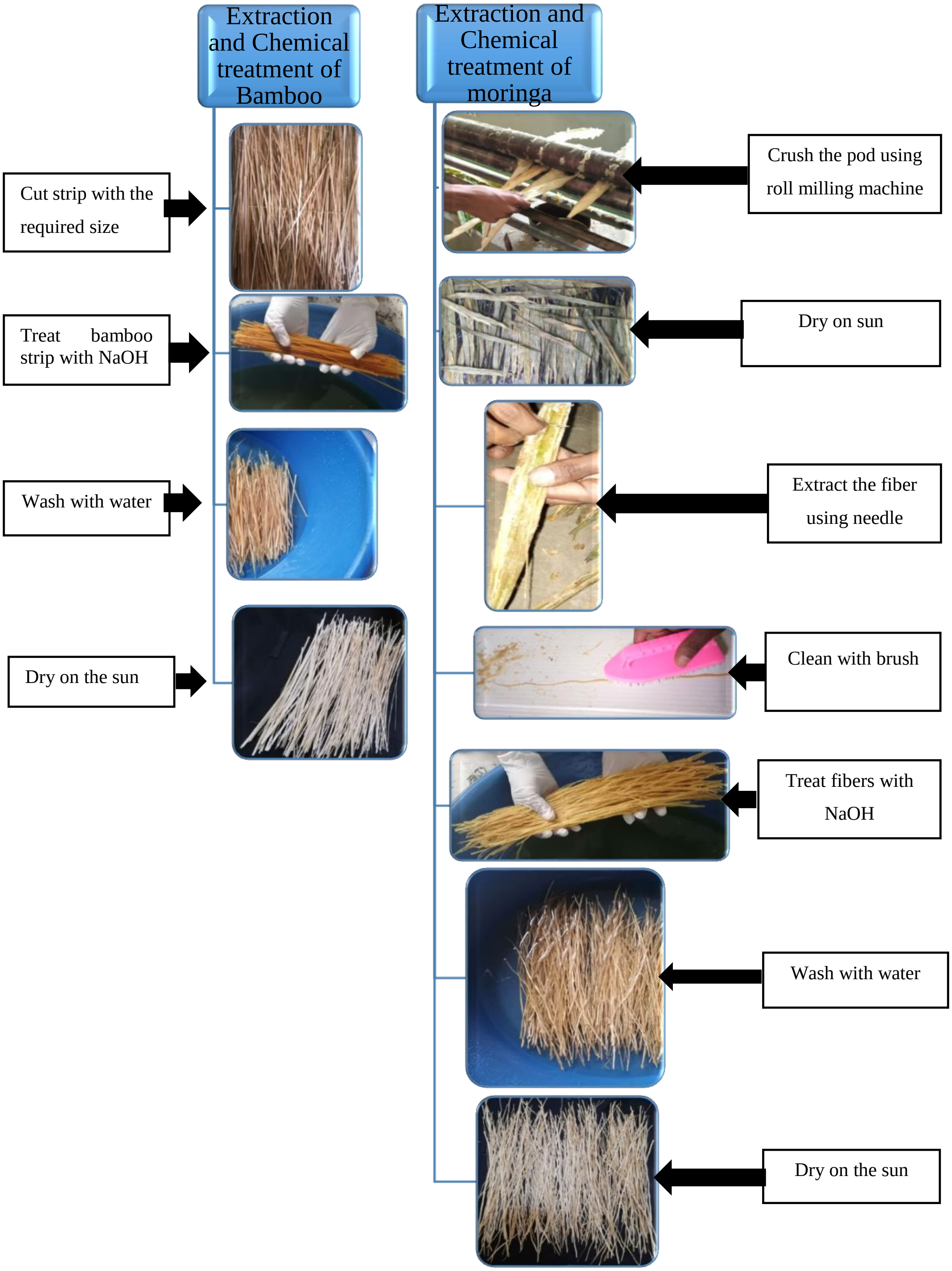
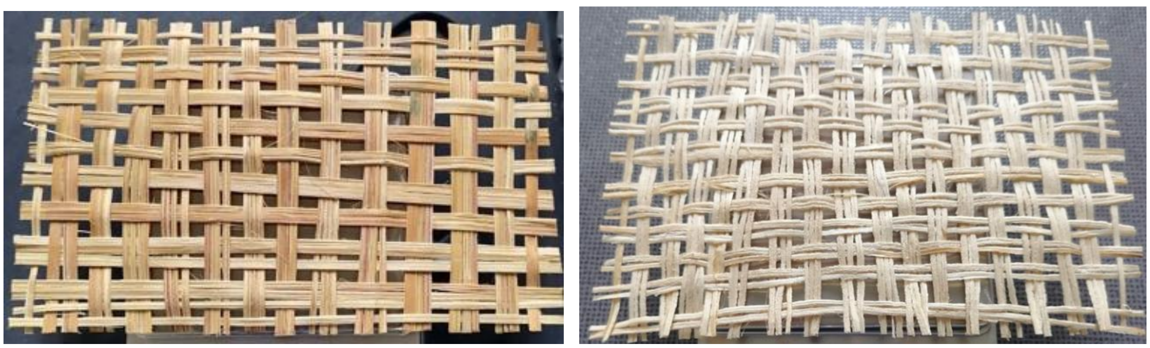


Figure 3.6: Pictorial summary of extraction and chemical treatment of moringa and bamboo fibers.

3.1.6. Preparation of Bamboo and Moringa woven fibers

These two reinforcements were formed as a woven by manually using hands. It is hard manually to develop a weave that is completely compact as shown in figure 4. As we know, fiber orientation has a great impact on the mechanical properties of fiber-reinforced composites, and the plane form of the woven ($90^0/0^0$ arrangement) has high mechanical strength. In preparing the woven, the following equipment was used: a needle (for developing a compact woven), scissors (for precise dimensioning), and a heavy RHS metal bar to fix in the opposite size, which allowed us to weave easily. At the end, these woven pieces were cut to the size of the mold cavity.



(a)

(b)

Figure 3.7: Woven preparation: (a) bamboo woven and moringa woven for mold-1, (b) bamboo woven and moringa woven for mold-2.

3.1.7. Matrix material and hardener

Epoxy resins are known for their good thermal and mechanical resistance, higher than those of polyesters. Due to its hydrophobic properties and resistance to chemical agents, it is highly recommended for metal and fiber reinforced composites (Hsissou, R., et al., 2021). This research study used epoxy as the matrix material with its designed hardener. For sample preparation, 1 kg of ARS 152 Epoxy resin (A) with 0.25kg of W 152 hardener (B) was purchased from ARC MARİN Kimya ve Denizcilik Hırdavat Dış Tic.Ltd.şti., Adana, Turkey. The samples were developed according to producer matrix/hardener ratio instruction, which is 4:1. So, the samples were fabricated based on the company's suggested ratio. The density of the epoxy resin (A) is 1.1 kg/cm^3 and the density of the hardener (B) is 1 kg/cm^3. The figures 3.8. show the epoxy and its designed hardener that are used for sample preparation. The properties of the matrix material (A) and hardener (B) described below in the table. 3.1.

Figure 3.8: Epoxy resin and hardener used for sample preparation.

Table 3.1: Properties of epoxy resin (A) and hardener (B).

Epoxy resin (ARC 152)			Hardener (W 152)		
Description	Unit	Value	Description	Unit	Value
Density	Kg/cm^3	1.1	Density	Kg/cm^3	1

Color	Colorless	1	Color	Colorless	1
Epoxy value	Eq/kg	5.35	Viscosity 25ºC	MPa	10
Viscosity 25ºC	MPa.s	11850	Pot life at 80ºC	S	4140
Volatile content at 105 ºC/h	%	0.4			
Hydrolysable chlorine	wt. %	0.08	Gel time at 80ºC	S	7080
Marten's value	ºC	150			

3.1.8. Mold Preparation

In developing composites, molds are used for casting the composite samples to the desired size and shape in the process of sample preparation. To fabricate the samples for the tests two mold was used. Mold-1 was developed from two pieces of smooth rectangular steel plate, 1 mm thick mastic sealant (locally called plaster), a 3 mm washer, and plastic film (2 pieces) that was inserted between the sample surface and metal plates. Mold-2 was fabricated from locally available materials: RHS steel, steel plate, and bolts. The dimensions of the mold cavities for mold-1 and mold-2 were 190 x 120 x 3 mm and 101 x 101 x 12.7 mm respectively. For mold-1, the steel plates were prepared according to mold cavity size. Then mastic sealant (locally called plaster), was stamped on metal plates and the mastic sealant was added layer by layer until the required thickness was reached, i.e., 3 mm for tensile and flexural testing. So, this was continued on all four sides of the steel plate.

To get an accurate dimension (3mm), four washers were put in the four outer corners of the mold. For mold-2 (compression, hardness, impact, and water absorption according to mold dimension), steel plates were prepared and then fixed with HRS steel using bolts. Next, the well-known multi-purpose cleaning agent called acetone was used. The basic properties of laboratory-grade acetone that are used for this work are mentioned in the table 3.2. The molds were thoroughly cleaned with a napkin and laboratory-grade acetone. This helps to remove all debris from the mold surface and decreases external reactions. At the same time, the adhesion in the interphase also increases. The last step for mold preparation was adding a releasing agent (wax), in our case petroleum jelly, throughout the mold cavity. Special attention was given to applying wax to all the small edges of the mold corners. Petroleum jelly was used because it was economical and easily available.

Table 3.2: Properties of acetone as a cleaning agent.

Properties	Value/Description
Formula	C_3H_6O
Molar mass	58.08g/mol
CAS number	67-64-1
Boiling point	560C
Density	784 kg/m3

Lower mold preparation

The sample was prepared on the lower mold. The mold was cleaned first with a napkin and then with a universal solvent (acetone). Put plastic films on the lower surface of the molds.

(a) (b) (c)

Figure 3.9: Lower mold preparation: (a) mold-1 after laboratory grade acetone and petroleum jelly applied finally fixed with four washers, (b) acetone, (c) Prepared mold-2.

Upper mold preparation

It is mostly utilized to cover the mold's upper portion. Additionally, it provided the upper portion of the samples with a smooth surface finish. Another reason for the nessesity of uppert mold is due to the fact that the curing process require a light compression on the sample after adding resin sample preparation is complete. A plastic film is also inserted between the mold's upper plate and the top surface of the samples this thin film makes it easier to remove the sample after the process is completed.

a) b)

Figure 3.10: Upper molds: a) for mold-1, b) for mold-2.

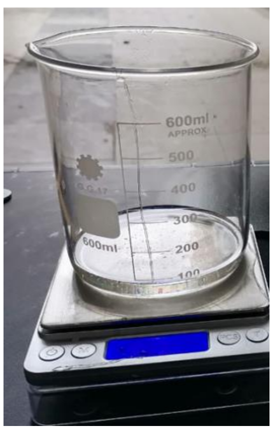
3.1.9. Composition

According to prior research and knowledge, the proper volume percentage composition of the reinforcement materials for these fiber-reinforced composites is 60% bamboo for bamboo composites, 60% moringa for moringa composites, and 30% bamboo and 30% moringa for bamboo-moringa hybrid composites. Each sample was tied to this representation ratio by a change in reinforcement and a fixed matrix proportion of 40%. Higher reinforcement is offered, especially for woven kinds of reinforcement.

