Experimental study on Mechanical behavior of Sisal and Sheep wool fiber reinforced Hybrid Polyester Composites

JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF POSTGRADUATE STUDIES

A Thesis Submitted to the Graduate Studies of Jimma University in Partial Fulfilment of the Requirement for the Degree of Master of Science in Mechanical Engineering (Manufacturing System Engineering)

By
Meseret Bezabih
Id no RM 7510/11

Dec – 2021
Jimma, Ethiopia

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Main Advisor: Dr. M.Dhakshnamoorthy (Asst.Prof)

Co-Advisor: Mr. Kancharla Srinivasarao

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Approval Sheet

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Declaration

I hereby declare that this thesis entitled **"Experimental study on Mechanical behavior of Sisal and Sheep wool fiber reinforced hybrid Polyester Composites"** is composed by myself, with the supervision of Dr. M.Dhakshnamoorthy (Asst.Prof), that the research presented here is my own except where clearly indicated such in the document and that work has not been submitted for any degree or formal certification in whole or in part for the award of any other degree or diploma. It is being submitted for the degree of Master of Science in Manufacturing System Engineering, and all sources of materials used for this thesis ensure be present accordingly acknowledged.

Meseret Bezabih

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Name of the candidate	Signature	Date

Acknowledgment

It is with the deepest senses gratitude of the almighty that gives strength and ability to complete this research successfully.

First of all, I would like to thank my Advisor **Dr. M. Dhakshnamoorthy** for taking me under his supervision. He has given me critics, encouragement, guidance, and valuable advice in order to complete this research proposal.

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I also thank others who have provided assistance at various occasions whether directly or indirectly in the completion of my thesis.

Last but certainly not least, my special thanks also extend to my family members for the continual encouragement and support.

Abstract

Natural fibers from Plants and Animals have a major role in developing 'green' economy. Because it has attractive features of abundant availability, renewable resources, environmentally friendly, high specific strength, non- corrosive, low cost and biodegradability. Most of these natural fibers are discarded in to land fill areas as wastes and removed by open burning that may lead to air pollution. Need of Structural material which are efficient and effective are vital issue for researchers. The present study focus on using of natural fibers like sheep wool and Sisal fiber for manufacturing the hybrid fiber composite (HFC) for structural application. This HFCM was synthesized by hand lay-up technique with design consideration of principal parameters like fiber orientation, fiber volume ratio, and ply arrangement. Then, mechanical tests and physical tests were conducted to characterize experimentally. Those fibers surface bind together by using polyester. In this work both theoretical and experimental studies were performed. The effects of fiber orientation, ply arrangement and fiber volume ratio on mechanical properties of the HFCM were studied. The results showed that increasing fiber content above optimum limit decreased the strength of the composite. In addition to that, concentrating Sisal fiber was preferable to enhance the strength of HFCM than concentrating wool fiber. Chopped orientation of the fiber also shows better strength than the other. SWS ply arrangement for the mat one and CSW-20% fiber volume ratio for chopped type is optimum model with 20.16 MPa and 50.22 MPa tensile strength and 127.01 MPa and 242.5 MPa modulus of elasticity respectively.

Keywords: *Sisal Fiber, Sheep Wool, Polyester Resin, Hybrid Composite, Mechanical Properties.*

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List of Acronyms

ASTM	American Society of testing materials
C	Chopped
CM	Composite material
CMC	Ceramic Matrix composite
CS	Chopped Sisal
CSW	Chopped Sisal Wool
CW	Chopped Wool
FCM	Fiber Composite material
M	Mat
M_F	Fiber Mass fraction
M_f	Mass of fiber (gm)
M_M	Mass of Matrix (gm)
MMC	Metal Matrix composite
MS	Mat Sisal
MSW	Mat Sisal Wool
MSWS	Mat Sisal Wool Sisal
MW	Mat Wool
MWSW	Mat Wool Sisal Wool
PMC	polymer Matrix composite
S	Sisal Fiber
SW	Sisal – Wool
SWS	Sisal – wool – Sisal
UTM	Universal Testing Machine
V_F	Fiber Volume
V_m	Volume of Matrix
W	Wool fiber
WSW	Wool – Sisal – Wool
ρ_f	Density of Fiber (gm/cm^3)
ρ_m	Density of Matrix(gm/cm^3)

CHAPTER – 1

1. Introduction

The present study will focus on developing sheep wool and sisal fiber hybrid polymer composite material and conducting experimental investigation to characterize its mechanical and physical performance for structural application. In this chapter, a general introduction of the research with a brief background on polymer composite is stated. It also includes statement of the problem, objective, and motivation of the study and scope of the work.