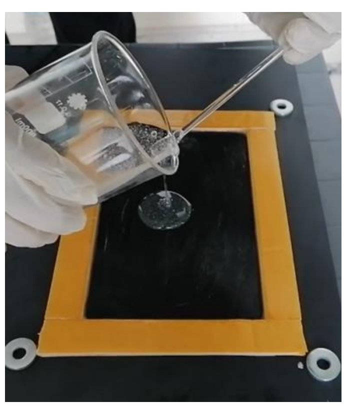
3.1.10. Composite preparation

According to volume percentage; the matrix, hardener and reinforcement were measured. Epoxy/hardener ratio was 4:1 or 25%. With this ratio epoxy and hardener were mixed until they mix uniformly. First mixed resin was added to the mold cavity and distributed with brush into all corner. First layer of woven was put on the resin and rolled by roller to bath the woven this used to increase the surface interaction between woven fiber and resin. After this, in the same way the resin and second layer of woven were added consecutively. This process was continued until the final dimension reached. At the end, the pressure was added to compress the sample, this helped to decrease void, to remove excessive resin and to get exact sample thickness. As much as possible quickly clean the beaker and rod with acetone and detergent. After 24-hour the sample were cured and ready. Then the samples were removed. This process shown as in following figure 3.11.

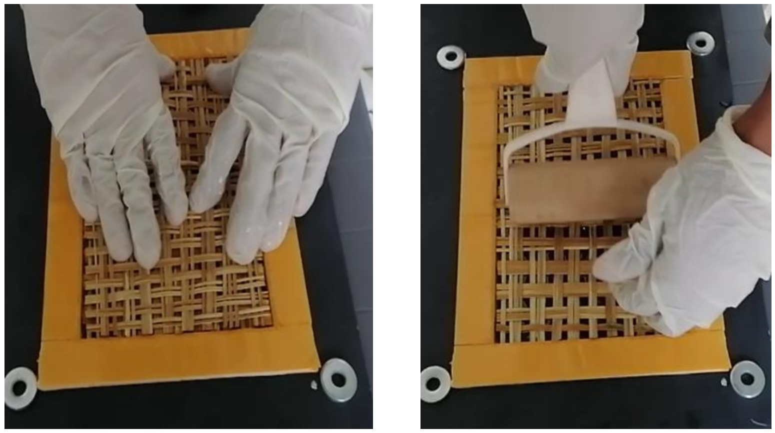
(a) (b)



(c) (d) (e)



(f) (g)



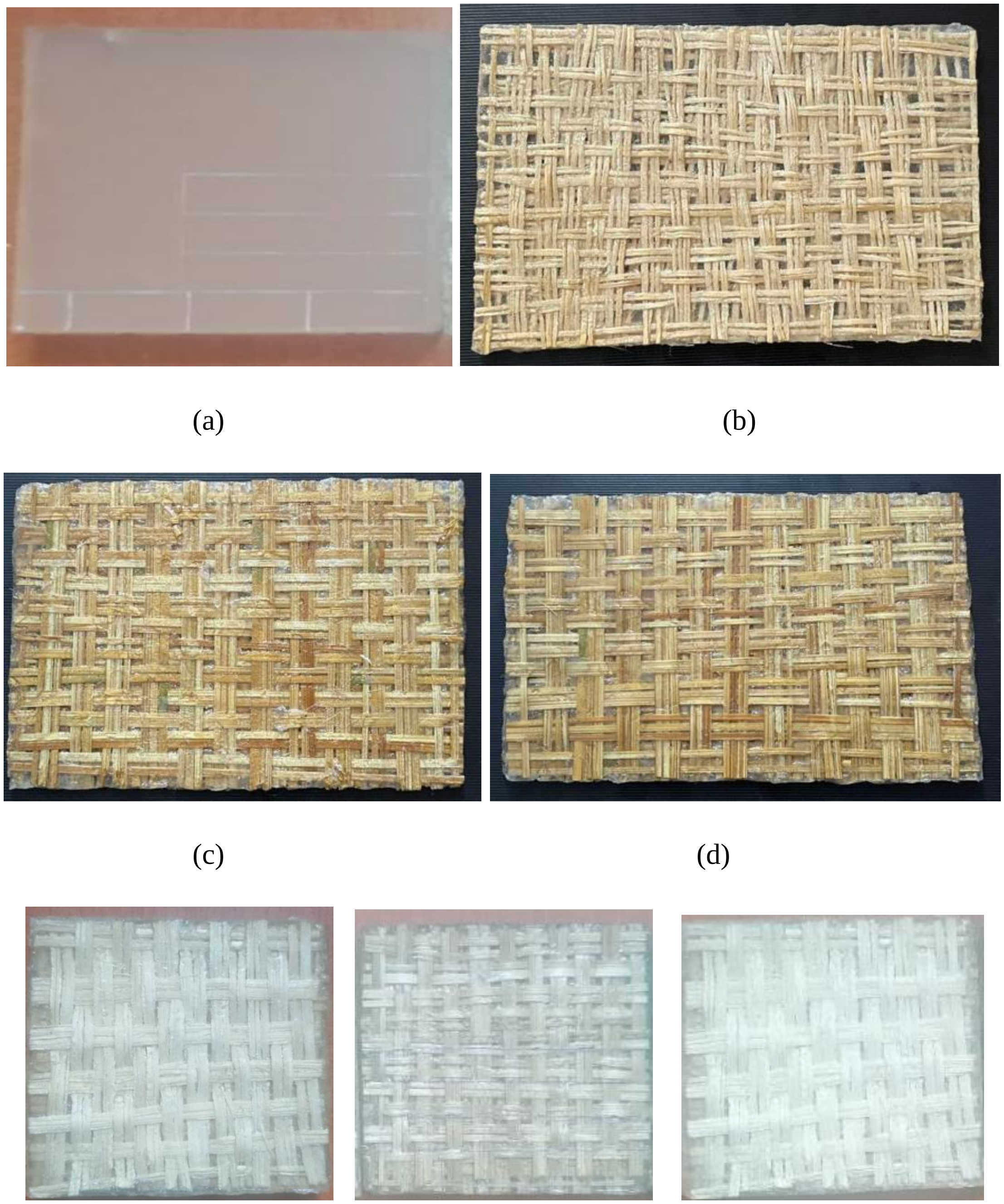
(h) (i)

Figure 3.11: Sample preparation process: (a) moringa woven for mold-2, (b) bamboo for mold-2, (c) measuring of epoxy and hardener using digital weight balance, (d) measuring moringa for mold-1, (e) measuring bamboo for mold-1, (f) Pouring properly mixed resin, (g) pouring resin and distributing to throughout the mold cavity by using brush, (h) adding the first fiber woven, (i) bathing the woven by using roller.

In this research, the bamboo composite (BB-60), moringa composite (MM-60), and bamboo/moringa hybrid composite (MB-30/30) samples were developed and compared with the epoxy resin (ER) sample having 0% reinforcement. So, four types of composites were synthesized for comparison. Samples were made 190 x 120 x 3 mm and 101 x 101 x 12.7 mm mold cavity size. Hand lay-up method was implemented for sample fabrication. The samples were cut using a water jet machine into specimens for tests. Then, these samples became ready for mechanical tests, and the result values were recorded. Tensile, flexural, compression, impact, hardness and water absorption were tests performed to study the mechanical properties of the composites.

3.1.11. Curing and removing of sample

The samples were cured after 24 hours. To facilitate the curing process and to minimize the amount of void, the light pressure was added to the upper mold. Then, after the curation process, the pressure was removed and the samples were easily released from the mold cavity. These four samples (ER, MM-60, BB-60, and B/M-30/30) were look like as shown in the below figures 3.12.



(a) (b)

(c) (d)

(e) (f) (g)

Figure 3.12: Prepared samples: (a) ER sample (b) MM-60 sample for mold-1, (c) BB-60 sample for mold-1, (d) BM-30/30 sample front face for mold-1, (e) MM-60 sample for mold-2, (f) BB-60 sample for mold-2, (g) BM-30/30 sample front face for mold-2.

3.1.12. Cutting the samples using water jet machine

After removing the sample from the mold, the surfaces were cleaned, and the samples became ready for the cutting step and cutting process was performed. The cutting process was done by a water jet machine because it allowed us to cut the samples in a precise way and with good edge texture. This type of precision cutting machine is highly recommended for cutting composites because it minimizes microstructural dislocation of fibers in the composite. In addition to this, uses of water jet machine protect delamination of fibers layers and keep surface regularity of the material. This machine uses high-pressure water to cut materials such as wood, metal, ceramic, polymer, and composites. First, the drawing was designed to the correct dimensional specification with AutoCAD software. Then this design is uploaded into the water jet machine using a USB drive. Therefore, the machine cut the sample according to the given dimensional specification. The cutting process was done by Yıldız Su Jet Company, Istanbul/Turkey.

(a) (b) (c)

Figure 3.13: Sample cutting process: (a) Water jet machine, (b) design insertion and controlling section, (c) cutting process.

Specimens: The resulting specimen after cutting process of samples for tensile, compression, flexural, hardness, impact and water absorption as shown in figure 3.14.

(a)

(b) (c) (d)

(e)

Figure 3.14: Specimen after cutting: (a) Tensile and flexural, (b) Hardness (c) Impact (d) Water absorption, and (e) Compression.

3.2. Methodology

3.2.1 Density measurement

The density of each fabricated specimen is measured in accordance with the ASTM D792-17 standard. The average densities of three specimens were taken. Natural fiber reinforcement offers the advantage of having a lower density and weight in composite materials when compared to other reinforcing phases. Once the solution had dried, the samples were removed from the mold.

The sample's void content is determined by comparing the theoretical and experimental densities of the specimens and then determining the difference between the two. The Archimedes principle is employed to calculate experimental density, while the rule of mixtures is utilized to determine theoretical density.

$$\rho_C = \rho_M \text{ x } V_M + \rho_R \text{ x} V_R \quad \text{.......... (3.2).}$$

ρ_C = Density of composite

ρ_M = Density of matrix

V_M = Volume of matrix

ρ_R = Density of reinforcement fiber

V_R = Volume of reinforcement fiber

The Archimedes principle uses weights in the air and submerged in liquid to measure a sample's density experimentally. Applying equation 3.3, the density of a sample can be computed.

$$\rho_C = \rho_{liq} \text{ x } \frac{m_{air}}{m_{air} - m_{water}} \quad \text{.......... (3.3).}$$

ρ_{liq} = Density of water

m_{air} = Mass of sample in air

m_{water} = Mass of sample in water

The amount of void content in a sample is calculated as:

$$Void\ content\ (\phi_V) = \frac{(Theoretical\ density - Experimental\ density)}{Theoretical\ density} \quad \text{.......... (3.4).}$$

3.2.2 Tensile testing

Tensile testing is performed in accordance with ASTM D3039-17 type-1 using a universal test system (Z020 Zwick Roell, USA). Samples have dimension based on ASTM D3039-17 type-1. Each sample has a gage length of 50 mm and a spacing of 115 mm between grippers.

Using a 50 kN load cell, a consistent cross-head speed of 5 mm/min was kept throughout the trials. The experiment was done until the specimen breaks. The stress and strain were evaluated using the supplied load and displacement data. On the stress-strain graph, the tensile modulus is computed using 0.2% offset method, and the tensile strength is calculated as the stress at maximum load. The percentage elongation is determined using the strain measurement at breakage. The tensile strength of the composite material was the highest tensile stress achieved prior to failure. It was the greatest tensile stress that defined the composite's ability to withstand a tensile load before failing.