1.1. Composite material

Composite materials are material systems which consist of one or more discontinuous phases embedded in a continuous phase. Thus, at least two distinct materials that are completely immiscible are combined to form a composite. Composites comprise strong load carrying material is known as *reinforcement* and weaker materials is known as *matrix*. Fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces (boundaries) between them. Reinforcement provides stiffness and strength which helps to support structural load. [1]

1.1.1. Classification of composites

Composite materials are classified into three types based on matrix. They are Polymer matrix Ceramic matrix and Metal matrix composites. A polymer matrix composite (PMC) is a composite material composed of a variety of short or continuous fibers or particles bound together by an organic polymer matrix. PMCs are designed to transfer loads between fibers of a matrix. Polymer matrix is classified into two types and they are thermoplastic and thermosetting polymers. Some of the advantages with PMCs include their lightweight, high stiffness and their high strength along the direction of their reinforcements. Other advantages are good abrasion resistance and good corrosion resistance. [2], [3]

Based on reinforcement, the classification of composites is shown in Fig.1.1. Also, the classification of natural fiber reinforcement is shown in Fig.1.2.

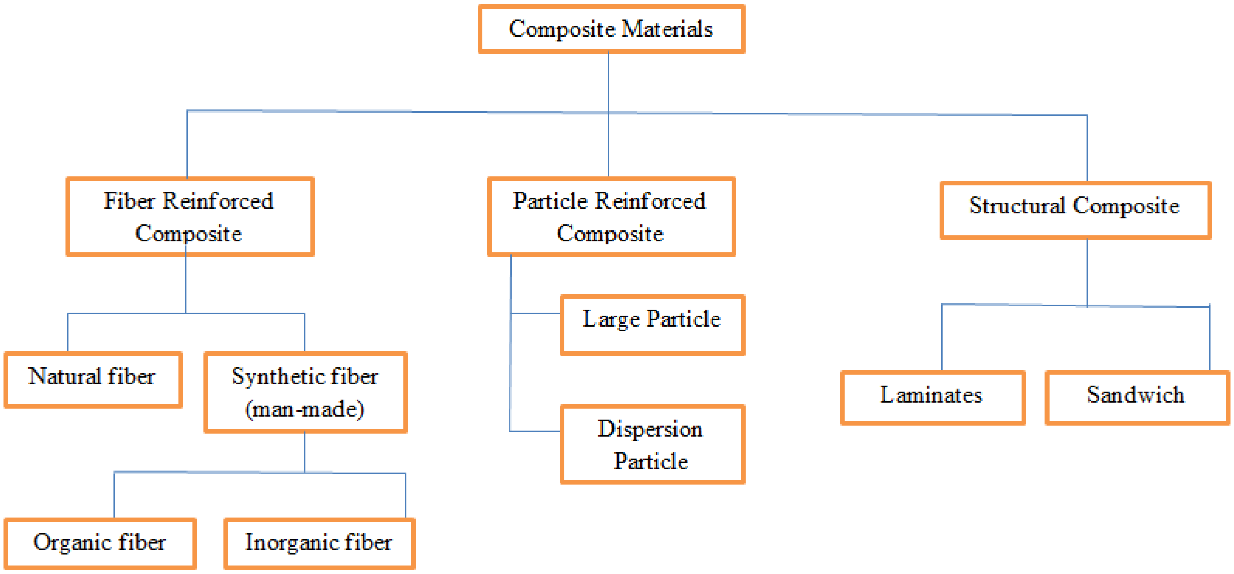


Figure 1. 1.Classification of Composite materials based on reinforcement.