Figure 3.16: Tensile test specimens and testing setup.

For each sample, the average modulus and strength values of five specimens are presented.

$$\sigma_t = \frac{P}{A} \quad \text{……………………………………………………………………………………(3.5).}$$

P = Load applied

A = Cross-section area

3.2.4. Compression testing

The compressive tests were done on a UTM with a load capacity of 50 kN. The compressive modulus and strength of all samples were measured. The compressive strength is determined by the peak stress at the tip of the elastic zone. The compression testing setup is seen in Figure 3.18. The load cell, which was mounted on the frame's top and also supported the top grip, can be used for compressive or tensile testing. The specimen dimensions were determined by ASTM D3410-17 and have dimensions of 12.7 x 12.7 x 25.4 mm. The standard testing speed was 1.2 mm/min. The compression strength was calculated by dividing the peak compressive load achieved by the specimen by the starting minimum cross-sectional area of the specimen.

Figure 3.18: Compression specimens and testing setup.

The compressive yield strength was computed by dividing the load carried by the specimen at the yield point by the starting minimum cross-sectional area of the specimen. The modulus of elasticity can be calculated by drawing a tangent line to the linear portion of the load deformation curve's early stages, selecting points along this linear region, and dividing the stress value given by this point by the corresponding strain.

$$\sigma_c = \frac{P}{A} \quad \ldots\ldots (3.6).$$

Where: σ_c = compressive strength

P = maximum compressive load carried by the specimen

A = specimen's original minimum cross-sectional area

3.2.3. Flexural testing

Flexural strength refers to a material's ability to withstand bending stresses applied perpendicular to a bar-shaped specimen. Flexural testing was performed using a Zwick (Z020, ZHU) equipment with a capacity of 20 kN. Flexure testing was carried out in accordance with the ASTM D7264-17 standard. A 0.1 MPa pre-load was employed with a cross-head speed of 1.4 mm/min. Each volume fraction combination was tested three times before the average data was provided for analysis. Tests were carried out until the specimen fails and the stress-strain data was obtained.

Figure 3.17: Bending specimen and its testing setup.

The calculation of flexural modulus is as follows:

$$E_{fm} = \frac{L^3 m}{4bd^3} \quad (3.7)$$

L is the length of the support (mm)

b is the width of the beam (mm)

d is the thickness of the beam (mm)

m is the gradient of the tangent line to the load-deflection curve's earliest straight-line segment.

The flexural stress is estimated by:

$$\sigma_{fs} = \frac{3PL}{2bd^2} \quad \text{......} \quad (3.8).$$

P denotes the force at a specific position on the load-deflection curve. The reported flexural strength values were taken post-fracture for comparison.

3.2.5. Impact Test

Toughness is the capacity of a substance to withstand suddenly applied stress or the quantity of energy absorbed by a material prior to failure. Composites' impact failures include fiber pull-out, fiber/matrix deboning, and matrix fracture. Fiber pull-out is viewed as an important energy dissipation principle in fiber reinforced composites. When the stress level exceeds the fiber strength, fiber fracture occurs. The damaged fibers may be ripped from the matrix, wasting energy. The test was conducted using a dial display impact testing machine (Charpy/Izod Hensgrand) with a 3.5 m/s impact speed. The ASTM D256 impact test is performed on specimens measuring 63.5 x 12.7 x 12.7 mm. The V-notch test specimens had notches that were 2 mm by 2 mm and were cut at a 45° angle. A notched specimen is shattered by swinging hammers mounted on testing devices with the striking point in the center.

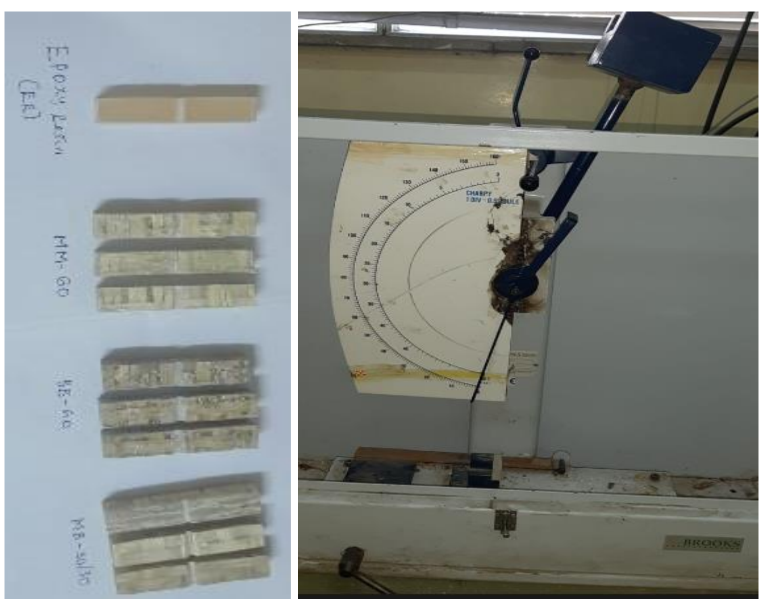


Figure 3.19: Impact specimens and testing machine.

3.2.6. Hardness test

Hardness testing was carried out by directly applying a predefined load to the specimen's surface with an indenter of a specific geometry. The indentation is measured after the force has been completely removed in order to determine the hardness of the material.

The HV50 Vickers hardness testing machine was used. The machine was used to determine the surface hardness of the specimens. A standard specimen manufactured in accordance with ASTM D2344-17 is gently placed on the surface of the testing machine. The specimen's hardness properties were analyzed using the Vickers Hardness Tester, a micro hardness testing tool. The test is performed on a smooth specimen with a properly prepared surface. The face was free of imperfections that could interfere with the indentation or subsequent diagonal measurement. During the examination, the indentation periphery and margins are almost always visible in the microscope field of view. To produce a diamond-shaped Vickers impression, a force of 10 kg. f is applied to the specimens. The Vickers hardness was calculated using the diagonals. The measurement is made at a single spot on one specimen and then at another specimen of the same weight percentage. For one composite's composition, at least 3 tests were performed.

Figure 3.20: Hardness specimens and Vickers Hardness Tester

The specimen's surface is indented with a defined force, F, using a square-based pyramid diamond indenter having an angle of 1360 between opposing sides at the vertex.

$$HV = \text{Constant x } \frac{Test\ force}{Surface\ area\ of\ the\ indention}$$

$$HV = 0.102 \text{ x } 2F\left(\frac{sin\left(\frac{136^0}{2}\right)}{d^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.9).}$$

Where: HV = Vickers Hardness

F = Test force

d = Diagonal Length

3.2.7. Water absorption test

A key characteristic of composites reinforced by natural fibers is their water absorption behavior. This activity determines how hydrophilic the composites are, which in turn affects how resistant they are to microbial attacks and how stable their dimensions are (Wang and Ying, 2014). The ASTM D5229-17 is followed when conducting the water absorption test. The water uptake test's dimensions were established at 20 x 20 x 6 mm in accordance with ASTM D5229-17 guidelines. The usual water absorption test is carried out using pure distilled water under normal ambient conditions. Specimens from each reinforcement sample was submerged in distilled water containers in a controlled atmosphere (50 percent humidity, 25 °C, or room temperature).

The average amount of water that has collected in a substance is expressed as a percentage and is computed by dividing the mass of the oven-dry material by the mass of the moisture mass.

Figure 3.21: Specimens and measuring specimen mass using weight balance.

Mathematical formula derivation for percentage rise in mass is give as follow:

$$M\ \% = \frac{M_f - W_i}{W_i} \times 100 \quad \text{……………………………………………………………………. (3.10).}$$

where: W_f = immersed specimen in grams.

W_i = oven-dry specimen in grams (before putting into water).

M% = Percentage moisture mass rise.

CHAPTER FOUR

4. RESULT AND DISCUSSION

This chapter is a crucial section in this research to discover the new optimal properties of fiber reinforced composites. The processing of composite materials is an essential component that provides information about the material's numerous characteristics (such as shape, particle size, and density), enabling the use of the new reinforcements in a widely recommended matrix. The findings of every experimental investigation are discussed in depth in this section. Flexural, tensile, hardness, impact, compression, density, void content, and morphological analyses of the produced composite materials, which are epoxy resin reinforced with bamboo/moringa fibers, are done in this study.

4.1. Density Test

In studying the mechanical properties of a composite, density is one of the major factors that affects the mechanical performance of the material. The density of composites has a strong relationship with void content, which reduces the required mechanical properties. The density and void content estimations of prepared samples are shown in table 4.1. The entrapment of air in the matrix during the mechanical mixing of ingredients, during the pouring process, and during the curing stage is responsible for mechanical performance reduction. The difference between theoretical density and experimental density gives void content in equation 3.4.

Table 4.1: Density and Void content estimation of specimens

Composition	Theoretical Density (kg/m3)	Experimental Density (kg/m3)	Void Content (%)
ER	1192.00	1192.00	0.000
BB-60	1050.00	1037.56	1.199
MB-30/30	994.00	980.08	1.420
MM-60	940.00	926.45	1.463

Table 4.1 shows the density of the biofiber composites is less than virgin epoxy. In particular, the density of BM-60 and MM-60 is less than 1. So, these composites can be considered as light

materials that are suitable for various applications, such as packaging and car interior components. The higher proportion of fiber content (60%) as compared to matrix (40%) minimizes the possibility of air entrapment, which decreases the presence of pores and voids. From table 4.1, as the density of the composite decreases, the void content will increase. This may be due to the compactness decrement of the material. The void content will increase.

4.2 Tensile Test

4.2.1. Tensile stress-strain curves

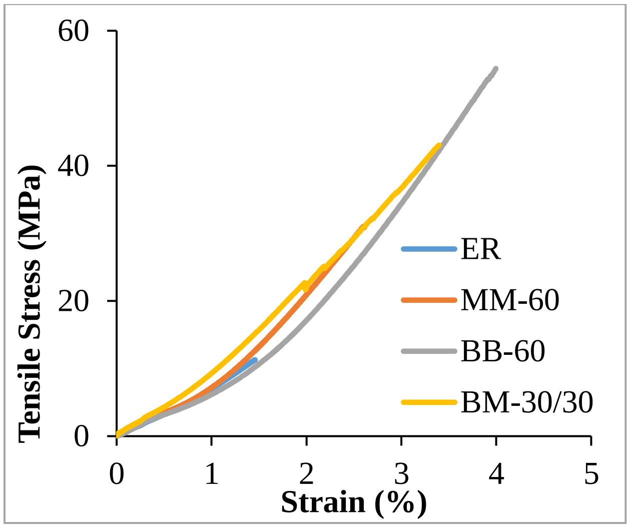


Figure 4.1: Representative Tensile stress-strain curves of composites.