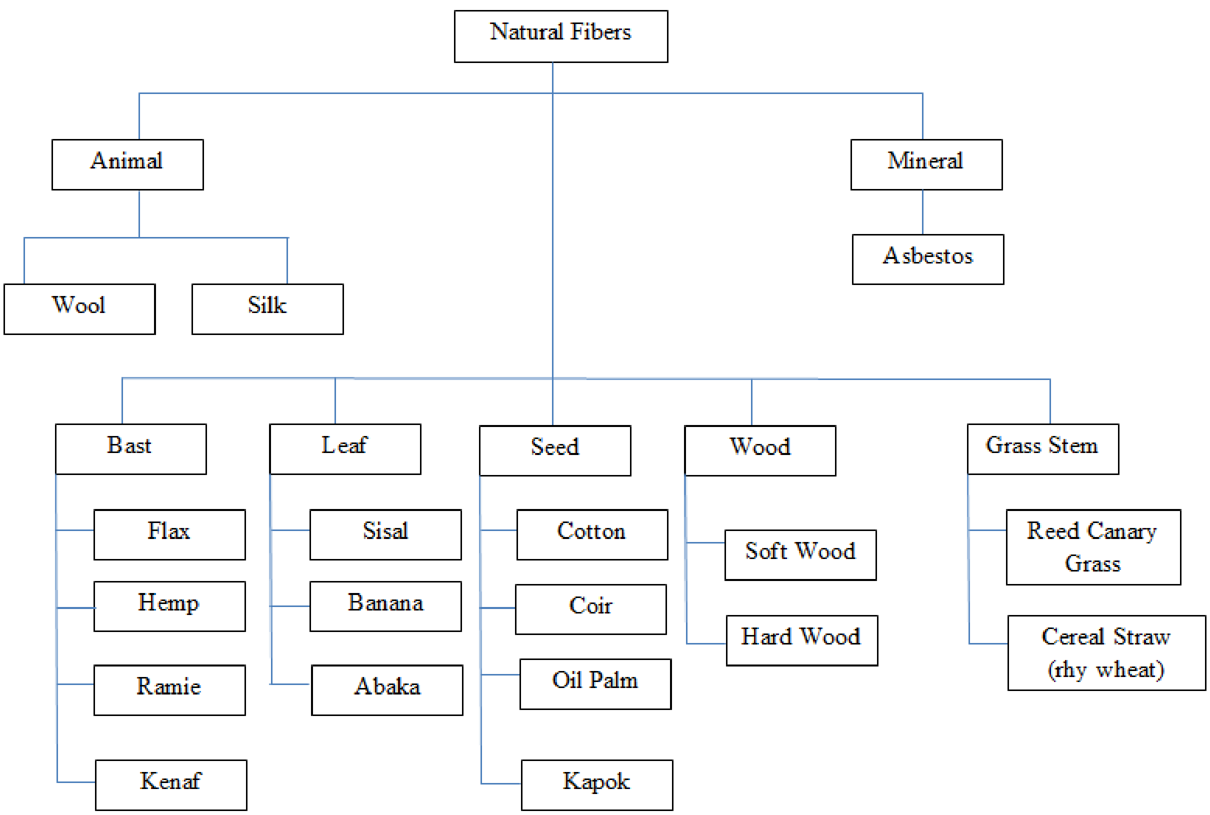


Figure 1. 2: Classification of natural fiber reinforcement. [4]

1.1.3. Hybrid fiber reinforced polymer composites

Hybrid composite materials are made up of two or more physically distinct and mechanically separable components, existing in two or more phases. Normally, this aims at exploiting properties of different fibres while retaining their desirable individual characteristics in the resultant product. Since time immemorial, synthetic fibres such as carbon, glass, and aramid have dominated the composite manufacturing sector because of their low cost of production and fairly good mechanical properties. [4]However, with increasing environmental concerns, studies on the possibility of replacing synthetic fibres with natural fibres for polymer composite manufacture are on the rise. [5]

Natural plant fibres possess attractive advantages in comparison to their traditional synthetic counterparts such as glass and carbon fibres. While offering low density, high specific strength, and stiffness, natural fibres produce comparatively less toxic fumes when subjected to heat or during incineration at end life. In addition, they are renewable and biodegradable reinforcing agents are not abrasive for processing tools, are cheap, and the feedstock for their production are usually readily available [6] [7]. Unlike synthetic fibres, such ecologically friendly materials hardly impact the health of workers using them. Also, their introduction in composites economies the amount of the polymeric matrix used, oaring obvious economic and environmental advantages [8]

1.1.4. Sisal fiber

Sisal fiber is a type of plant fiber that obtained from the leaves of the plant Agave sisalana, which was originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia [9]Ethiopia produces approximately 784 tons of sisal fibers annually.

Sisal fibers are widely used due to their availability with each plant producing 200–250 leaves, and each leaf produces 1,000–1,200 fiber bundles [10]. On account of their better mechanical properties and abundance in most parts of the country, sisal fibers could be a promising reinforcement material in hybrid composites. Fig.1.3. shows the production of sisal fibers from the sisal plant leaves.