The tensile stress-strain curves of neat epoxy resin and epoxy composites with bamboo/moringa fiber reinforcement are shown in figure 4.1. The stress-strain graphs of all the specimens have a similar pattern until the elastic area's maximum stress, which is followed by a rapid brittle failure. Figure 4.1 further demonstrates how the tensile stress evolves when the epoxy matrix is reinforced by bamboo, moringa, and their hybrids. All of the specimens failed suddenly after achieving maximum tensile strength in the stress-strain curves. As shown in figure 4.1, the epoxy resin specimen has a 1.46% strain at 11.32 MPa tensile stress. The MM-60 specimen has a 2.60% strain at 31.05 MPa tensile stress. The BB-60 specimen has a 3.99% strain at 54.43 MPa tensile stress. The MB-30/30 specimen has a 3.38% strain at 43.08 MPa of tensile stress. In comparison to ER, all natural fiber reinforced specimens have the highest increments of tensile strength, which is observed in figure 4.1. Chemical treatment may be one of the reasons for the considerable rise in the tensile strength of composite materials. The maximum tensile strength is 54.43 MPa, which is achieved by bamboo reinforced composite (BB-60). The stress-strain curves show tensile stress has increased when reinforcements are varied as compared to pure epoxy. Figure 4.1 of stress-strain curves demonstrates that after reaching their ultimate tensile strength, each specimen fails brittlely. The tensile strength of composites is greatly increased by the addition of natural hybrid fibers (Mahesh et al., 2021). The hybrid composite shows an optimum tensile strength, which can be put to better use (Praveena et al., 2021).

4.2.2. Tensile Modulus

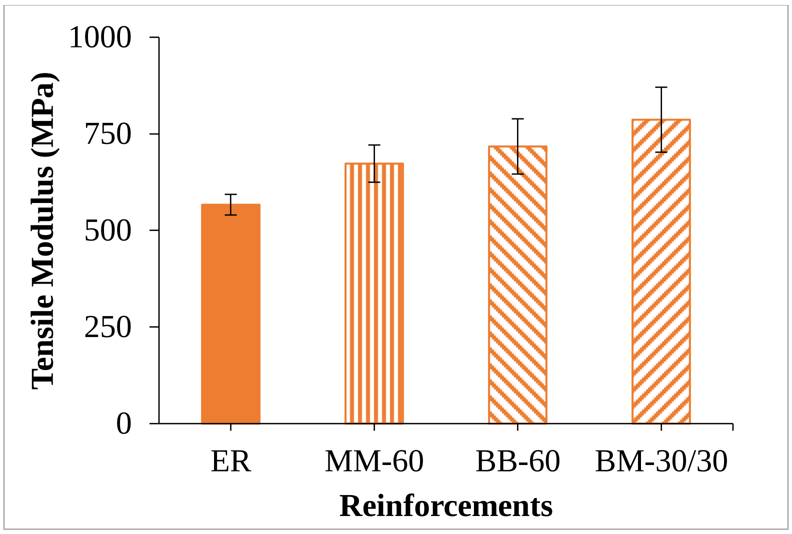


Figure 4.2: Experimentally measured tensile modulus.

The experimental measurements of the tensile modulus are shown in Figure 4.2. The tensile modulus of MM-60, BB-60, and MB30/30 increased as compared to neat epoxy. The stiffness of a material is expressed by its modulus. The increase in modulus is mostly due to the incorporation of moringa and bamboo fibers into the matrix. The epoxy specimen had a tensile modulus of 566.58 MPa and was fabricated from pure epoxy with no fiber reinforcement.

Specimen MM-60 had a tensile modulus of 672.96 MPa which was fabricated from 60 vol.% of moringa fiber. Specimen BB-60 had a tensile modulus of 717.38 MPa which was fabricated from 60 vol.% of bamboo fiber. Specimen MB-30/30 had a tensile modulus of 786.61 MPa which was fabricated from 30 vol.% of moringa fiber and 30 vol.% of bamboo fiber. All composites' tensile moduli increase with the addition of cellulosic fibers into the pure epoxy, and the increase is between 19 to 39% higher than the neat epoxy. In an epoxy matrix, relatively strong fibers are combined to improve the composites' modulus and aid in load transfer. Due to the combined effect of hybrid fibers maximum tensile modulus exhibited in BM-30/30 hybrid composite which is 786.61 MPa. The presence of reinforcement in the matrix material alters the stiffness of the epoxy-based materials (Mohan and Kanny., 2018).

4.2.3. Tensile Strength

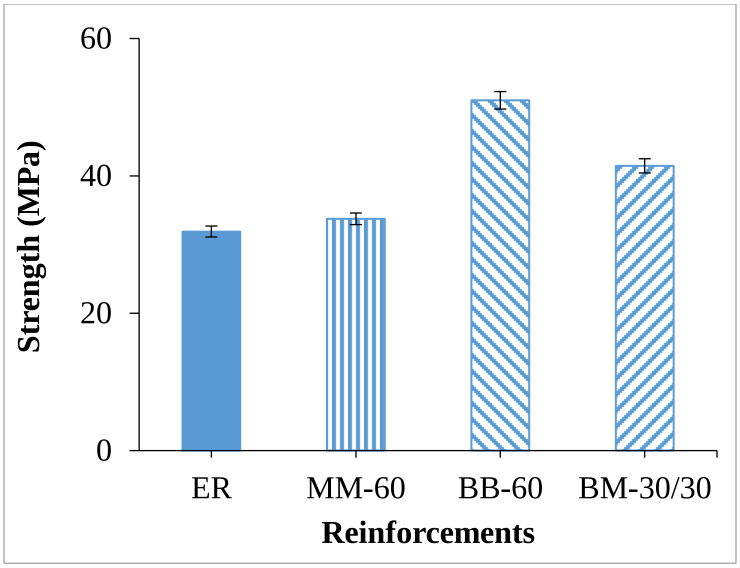


Figure 4.3: Experimentally measured tensile strength.

Figure 4.3, shows the experimentally determined tensile strength of the specimens. When compared to virgin epoxy all bamboo/moringa specimens' composites show superior strength. The strength increases ranged from 5.8 to 70.53%, with BB-60 showing the greatest improvement. The strength of the BB-60 specimen was 54.4 MPa, which was about 70.53% greater than the pure epoxy, 61.19% greater than the MM-30, and 31.2% greater than the specimen of the MBF-reinforced composites. The nature of the fibers has an impact on the strength and performance of the fibers in bio composites. Generally, the most significant factors that affect the overall qualities of plant fibers are their structure, microfibrillar angle, cell size and defects, and chemical content. Furthermore, with the increase in the cellulose content, the strength of the fiber improved (Djafari., 2022). For better tensile strength, chemical treatment had crucial role by providing compatibility between fibers and reinforcements. In every instance, it was discovered that the alkali-treated composites' mechanical qualities were significantly better than those of the simple epoxy (Wang and Ying, 2014).

4.3. Flexural Test

4.3.1. Flexural Stress

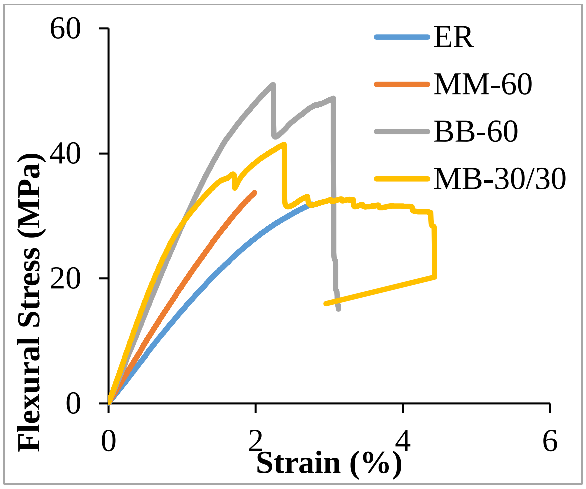


Figure 4.4: Representative Flexural stress-strain curve of the composite specimens.

Figure 4.4. Represents the flexural stress-strain profiles of the samples subjected to a flexural load. It was done to examine the natural fiber reinforced composites' resistance (rigidity) to distortion. The stress-strain profiles of plain epoxy and MM-60 composite specimens are almost linear until failure, indicating that both composites fail brittlely. The non-linear stress-strain profiles of the BB-60 and MB-30/30 composite specimens near failure indicate that the composites failed non-brittlely. Specimen Epoxy resin has 2.77% strain at 31.90 MPa flexural stresses. Specimen MM-60 has a 1.98% strain at 33.75 MPa flexural stresses. Specimen BB-60 has 2.24% strain at 51 MPa flexural stresses. Specimen MB-30/30 has a 2.38% strain at 41.45 MPa flexural stresses. So. Among the composites specimens studied, the maximum flexural properties were exhibited by BB-60 specimen compared to others which was 51 MPa. In blending natural fibers into the matrix, the significant increment in flexural stress show. The chemical treatment was responsible for the increase in flexural stress because the better interaction between fiber/matrix which greatly change stiffness of a composites (Mishra and Sinha., 2020). Epoxy and MM-60 composite specimens displayed greater brittle behavior, whereas BB-60 and MB-30/30 specimens exhibited non-brittle behavior.

4.3.2. Flexural Modulus

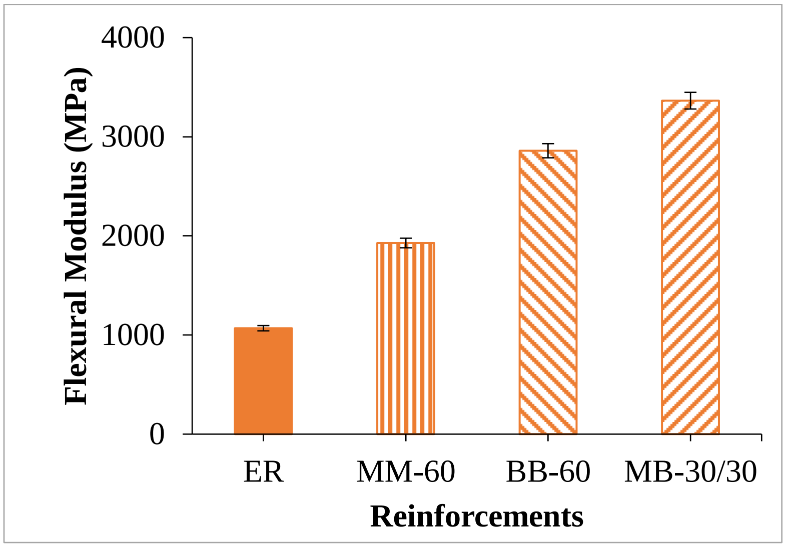


Figure 4.5: Experimentally measured flexural modulus

Figure 4.5. demonstrates the experimental values of flexural modulus of epoxy composites and a composite that reinforced with moringa and bamboo fibers. When compared to neat epoxy, the flexural modulus of MM-60, BB-60, and MB-30/30 considerably improved. The integration of moringa and bamboo fibers into the matrix is primarily responsible for the rise in modulus. Specimen Epoxy (ER) had a flexural modulus of 1068.46 MPa which was fabricated from pure epoxy with no fiber reinforcement. Specimen MM-60 had a flexural modulus of 1928 MPa which was fabricated from 60 vol.% of moringa woven fiber. Specimen BB-60 had a flexural modulus of 2858.66 MPa which was fabricated from 60 vol.% of bamboo woven fiber. Specimen MB-30/30 had a flexural modulus of 3363.56 MPa which was fabricated from 30 vol.% of moringa fiber and 30 vol.% of bamboo fiber. All composites' flexural moduli increase with the addition of moringa and bamboo fibers into the pure epoxy, and the increase is between 80.45 to 214.8% higher than the neat epoxy. The maximum flexural modulus was revealed in hybrid specimens (BM-30/30%). The great improvement of modulus may be due to synergy natural characteristics effect of the two reinforcements The composites' higher bending modulus was primarily a result of the strong interaction between the cellulose fibers and epoxy resin (Ayrilmis et al., 2018).