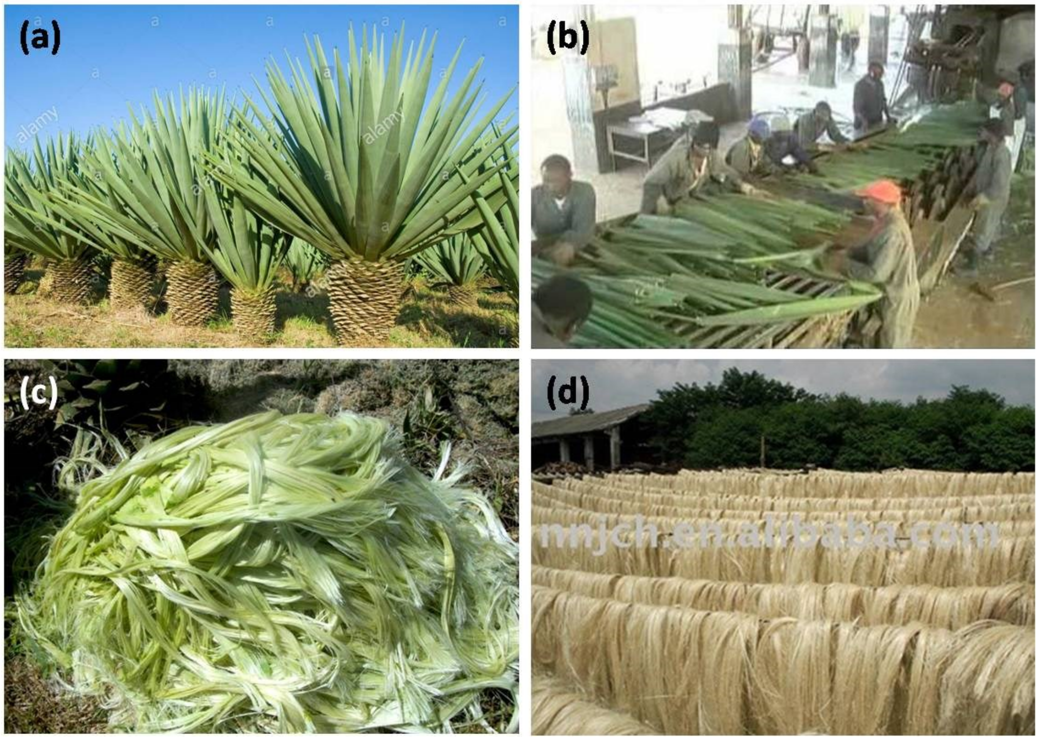


Figure 1. 3 Production of Sisal fiber (a). Sisal Plant (b). Processing of Sisal leaves (c). Wet sisal fibers and (d). Dried sisal fibers [12]

1.1.5. Sheep wool

Sheep wool is a byproduct of sheep farming. Increasing application area of sheep wool in added value engineering material will contribute the environmental, economical, and social sustainability to the societies. [11]

Sheep wool is the most commonly used animal fiber which is obtained from the soft, hairy covering of sheep. Raw wool is one of the major export commodities of a number of countries, including Australia. It is one of the oldest naturally renewable fibers in use. It is epidermal in origin and grown naturally on the bodies of sheep. The wool is obtained by shearing the fleece from the sheep, and then graded, washed and combed to remove any extraneous matter such as grease, dirt, moisture and vegetable matter. The fibers are generally entangled and crimped. Fig.1.4. shows the preparation of handmade sheep wool fiber yarn. [12] [13]

Figure 1. 4 Preparation of Sheep wool yarn (a). Ethiopian Sheep (b). Raw wool fleece (c). Hand-spinning of sheep wool and (d). Sheep wool spun yarn [16]

1.1.6. Polyester resin

Unsaturated polyesters are condensation polymers formed by the reaction of polyols (also known as polyhydric alcohols), organic compounds with multiple alcohol or hydroxyl functional groups, with saturated or unsaturated dibasic acids. Typical polyols used are glycols such as ethylene glycol; acids used are phthalic acid, isophthalic acid and maleic acid. Water, a by-product of esterification reactions, is continuously removed, driving the reaction to completion. The use of unsaturated polyesters and additives such as styrene lowers the viscosity of the resin. The initially liquid resin is converted to a solid by cross-linking chains. This is done by creating free radicals at unsaturated bonds, which propagate in a chain reaction to other unsaturated bonds in adjacent molecules, linking them in the process. The initial free radicals are induced by adding a compound that easily decomposes into free radicals. This compound is usually and incorrectly known as the catalyst. [4]Initiator is the more correct term. Cobalt salts are usually used as a true catalyst. Substances used are generally organic peroxides such as benzoyl peroxide or methyl ethyl ketone peroxide.

Polyester resins are thermosetting and, as with other resins, cure exothermically. The use of excessive initiator especially with a catalyst present can, therefore, cause charring or even ignition during the curing process. Excessive catalyst may also cause the product to fracture or form a rubbery material. [14]

1.2. Background of the study

The use of composite material was started with Egyptian and Mesopotamian carpenters. They have used a mixture of mud with grasses to create a strong and durable building, around 1500 B.C [8]The modern era of composite starts with the invention of plastic in the early 19^{th} century that replaced metallic and timbered materials. Later in 1935, high performance fibers like glass fibers were developed and binding with plastic polymer to get strong and rigid materials. In 1970s the composite industry began to advance since improved resins and reinforcements were developed. It can be alternative material for many applications like civil, transport, aerospace, medical and sports industry. [9]

For the last three decades, researchers and engineers are interested in making extensive research and developing innovative materials due to the need of efficient and effective engineering materials. Composite materials, ceramics and plastics can be listed as engineering materials. For advanced applications, the use of composite materials is not only decreasing the dead weight but also for absorbing shock and vibration. For ordinary application composite materials will be designed with consideration of its area of application and structural aspects.

Composite materials are defined as bi-component of its constitute such as reinforcing phase and matrix phase or binding phase. However, it can achieve improved properties over their individual constituents. Composite materials are classified based on the nature of constituents. Based on the matrix or binding material, it will be polymer, metal or ceramic. Based on reinforcing material type composite may classify in to structural, particulate and fibrous.

Polymer matrix materials (PMC) are a type of composite material it uses polymer matrix reinforced with natural or synthetic fibers. These polymers will be thermosetting or thermoplastics. Thermosetting polymers have qualities of a well-bonded three-dimensional molecular structure after curing. It can be decomposed instead of melting. [15]Due to this, thermoset matrix has a wide range of application in the fiber composite. Low density, good corrosion resistance, low thermal conductivity, and lower electrical conductivity, and so on are listed as common merits in PMC. Epoxy, polyester, phenolic and polyimide resins are thermoset matrices. Polyester resin has a wide range of industrial application because of their high strength and mechanical adhesiveness characteristics. [16]

Fibrous composites constitute fiber as reinforcement and polymer as matrix. Fibers in the composite are the load carrying element and provide strength and rigidity. Polymer matrices in the composite maintain the alignment of the fibers (position and orientation). Fibers are very effective in improving the fracture resistance of the matrix since it discourages the growth of emerging cracks if it is normal to the fiber distribution. [17]Fibers are classified into natural fiber (plant, animal and mineral fibers), and synthetic fibers such as glass fiber, carbon fiber, Aramid, etc.

The concern of environmental sustainability and the demand of cost-effective material forcing engineers to develop and bring natural fiber reinforced composite material to the market. Natural fibers also further divided into different classes such as plant, animal and mineral based on its source. Besides that natural fiber composite have many advantages like abundantly available, non-toxic, thermal and sound insulation, hydrophobic, corrosion resistant, non-abrasive, renewable, strong and light-weight and cheap processing methods. Various sectors like automotive, furniture, construction, sporting industries, packaging, and consumable goods are commonly listed in current applications of natural fiber reinforced polymer composite. [18] [19] [20]

The aim of the present research work proposal will be to develop a new class of two natural fiber woven fabric reinforced hybrid polymer composite and to study their mechanical behavior.

1.3. Statement of the problem

In the current era, the need for an alternate and effective engineering material for structural application is a vital issue for researchers. When the rapid growth of world's population increase also there will be increase in consumption of world resources but the world resources remain limited.

On the other hand, both plant and animal sourced wastes are becoming an alarming problem. These waste materials usually discarded into landfill area and removed by open burning that may lead to air pollution.

The basic component for static and dynamic physical system is the structure. It may be the load carrying or it may be partition, it may be system case or container. The need of economical, safe, lightweight, and durable material is a vital issue for the researcher's to get an alternative solution for today's structural application. Now days, mostly used materials for structural application are metals, woods, stones, ceramics and plastics.

Before natural fibers reinforced composite materials, synthetic fiber reinforced composite materials are widely used in industries. But they have some limitations such as non-recyclable, non-renewable, and healthiness risk. For this reason, the preparation of an alternative material is the main goal of this study. In this research, it uses to utilize sisal and sheep wool fiber woven fabric and chopped reinforcement with polyester to prepare a new hybrid composite with improved mechanical properties.

1.4. Objective

The general and specific objectives of the research are given below.

1.4.1. General objective

The general objective of this research is to focus on Experimental study of characterizing mechanical property of sheep wool and sisal fiber reinforced polymer composite for structural application.