4.3.3. Flexural Strength

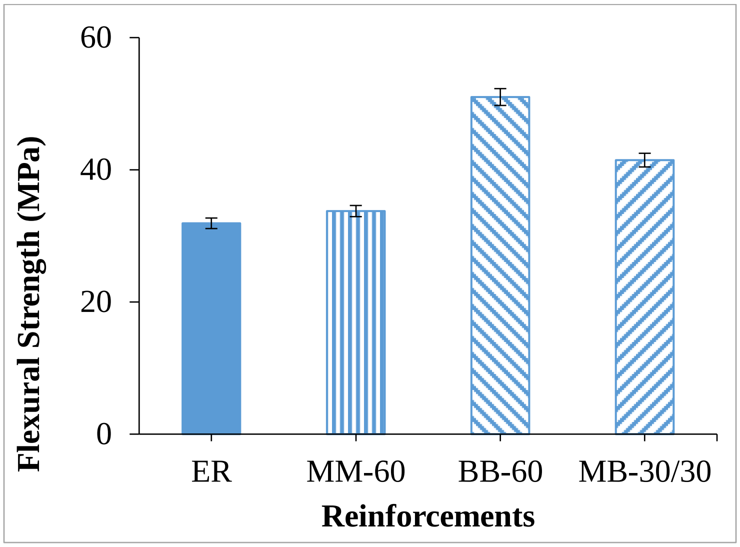
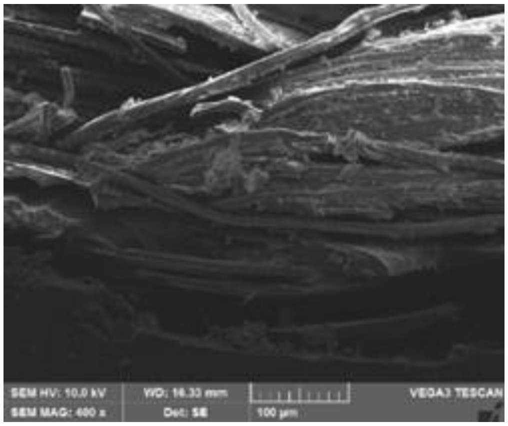


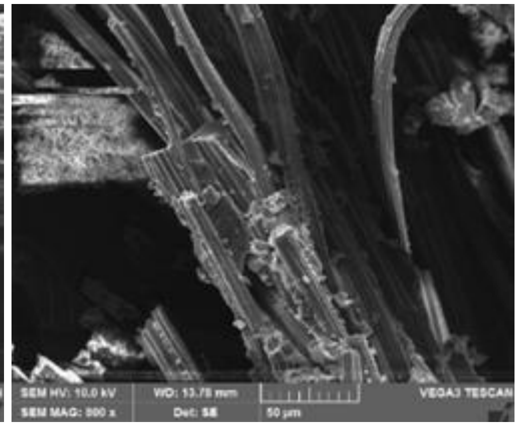
Figure 4.6: Experimentally measured flexural strength

Figure 4.6 demonstrates the impact of fiber reinforcement on the flexural strength of epoxy composites reinforced with moringa and bamboo fibers. When compared to neat epoxy, the flexural modulus of MM-60, BB-60, and MB-30/30 increased, with the BB-60 composite showing the highest improvement. Specimen epoxy had a flexural strength of 31.9 MPa, specimen MM-60 had a flexural strength of 33.75 MPa, which was fabricated from 60 vol.% of moringa fiber, specimen BB-60 had a flexural strength of 51 MPa, which was fabricated from 60 vol.% of bamboo fiber, and specimen MB-30/30 had a flexural strength of 41.45 MPa, which was fabricated from 30 vol.% of moringa fiber and 30 vol.% of bamboo fiber.

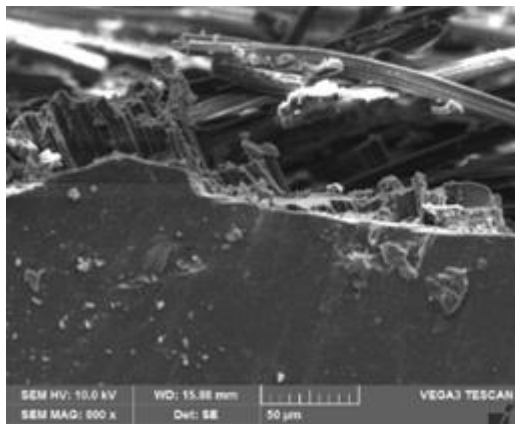
All composites' flexural strength increases with the addition of moringa and bamboo fibers into the pure epoxy, and the increase is between 5.79 to 59.87% higher than the neat epoxy. Out of all the composite materials, BB-60 had the greatest flexural strength, showing a 59.87% improvement in strength over neat epoxy. This shows the effect of addition of different types of natural fibers that have different compositions and their combination effects on the epoxy matrix. The fiber orientation and arrangement have considerable effect on the composite because in flexural testing due to specimens subjected for both tension and compression in the two specimen surfaces that are perpendicular to load direction. The dispersion of cellulose fibers throughout the epoxy resin may have an impact on flexural strength (Ayrilmis et al., 2018). Moreover, the process used to extract the fiber had an impact on mechanical strength as well (Tang et al., 2018).

4.3.4. Scanning Electron Microscope (SEM) analysis





(a) (b)



(c)

Figure 4.7: Scanning electron micrographs of (a) MM-60, (b) BB-60, and (c) MB-30/30.

The fractured flexural specimens are presented in Figure 4.7. The amount of resin on the MM-60 was seen to be very poor compared to BB-60 and MB-30/30 composition inferring a higher amount of resin on the surface of fiber. Furthermore, tested specimens show loose filaments due to fiber pullouts in MM-60, whereas in the BB-60 and MB-30/30 bundle failure occurred due to fiber breakages, indicating a higher fiber/matrix bonding ratio and better interface as evident from Figures 4.7. a, b and c, respectively.

4.4. Compression testing

4.4.1. Compressive Stress

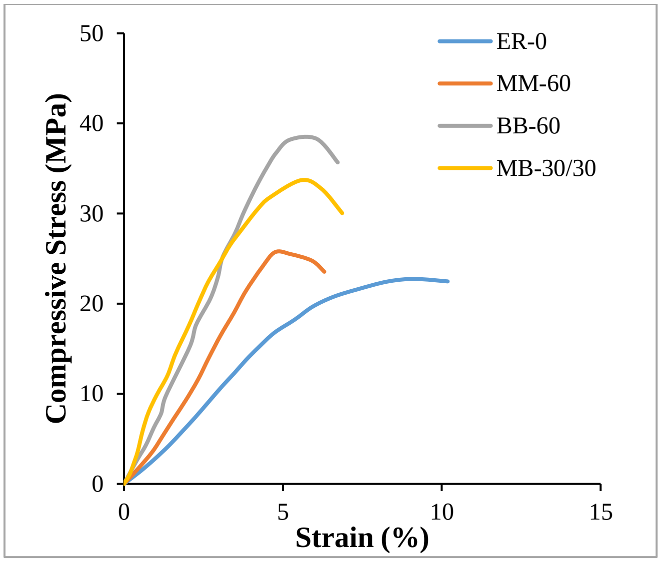


Figure 4.8: Representative graph of compressive stress of the composite specimens.

The above figure 4.8 demonstrates the compressive stress of both pure epoxy resin and fiber-reinforced composites and reveals that they have similar profiles. The compressive stress of all fiber-reinforced composites is higher as compared with a neat epoxy. Therefore, incorporating fibers into the matrix can boost compressive stress as shown in figure 4.8. Compressive stress is also affected by the natural properties (composition) of reinforcing fibers. Within the elastic region, the maximum compressive stress for epoxy resin (ER) at a strain (%) of 9.16 is 22.74 MPa of compressive stress. MM-60 at strain (%) 4.75 is 25.71 MPa of compressive stress. BB-60 at strain (%) 6.06 is 38.29 MPa of compressive stress. BM-30/30 at strain (%) 5.58 is 33.7 MPa of compressive stress. So, the BB-60 MPa composite exhibits a higher compressive stress value. This test is mainly recommended for brittle materials in order to notice the ultimate compressive stress. When compressive stress is exerted, ductile materials become harder. Therefore, it is difficult to determine the maximum compressive strength. Pure epoxy (ER) is ductile, but when reinforced with natural fibers (MM-60, BB-60, and BM-30/30), the properties change slightly from ductile to brittle due to the high proportion of fiber content. These properties change, leading to the sudden failure of the composite's materials. The inclusion of fibers has diminished the ductility of composite materials (Mahesh et al., 2021). The higher fiber content of the composite material led to improved stress transmission. As a result, the material can withstand high compressive stress

4.4.2. Compressive modulus

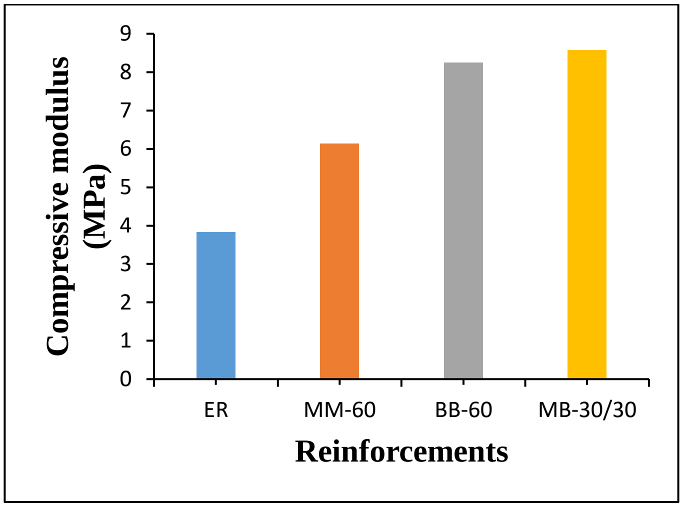


Figure 4.9: Representative of compressive moduli of composite specimens.

In the above compressive modulus graph in figure 4.9, the modulus of plain epoxy and fiber-reinforced composites are shown. The slope of the compressive stress-strain profile represents the modulus of material, which shows how much the material is stiff. All fiber-reinforced specimens revealed better compressive modulus as shown in figure 4.9. Epoxy resin ER has a 3.84 MPa compressive modulus, MM-60 has a 6.15 MPa compressive modulus, BB-60 has an 8.25 MPa compressive modulus, and MB-30/30 has an 8.57 MPa compressive modulus. From this, bamboo-moringa reinforced composites (BM-30/30) show the greatest compressive modulus of 8.57 MPa. In this graph, the hybrid composite demonstrates the optimal compressive modulus result. Good fiber matrix adhesion, fiber nature (cellulose content), and fiber content percentage (60 vol.%) all contributed to a significant change in compressive modulus.