1.4.2. Specific objective

- ✓ To develop hybrid fiber composite material using sisal fiber and sheep wool as reinforcement and thermosetting matrix Polyester resin as binding material
- ✓ Conducting an experimental investigation to characterize the mechanical performance of the developed composite material
- ✓ To determine the effect of process parameter, which particularly affect the mechanical strength of composite material. (i). Fiber and matrix composition (wt. %), (ii). Fiber-matrix interface, (iii). Fiber orientation
- ✓ To investigate the effect of hybrid sheep wool and sisal fiber composite material with respect to the mono fiber polyester composites

1.5. Scope of the research

The scope of this research will include

- ✓ Developing composite material using Sheep wool and Sisal fiber as reinforcement and polyester as resin
- ✓ Conducting mechanical tests such as tensile, flexural, and impact test
- ✓ Carrying out comparison study on the mechanical performance of hybrid fiber and mono fiber composite materials

1.6 Research questions

- ✓ How to develop, sisal-sheep wool fiber reinforced hybrid composite material?
- ✓ What are the effects of process parameters (fiber orientation, fiber weight fraction, and ply arrangement) on the mechanical properties of developed material?

- ✓ How do the process parameters affect the physical properties (water absorption and burning)?
- ✓ Does the material suitable for the intended application?

1.7 Significance of the study

This study can be used to develop hybrid sisal-sheep wool fiber-reinforced composite material with sufficient strength for automobile door internal panel application. On the side of the community, it will be used in industries to create job vacancies for many people from fiber extraction up to manufacturing composite materials. Additionally, this research work is used for structural applications such as panels, tables, partition boards, tables and chairs.

1.8 Thesis outline

With the aim of complete fully the objective of this thesis, the entire studies divide in to the following five chapters.

- ✓ In the first Chapter, a general introduction to the composite material, background studies and problem of the statement, objectives and outline of the thesis are presented in this section.
- ✓ In the second chapter review of the previous work related to natural fiber reinforced composite material, overview of composite material, its constitute, classification, method of manufacturing and advantages and disadvantages are presented.
- ✓ In the third chapter methodology of the thesis with detail of experimental material and methods and laboratory testing used throughout the studies are presented in detail and literature review concerning to the test also presented.
- ✓ In the fourth chapter, the result of the experimental studies is presented. The mechanical investigation of the HFCM is recorded in this chapter.
- ✓ In the last chapter five, the summery of the result conclusions drawn from the above analysis and future recommendation are presented.

CHAPTER – 2

2. Literature review

This chapter contains some reviews associated to natural fiber reinforced hybrid polymer composite materials in order to create enough understanding and to assess the current status in the field of composite material.

2.1. Natural fiber reinforced composites

Currently manufacturing of material is difficult because of energy consumption, cost and environmentally friendly row material. For this reason we have to find alternate eco- friendly and cheap material resource. Natural fiber reinforced composite material get researcher's attention because of availability, biodegradable, corrosion resistance and cheap manufacturing processes. [9]It uses plant, animal or mineral sources to get these natural fibers. Plants like sisal, cotton, banana, jute, etc. are widely used to get plant fibers. Wool and silk fibers are obtained from animal sources. In mineral like asbestos, ceramic fiber and metal fibers are listed as natural fibers. [11]

T.P. Sathishkumar et al. reported Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites. The maximum flexural strength and modulus of the chopped fiber isophthallic polyester composite is achieved at 25% V_f for 120 mm and 150 mm fiber lengths. But the values have significant improvement in 150 mm. [6] [13]*Duppala et al.* reported processing and mechanical behavior of human hair fiber reinforced polymer composites. The fiber parameters, for example, fiber stacking and length has basic effect on the mechanical properties of the composites. [14]

A. S. Blicblau et al. prepared novel composites utilizing raw wool and polyester resin. Utilizing wool fibers as reinforcement for polyester resin shows that over 50% by weight is required to achieve impact toughness value of 60 kJ m^{-2}, which is an increase of six-fold over virgin polyester resin. Flexure performance of the composite resulted in failure only at low levels of reinforcement, suggesting that high volume fractions (.50%) of wool fibers can be used to successfully reinforce polyester resin matrices. [15]

Flávio de Andrade Silva et al. reported the tensile and fatigue behavior of natural sisal fibers. The Young's modulus of sisal fibers, corrected for machine compliance, was around 18 GPa. The modulus was not influenced by the gage length. The strain-to-failure decreased from approximately 5.2% to 2.6% when the gage length was increased from 10 mm to 40 mm. The tensile strength, on the other hand, was found to be independent of the gage length. [21]

2.2. Hybrid fiber reinforced polymer composites

Several researchers have investigated the effect of hybridizing natural fibers such as sisal, jute, hemp, coir, and cattail on polymer matrices and how they improve the mechanical properties of the resultant polymer composites. In one of the pioneer studies, *Silas et al.* evaluated mechanical properties of Sisal/Cattail Hybrid reinforced polyester composites. At a constant fiber weight fraction (20%), a positive improvement in flexural, tensile, and compressive properties was registered as the fiber blend ratio varied between 0 and 75% with optimal values at a sisal/cattail ratio of 75/25. [18]