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4.4.3. Compressive Strength

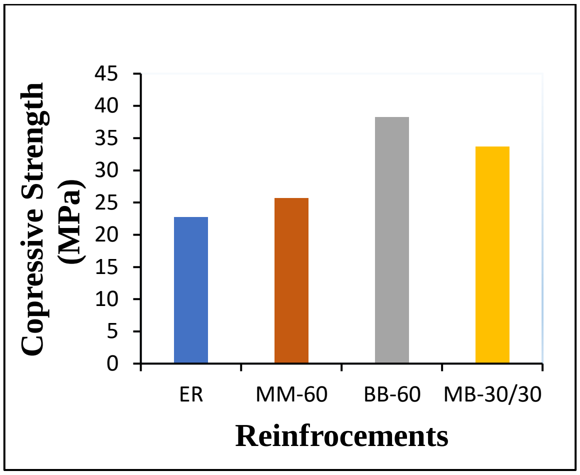


Figure 4.10: Representation of compressive strength of the composite sample.

The above compressive representation profile in figure 4.10, illustrates the specimen's strength toward compressive load in the longitudinal direction. The compressive strengths of specimens for ER, MM-60, BB-60, and BM-60 are 22.74, 25.71, 38.3, and 33.7 MPa, respectively. Bamboo reinforced composite specimens show the highest compressive strength. This may be due to bamboo fibers' good chemical composition (cellulose content). In this work, the sample fibers are anisotropic and arranged in a $90^0/0^0$ orientation, which is in plane form. So, it has better strength when force is applied in a perpendicular direction to the woven plane.

In this result, the samples have low compressive strength. This may be due to the compressive force exerted in the parallel direction to the woven plain. Furthermore, void content, operational error, weak interfacial bonding, and surface finish are also other factors that have contributed to the reduction of compressive strength. As a result of poor interaction between the primary and secondary phases at the interface, the capacity for stress transfer from the polymer matrix to the cellulose is diminished, which results in a reduction in strength. In anisotropic natural fiber composites, the uneven distribution of cellulose fibers may result in reductions in compressive strength (Ayrilmis1 et al., 2018).

4.5. Impact test

An impact test is one type of distractive test that describes the amount of energy absorbed by a material during fracture. It describes the flexibility properties, or the ability to deform until fractured, by absorbing a specific amount of energy. Each formulation utilized three specimens, and their average result was recorded. This energy can be used to determine the toughness and impact strength of the composite material. Below table 4.2. Display the average energy absorbed by specimens (S), the swing angle, and the average impact strength.

Table 4.2: Impact test result for different reinforcement and their combination.

Sample Name and trial		Energy Absorbed in(J)	Average impact energy (J)	Average impact strength (kJ/m^2)	Angle (degrees)
ER	S1	17	17	170	107
MM-60	S1	15	15	150	112
	S2	16			109
	S3	14			114
BB-60	S1	20	20	200	99
	S2	19			102
	S3	21			97
MB-30/30	S1	22	21	210	95
	S2	20			99
	S3	21			98

The average energy is shown in table 4.2. Shows that plain epoxy (ER) has 17J of energy, MM-60 has 15J of energy, BB-60 has 20J, and BM-30/30 has 21J. Average impact strength is derived by multiplying average impact energy and specimen cross sectional area (10 × 10 mm). The below figure 4.11, shows the average impact strength of the prepared specimens.

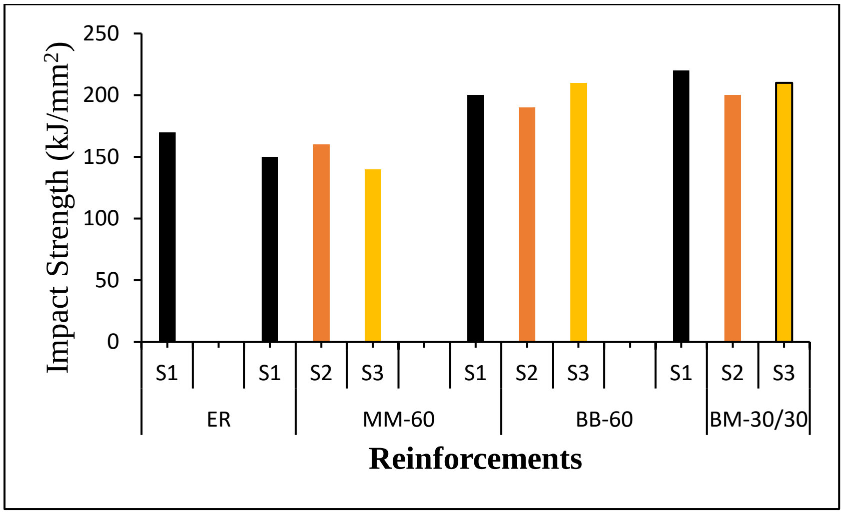
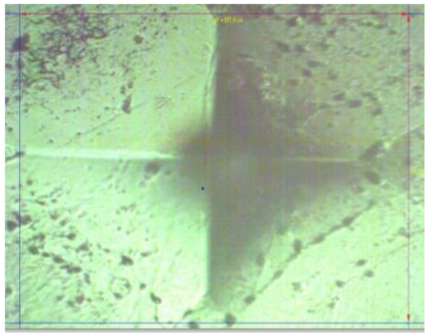


Figure 4.11: Impact strength of individual test specimen.

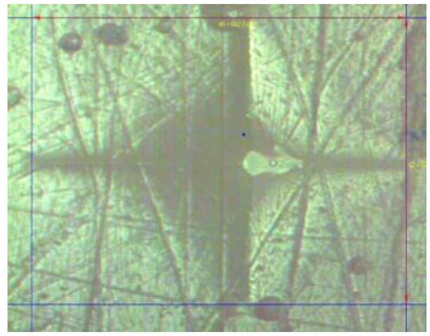
Figure 4.11 demonstrates that all fiber reinforced composites significantly increase in impact strength as compared to pure epoxy except moringa fibers. MM-60 recorded the minimum impact strength. This may be incompatibility (poor interaction) of fiber/matrix and the natural composition of fibers. Better interaction between reinforcement and matrix has a great influence on impact strength capacity. The hybrid composite (BM-30/30) recorded a maximum impact strength of 210 kJ/m^2. This significant impact strength showed BM-30/30 had better toughness, which is required in the automotive sector. The impact strength and absorption energy of fiber reinforced composites may increase or decrease depending on the nature of the composition of fibers that are blended into the matrix. The fiber composition primarily determines the impact strength of a material (Mahesh et al., 2021). The flexibility properties of natural fiber are also another factor that influences the impact strength of the composites. Different fibers and their combinations exhibit different flexibility properties. Another factor may be due to chemical treatment of fibers that improves the matrix's wettability with it and makes the matrix more elastic. More surface area will be in contact with the matrix. As a result, high strength and energy absorption will exist (Ravindran et al., 2021). High fiber content also contributes to the improvement of average absorption energy and toughness. Fiber content and toughness of composites have a direct relationship (Tang et al., 2018).

4.6. Hardness test

The hardness testing was conducted to determine the composites' hardness by calculating the degree of penetration of the indenter tip. The testing was performed using the standard Vickers hardness tester, 10 Kgf. The optical microscope was used to view the indented surface of specimens. The optical microscope has a 125X magnification and measures scales down to 0.5 micrometers.

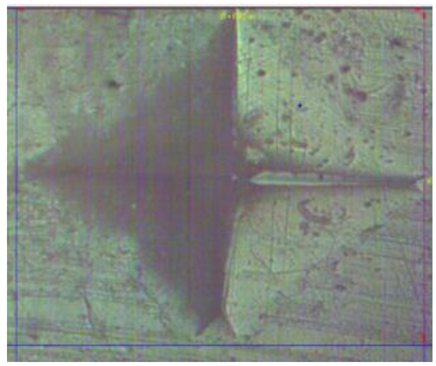


(a)



(b)

(c)



(d)

(e)

Figure 4.12: Optical microscopic view in Vickers hardness tester: (a) epoxy resin (ER), (b) MM-60, (c) BB-60, (d) BM-30/30 bamboo surface, and (e) BM-30/30 moringa surface.

The above figure 4.12. illustrates by varying the reinforcements such as moringa, bamboo, and their combinations. Testing results revealed the hardness of ER, MM-60, BB-60, and BM-30/30. From figure 4.12. the hardness of the natural fiber composites specimen seems low. This may be due to the fact that in the fabrication process the void and porosity were created, which resulted in low hardness. Because of the micro-cracks and matrix swelling caused by the trapped air inside the composite material, its hardness was reduced (Nayak et al., 2022). The void content highly affects the hardness of the composites. With an increase in fiber content, a higher void content led to a poor load transfer efficiency (Tang et al., 2018).

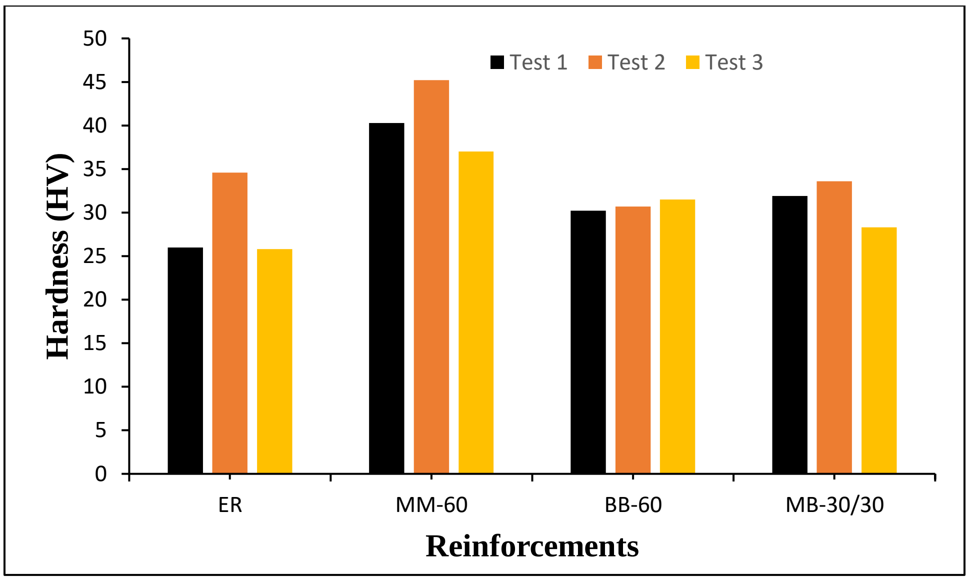


Figure 4.13: Relationship of fiber composition and hardness of the composites

Figure 4.13 depicts the effect of fiber loading on the hardness of composite materials. The data shows that when the epoxy resin is reinforced with moringa and bamboo fibers, the hardness of the composite is slightly increased. An anisotropic material has greater hardness along the longitudinal axis and less hardness along the transverse axis.

Average hardness of the composites

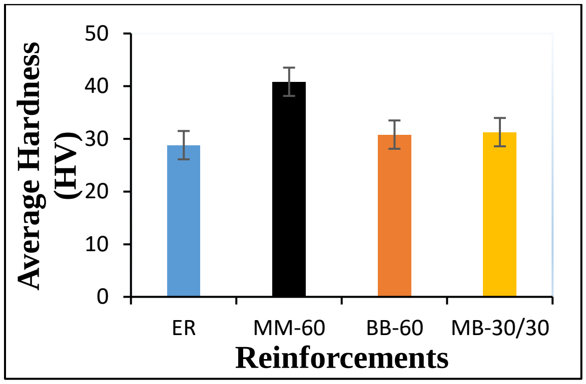


Figure 4.14: Average hardness of the composites.