Puneet et al. investigated on experimental study of Sisal and Jute Fiber based Biocomposite. In this work, eco-friendly natural fiber composites were manufactured using jute and sisal fiber along with epoxy. Different fiber lengths were chosen such as (2.5cm, 2.0cm, 1.5cm, 1.0cm) and are manufactured by hand layup system. The maximum tensile strength for jute and sisal fiber based composites for 2.5cm fiber length was found to be 22.19391 MPa and 25.89 MPa whereas in case of Izod test sisal fiber based composite exhibits good results. [17]

In another investigation, *J. Tusnim et al.* reported properties of Jute and Sheep wool fiber reinforced hybrid polypropylene composites. Jute fiber and sheep wool fiber reinforced hybrid polypropylene composites were prepared by varying fiber loading and fiber ratio. Prepared composites were subsequently characterized. Mechanical properties increased with an increase in fiber loading. Best set of properties were obtained from 15% fiber loading with jute and wool fiber ratio of 3:1. These tests could help further to unveil other properties besides mechanical ones and help in comparison of raw fibers with chemically treated fibers in future. [20]

Franciszek Pawlak investigated the Silane-Functionalized Sheep Wool Fibers from Dairy Industry Waste for the Development of Plasticized PLA Composites with Maleinized Linseed

Oil for Injection-Molded Parts and stated that Sheep wool fibers were successfully surface functionalized with TVS silane coupling agent. The increasing amount of TVS from 1 to 2.5 phr revealed an increased thermal stability as well as an increased detachment of cuticle cells from the fiber bulk, as confirmed by SEM observations. The functionalized sheep wool fibers with 1 and 2.5 phr of TVS were used to reinforce the plasticized PLA/MLO matrix at three divergent loadings (1, 5, and 10 phr). [22]

Puneet Gondal states that the maximum tensile strength for jute and sisal fiber based composites for 2.5cm fiber length was found to be 22.19391Mpa and 25.89Mpa whereas in case of Izod test sisal fiber based composite exhibits good results. [23]

2.3. Classification of composites

Composite material is classified into different groups. Based on its constitutes properties and nature. Shown in figure 1.1

2.4. Merits of composites

Some benefits of composite material over a conventional one

- ✓ Enhanced torsional stiffness and impact strength
- ✓ Better tensile strength
- ✓ Higher fatigue endurance limit (up to 60% of ultimate tensile strength) 30%- 40% lighter than aluminum alloy structure
- ✓ Lower embedded energy compared to other structural metallic materials like steel, aluminum etc.
- ✓ Good damping effect, provide lower vibration transmission than metals
- ✓ More versatile and flexible during manufacturing to meet the design requirement
- ✓ Less life cycle cost than metals due to its long life offer and reduce maintenance
- ✓ composite exhibit excellent corrosion resistance and fire retardancy
- ✓ improved appearance with smooth surface and readily incorporable integral decorative melamine
- ✓ Composite parts can eliminate joints/ fasteners, providing part simplification and integrated design compared to conventional metallic parts. [24] [25] [26]

2.5. Constitutes of Composite material

Composite material is materials that differ from other are it is made from macro scale combination of the reinforcement and matrix material.

2.5.1. The reinforcement

Reinforcement is the discontinuous and stiff phase of composite constitutes which has the role of withstanding the mechanical loadings and rigged the composite material. [27]

Based on its shape size or aspect ratio and structure it divides into three types these are, fiber, particle or lamina.

- ✓ particle reinforced composite
- ✓ Lamina or structure reinforced composite
- ✓ Fiber-reinforced composite

According to the reinforcement type, the fiber composite may be classified into the following types.

2.5.2. Particle reinforced composite

In the particle reinforced composite material, the discontinuous phase is found in the form of particle or dispersion form. From 0.01µm to 200µm particle size is used in particle reinforced composite material. Based on particle size it also categorized into two groups. [28]

The particle can be found in different shapes like spherical, disk-shaped, rod-shaped and plate-shaped. it has an aspect ratio close to unity. Particle reinforced composite have enhanced hardness and wear resistance but decreased tensile strength. Some of commonly used particles include Aluminum oxideAl_2O_3, Titanium carbide (TiC), and silicon carbide (SiC). [29]

2.5.3. Laminar composite

It is composed of two or more layers or lamina and bind together by the matrix binder. It can be a sandwich or serious of a lamina. Laminate composite is composed of layers of material held together by matrix. Generally, these layers are arranged alternately for better bonding. This layer lamina may vary with fiber orientation. These laminates can have unidirectional, angle ply, cross-ply, and symmetric laminates. [30]A hybrid laminate composite material can also be fabricated by using different constituent material.