Moringa/bamboo fiber reinforced epoxy composites have an average hardness of 28.8, 40.83, 30.8, and 31.27 HV for ER, MM-60, BB-60, and MB-30/30, respectively. This demonstrates that the incorporated fibers have a low impact on the hardness of the composites. The hardness of material is directly related to the wear resistance of material. When compared with a neat epoxy resin, the hardness value of MM-60, BB-60, and MB-30/30 showed 41.77, 6.94, and 8.57% improvement, respectively. The hardness test of a specimen is the surface analysis of the material

4.7. Water absorption

Water absorption properties are an essential parameter that has to be studied to determine the nature of material with interaction to water. The major drawback of natural fibers is their tendency to absorb water, which leads to inconsistency in mechanical performance. So, studying the water absorption properties of cellulosic composites is crucial. Water absorption experiment was done by putting the composite specimens in to distill water for 24 hours then measure its mass using digital weight balance then calculate the rate of water absorption. This task was done repeatedly for 3 weeks, i.e. after 24hrs, 48hrs, 72hrs, 96hrs and 120hrs, 144 hrs, …, etc. Table 4.3 shown the water absorption rate (%) of neat epoxy and fiber reinforced composites or consecutive 6 days.

Table 4.3: Specimens' water absorption test results immerse in distill water.

Specimens	Mass before immersion(g)	Immersion result of water absorption in rise (M%)					
		24 hrs	48 hrs	72 hrs	96 hrs	120 hrs	144 hrs
ER	21.684	0.01817	0.03634	0.05451	0.07268	0.09085	0.1075

MM-60	13.24	1.04773	2.0955	3.1432	4.1909	5.2386	6.305
BB-60	8.85	0.54485	1.0897	1.63457	2.17944	2.7243	3.2429
BM-30/30	11.39	1.07726	2.1545	3.2319	4.309	5.3863	6.4119

From the investigation of the water absorption of specimens by immersing them in distilled water. Table 4.3 describes the water absorption rate as linearly increasing, then the rate of water absorption slowly decreases until saturation point, after which the absorption rate starts to decline. It has been discovered that the absorption of water starts out fast before leveling off as equilibrium approaches. The densities of the composites and the empty areas significantly affect the rate of water absorption (Das et al., 2.16). For the first 24 hours, the percentage rise in mass for ER, MM-60, BB-60, and BM-60 was 0.01817, 1.04773, 0.54485, and 1.07726 respectively. Following a 48-hour period, the water absorption percentage rise of all composite specimens was found to be 0.03634, 2.0955, 1.0897, and 2.1545%, respectively. Additionally, the first water uptake occurs within the first 5 – 8 days of immersion; After that water absorption rate is negligible which composite reach to equilibrium condition (Mishra and Sinha., 2020). The water absorption trends continue in the same way linearly for a few consecutive days as described in the above table 4.3.

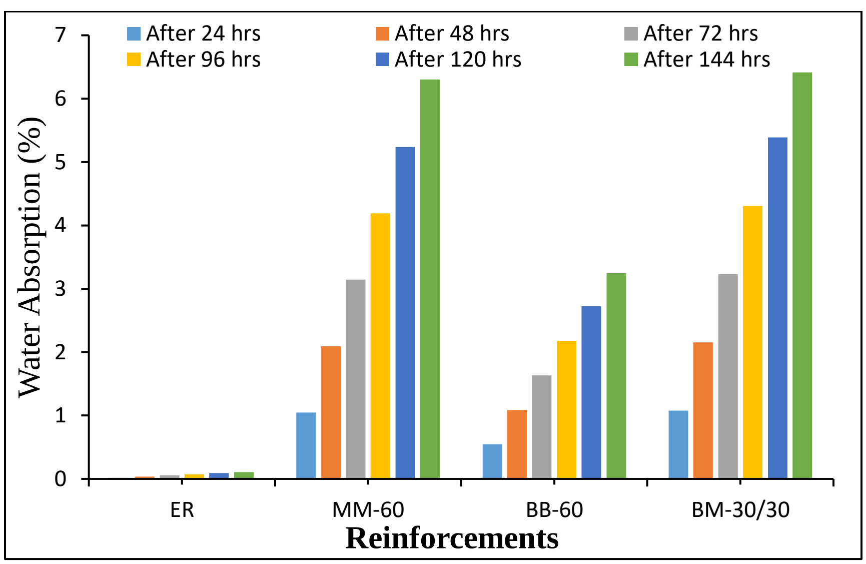


Figure 4.14: Water absorption percentage of specimens after immersed in distill water.

The water absorption tendency of fiber reinforced composites was compared to that of neat epoxy resin. From the data in figure 4.14, neat epoxy has no considerable change due to its hydrophobic properties. In contrast to this, MM-60 showed the maximum water intake properties due to the nature of fiber. The rest of the two samples (BB-60 and BM-30/30) also had a great tendency to moisture absorption as compared to neat epoxy. The reasons for these high hydrophilic properties may be the nature of fibers, void content due to low quality of the fabrication process, and higher fiber content. Fiber treatment also hinders the water absorption rate. Alkali-treated composites were shown to absorb less water than untreated composites (Wang and Ying, 2014).

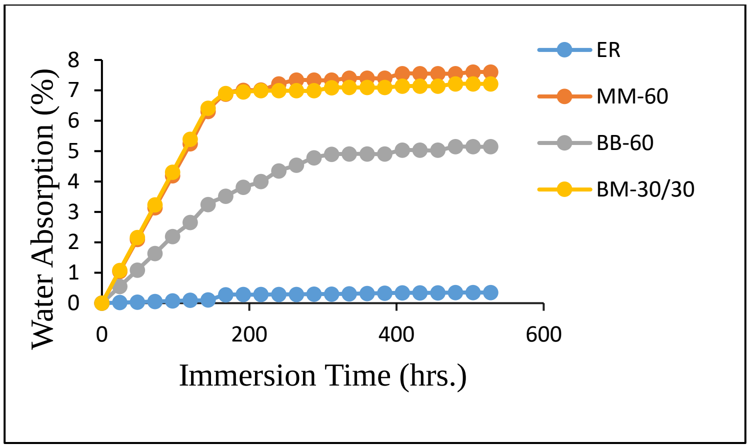


Figure 4.15: Water absorption rate of fiber reinforced composite material that immersed in distil water.

A test was performed for four specimens, such as epoxy resin (ER), moringa-moringa (MM-60), bamboo-bamboo (BB-60), and bamboo-moringa (BM-30/30). The test was conducted for 3 weeks (504 hours). The water uptake of a composite is proportional to the immersion duration. However, it's rate declines with increased time duration. ER had almost negligible water absorption rate. However, the remaining fiber-reinforced composites have a high water uptake tendency. With more fibers present, more water is absorbed. From figure 4.15, it is observed that fiber reinforced bio-composites have a high rate of water absorption until the first few days, after which its rate decreases through time. After this, the composites attain saturation level. After a week, the change becomes negligible. At the equilibrium point, water absorption for ER, MM-60, BB-60, and BM-30/30 became 0.35. 7.64, 5,145, and 7.215% in distill water, respectively.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study uses moringa and bamboo fibers placed in woven structures to produce composite materials using a hand layup method with an 80N pressing force for better compactness and to minimize void content. The mechanical properties such as tensile, compression, flexural, and impact properties are investigated. Extensive scanning electron microscopy is used to examine failure mechanisms and study structure-property connections for flexural tested specimens. All bamboo/moringa sample composites show superior strength. The tensile strength increases ranged from 5.8 to 70.53%, with BB-60 showing the greatest improvement, having 54.4 MPa, which was about 70.53% greater than the pure epoxy, 61.19% greater than the MM-30, and 31.2% greater than the specimen of the MBF-reinforced composites. Specimen ER had a flexural strength of 31.9 MPa, specimen MM-60 had a flexural strength of 33.75 MPa, which was fabricated from 60 vol.% of moringa fiber, specimen BB-60 had a flexural strength of 51 MPa, which was fabricated from 60 vol.% of bamboo fiber, and specimen MB-30/30 had a flexural strength of 41.45 MPa, which was fabricated from 30 vol.% of moringa fiber and 30 vol.% of bamboo fiber. Flexural strength increase ranged between 5.79 to 59.87% higher than the neat epoxy. Out of all the composite materials, BB-60 had the greatest flexural strength, showing a 59.87% improvement in strength over neat epoxy. The compressive strengths of specimens for ER, MM-60, BB-60, and BM-30/30 are 22.74, 25.71, 38.3, and 33.7 MPa, respectively. Bamboo-reinforced composite specimens show the highest compressive strength. The low impact strength of MM-60 could be attributed to fiber/matrix incompatibility and the natural fiber composition of moringa. The hybrid composite (BM-60) records a maximum impact strength of 210 kJ/m^2. This implies that the impact strength of the composites depends on the nature of the composition of fibers that are blended into the matrix and material flexibility. Moringa/bamboo fibers reinforced epoxy composites have an average hardness of 28.8, 40.83, 30.8, and 31.27 HV for ER, MM-60, BB-60, and MB-30/30, respectively. This shows that the incorporated fibers have a significant impact on the hardness of the composites. When compared with a neat epoxy resin, the hardness value of MM-60, BB-60, and MB-30/30 showed 41.77, 6.94, and 8.57% improvement, respectively.

5.2. Recommendation

The current research illustrates the fabrication of epoxy-based composite materials reinforced with moringa and bamboo fibers. These composite materials are biodegradable, lightweight, and safe for the environment. Utilizing natural fibers like moringa and bamboo helps the environment. Experiments were conducted to determine how changes in reinforcement influence various mechanical properties. This might be used in the automotive industry to make car door interior part, bus seats and vehicle dashboards. From the density of the composite result, these materials are considered as a lightweight material. So, they are provided as options for the packaging industry. Any sector that wants to replace heavy metals with lighter, recyclable, and environmentally safe materials should consider such materials. We can infer from all the comparisons and results that the manufactured composite material may be a potential replacement for synthetic fibers like fiber glass in lightweight applications that do not require very high mechanical performance.

5.3. Future work

One of the several future plans is to treat the fibers using more effective treatment chemicals other than NaOH, i.e., using better compatibilizers. To make advanced research on the physical, tribological, morphological, thermal, and chemical properties of fibers of various ages. It is also possible to compare alkaline-treated fiber reinforcement with untreated ones. This study may be expanded by integrating the created material's wear properties and machinability. The current work may be extended by employing hard particle fillers in addition to moringa and bamboo fibers to increase strength. This study may be expanded to include various fiber volume percentages to investigate the influence of wt.% on the mechanical, machinability, and tribological characteristics of the composite. Another horizon of this research is to use optimization methods to study and use the optimum parameters. Studying the thermal stability of this natural fiber is also possible because the thermal instability properties of natural composites are one of the key challenges that limit the application of natural fibers.

Published conference paper at Bule Hora University:

M. Yassin, K. Selman, Gossaye. K, P.J Ramulu, M. Gelaw, K. Shahapurkar. (2021). Comprehensive Review on the flexural behavior of polymer matrix composites reinforced with waste materials.

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APPENDIX

Appendix-A: Density calculation of reinforcements and composites.

Density calculation of reinforcements

- Density of Moringa

Mass of water (Mw) = 58.5 gm

Total Mass (M_T) = Mw + Mm= 60.5 gm

Mass of moringa (Mm) = M_T - Mw = 60.5gm – 58.5gm = 2 gm …. After immersed in to water.

Displaced water volume (Vdw) = 2.4ml = 2.4 cm^3 = V_f

According to Archimedes' principle: Displaced volume = volume of fiber (V_f)

Density moringa (ρ_m) = M_f/V_f = $2gm/2.4cm^3 = 0.833gm/cm^3$

$\rho_m = 0.833gm/cm^3$

- Density of Bamboo

Mw= 860 gm

M_T = 867.5 gm

Mass of bamboo (Mf) = M_T - Mw = 867.5gm – 860gm = 7.5gm

Vdw= 7.4ml

Density (ρ_b) = Mf/Vf

$\rho_b = M_f/V_f = 7.5gm/7.4cm^3 = 1.014gm/cm^3$

- Density of composites

For mold-1

$$\rho_c = \rho_r \times f_r + \rho_m \times (1- fr) \text{ … law of mixture}$$

Overall volume of specimen (V)

$V = l \times w \times t$ …. Where l = length, w = width, and t = thickness

The samples size are

Mold-1.

l = 190mm, w = 120mm, and t = 3mm

Therefore, V_T = 68,400 mm^3 = 68.4 cm^3 = 68.4 ml, … 1cm^3 = 1000mm^3

- Experiment:1

Composite density for Moringa- Moringa (MM-60) sample.

The volume fraction (V_r) for this sample was volume fraction of fiber (f_r) = 60 % and volume fraction of matrix (f_m) = 40%.

Density of composite (ρ_c) using Law of mixture:

$\rho_c = \rho_r \times f_r + \rho_m \times (1 - fr)$

$= 0.833 gm/cm^3 \times 0.6 + 1.1\ gm/cm^3 \times 0.4$

$\rho_c = 0.94\ gm/cm^3$

Therefore, the density of MM-60 composite become, $\rho_c = 0.94\ gm/cm^3$

The total mass (M_c) of composites:

$M_c = \rho_c \times V_c$

$= 0.94\ gm/cm^3 \times 68.4\ cm^3$

$M_c = 64.3\ gm$

The total mass of moringa woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2$ where m_1, m_2 is the mass of individual moringa woven layer

$= 3.86gm + 4.13gm = 8\ gm$

Then, Mass of matrix or epoxy (M_e)

$M_e = M_c - M_r$

$= 64.3\ gm – 8\ gm = 56.3\ gm$

At the end, the mass of hardener (M_h) became 25%Me = $M_h = 56.3/4 = 14.08gm$

- Experiment:2

Composite density for Bamboo-Bamboo (BB) sample.

Volume fraction of fiber (f_r) = 60 % and volume fraction of matrix (f_m) = 40%.

Density of composite (ρ_c) using Law of mixture:

$\rho_c = \rho_r \times f_r + \rho_m \times (1- fr)$

$= 1.014gm/cm^3 \times 0.6 + 1.1\ gm/cm^3 \times 0.4$

$\rho_c = 1.05\ gm/cm^3$

Therefore, the density of BB-60 composite become, $\rho_c = 1.05\ gm/cm^3$

The total mass (M_c) of composites:

$M_c = \rho_c \times V_c$

$= 1.05\ gm/cm^3 \times 68.4\ cm^3 = 71.82\ gm$

The total mass of bamboo woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2$ where m_1, m_2 is the mass of individual bamboo woven layer

$= 11.5\ gm + 12.77\ gm$

$= 24.27\ gm$

Then, Mass of matrix or epoxy (M_e)

$M_e = M_c - M_r$

$= 71.82\ gm – 24.27\ gm = 47.55gm$

At the end, the mass of hardener (M_h) became 25%Me = $M_h = 47.55/4 = 11.89gm$

- Experiment:3

Composite density for Bamboo-Moringa (BM-60) sample.

Volume fraction of Bamboo fiber (f_{r1}) = 30 %, volume fraction of Moringa fiber (f_{r2}) = 30% and volume fraction of matrix (f_m) = 40%.

Density of composite (ρ_c) using Law of mixture:

$\rho_c = \rho_{r1} \times f_{r1} + \rho_{r2} \times f_{r2} + \rho_m \times (1- (f_{r1}+fr_2))$

$= 1.014 gm/cm^3 \times 0.3 + 0.833\ gm/cm^3 \times 0.3 + 1.1\ gm/cm^3 \times (1- (0.3 + 0.3))$

$\rho_c = 0.994\ gm/cm^3$

Therefore, the density of BB-60 composite become, $\rho_c = 0.994\ gm/cm^3$

The total mass (M_c) of composites:

$M_c = \rho_c \times V_c$

$= 0.9942\ gm/cm^3 \times 68.4\ cm^3$

$M_c = 68\ gm$

The total mass of bamboo and moringa woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2$ where m_1, m_2 is the mass of individual bamboo weaved layer

$= 15.14gm + 4.01gm$

$= 19.15\ gm$

Then, Mass of matrix or epoxy (M_e) = M_c - M_r

$= 68\ gm – 19.15\ gm = 48.85\ gm$

Therefore, the mass of hardener (M_h) became 25%Me = 48.85/4 = 12.2 gm

For mold-2

Overall volume of mold cavity(V)

$V = l \times w \times t$ …. Where l = length, w = width, and t = thickness

The samples size are:

l = 100mm, w = 100mm, and t = 12 mm

Therefore, V_T = 120,000 mm^3 = 120 cm^3 = 120 ml.

N.B. **Volume fraction of mold-1 = mold-2**

- Experiment:1

Composite density for Moringa- Moringa (MM-60) sample.

From mold-1 the density of MM-60 sample.

$\rho_c = 0.94\ gm/cm^3$

The total mass (M_c) of composites = $\rho_c \times V_c$

$M_c = 0.94\ gm/cm^3 \times 120\ cm^3 = 112.8\ gm$

The total mass of Moringa woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2 + m_3 + m4 + m_5 + m_6$ ………………………… where m_1, $m_{2, \ldots}$ m_6 is the mass of individual moringa woven layer

= 2.45 gm + 3.55 gm + 3.1 gm + 3.21 gm + 2.98 gm + 3.02 gm

M_r = 18.31 gm

Then the Mass of matrix or epoxy (M_e) = M_c - M_r

= 112.8 gm – 18.31 gm = 94.49 gm

At the end, the mass of hardener (M_h) became 25%Me = 23.623 gm

- Experiment:2

Composite density for Bamboo-Bamboo (BB-60) sample.

ρ_c = 1.05 gm/cm^3

The total mass (M_c) of composites: = $\rho_c \times V_c$

M_c = 1.05 gm/cm^3 × 120 cm^3 = 126 gm

The total mass of bamboo woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2 + m_3 + m_4 + m_5 + m_6$ ………………………… where m_1, m_2, … m_6 is the mass of individual bamboo woven layer

M_r = 5.87gm + 6.23gm + 5.95gm + 6.03gm + 6gm + 6.19gm = 36.27 gm

Then the Mass of epoxy (M_e) = M_c - M_r

= 126 gm – 36.27 gm = 89.73 gm

So, the mass of hardener (M_h) became 25%Me = 22.433gm

- Experiment:3

Composite density for Bamboo-Moringa (BM-30/30) sample.

ρ_c = 0.994 gm/cm^3

The total mass of composites (M_c) = $\rho_c \times V_c$

M_c = 0.9942 gm/cm^3 × 120 cm^3 = 119.3 gm

The total mass of bamboo (m_1, m_2, m_3) and moringa (m_4 m_5 m_6) woven (M_r) was measured using weight balance:

$M_r = m_1 + m_2 + m_3 + m_4 + m_5 + m_6$ …………………………. where m_1, m_2, … m_6 is the mass of individual bamboo weaved layer

= 6.2 gm + 5.94 gm + 5.97 gm + 3.05 gm + 3.3 gm + 2.89gm

= 27.35 gm

Then, Mass of epoxy (M_e) = M_c - M_r = 119.3 gm – 27.35 gm = 91.95 gm

Therefore, the mass of hardener (M_h) became 25% Me = 91.95/4 = 22.988 gm

Table A.1: Quantitative information for sample preparation.

Represe-ntation	Volume (%) reinforcements	Weight (%) reinforcements	Mass of epoxy (gm)	Mass of hardener (25%) (gm)	Density of composite (gm/cm^3)
Mold-1					
ER	0	0	-	-	1.1
MM-60	60	53.17	56.3	14.08	0.94
BB-60	60	57.94	47.55	11.89	1.05
B/M-30/30	30/30	55.74	48.85	12.2	0.994
Mold-2					
ER	0	0	-	-	1.1
MM-60	60	53.17	94.8	23.7	0.94
BB-60	60	57.94	89.52	22.38	1.05
B/M-30/30	30/30	55.74	92.3	23.08	0.994

Appendix-B: Defective Samples

Bamboo/moringa hybrid sample in figure B.1 (a) was made from chopped bamboo fibers and moringa woven. When the sample was prepared by using the amount bamboo was fixed (10 wt.%) and then studying the mechanical properties by varying weight percentage of moringa. But when the sample was developed it was stacked in the mold cavity due to the lack of wax and high proportion of hardener.

(a) (b)

Figure B.1: Defective samples

The figure B.1 (b) sample was made from bamboo/moringa fibers with wrong proportion of epoxy-hardener ratio (10:1). After preparation of the sample the curing process took more than three days.

Appendix-C: Sample preparation and Testing images

Samples and specimens for testing

(a)

(b) (c)

(d) (e)

(f)

(g)

Figure C.1: Woven and samples: (a) to (c) woven, (d) mold- 2, (e) mold-1, (f) samples from mold-1, and (g) samples from mold-2.

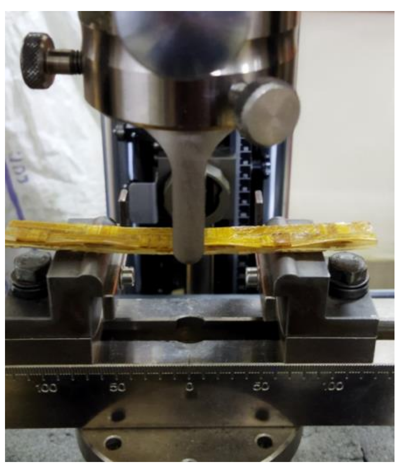
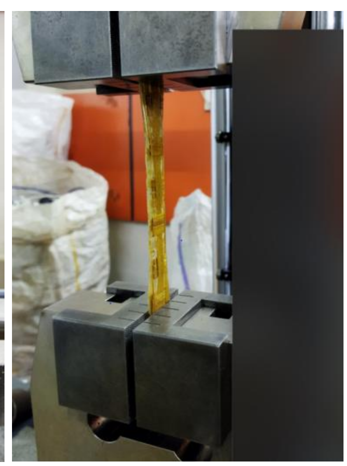
(a) (b) (c)

(d)

(e)

Figure C.2: Specimens for testing: (a) tensile, (b) flexural, (c) compression, (d) hardeness (e) impact.

- Testing images

(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure C.3: Testing images: (a) hardness, (b) flexural, (c) tensile, (d) compression, (e) and (f) impact, (g) and (h) water absorption test.

Appendex-D: Specimes after testing

Figure D.1. Compressive specimens after testing.

Figure D.2. Impact specimens after testing.