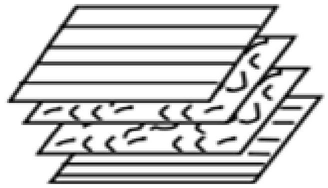


Figure 2. 1 Figure laminar composite redrawn from [32]

2.5.4. Fiber reinforced composite

In fiber-reinforced composite material the discontinuous or the reinforcement phase are found in the form of thin thread or in hairy structure. Fibers are in circular in cross- section with high specific strength and stiffness. Its length is many times greater than its diameter, having an aspect ratio greater than 100. It can be used as continuous or chopped fibers. [31]

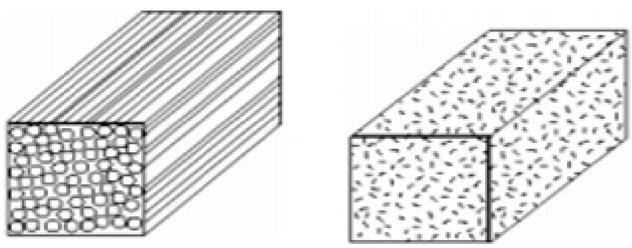


Figure 2. 2 a) Continuous longitudinal oriented fiber b) Random oriented chopped fibers redrawn from [32]

Due to its excellent structural performance, fiber-reinforced composite is gaining potential in tribological applications. The fiber in the composite material has a role of carries the major shared load. There are two types of fibers namely; synthetic or man-made and natural fiber.

a) Synthetic fibers

Synthetic fibers are man-made fibers such as glass fibers, carbon fibers, and aramid fibers. It can be used as reinforcement in polymer and metal-based high-performance composite material. Composite reinforced with synthetic fiber have good mechanical performance but it also possesses severe drawbacks like high cost, poor recyclability, environmental pollutant, and non-biodegradability. [32] [33]

b) Natural fiber

Natural fibers are fibers that originated from a plant, animal or mineral sources naturally it can be used as reinforcement in composite material. Based on the origin of natural fibers categorized into these: plant fibers, animal fibers, and mineral fibers.

In the last three decades, the use of natural fibers has been growing area of interest due to its important features like low specific weight, biodegradability, renewability and low production cost. The main focus of this research is natural fiber and it's composite. [34]

2.5.5. Matrix

Matrix is a substance that has the role of fixing the reinforcement together which has adhesive properties. Matrixes are the continuous phase of the composite material, which has a role of fixing reinforcements as its orientation and keeping the composite in its shape as designed. [35] [33]

The role of the matrix in the composite material:

- ✓ Hold the fibers in place and isolated one another to prevent the fibers from the formation of surface flaws
- ✓ Transfer and distribute the load into the fibers and evenly distributive stress concentration
- ✓ provides resistance to crack propagation and damage tolerance to the plastic flow at cracked tips
- ✓ keep the reinforcing fibers in the proper orientation and position
- ✓ protect the surface of the reinforcement from environmental effect and
- ✓ protect the reinforcements from handling damage
- ✓ with stand all of the interlinear shear strength of the composite
- ✓ determine the service temperature limitation of the composite [36] [37]

2.5.6. Metal matrix

Light metals like Magnesium, aluminum and titanium alloys are commonly used metals matrixes reinforced by ceramic fibers and particles. It used to improve the stiffness and strength of the material. High temperature cobalt and nicker based alloys are also reinforced with ceramic particle to create a class of MMCs called cermet. Ceramic fiber reinforced aluminum alloys have been developed for making propeller shafts used in automobile. In aluminum alloy 383-SiO2 particle composites plasma electrolyte oxidation (PEO) method was used for the production of engine block cylinder liners. It minimizes the weight, increase wear resistance and production cost. [38] [39]

Metal matrix composite (MMC) has some important features over the conventional organic material. Such as

- ✓ Good strength retention at higher temperature
- ✓ Higher transvers strength
- ✓ higher specific modulus
- ✓ lower coefficient of thermal expansion
- ✓ Better electrical conductivity
- ✓ Superior thermal conductivity and
- ✓ higher erosion resistance etc.

However, the major disadvantage of metal matrix composite is their higher densities and lower specific mechanical properties compared to polymer matrix composite.

2.5.7. Ceramic matrix

Ceramic have important features of high stiffness, hardness, compressive strength, and relatively low density. However, it is also brittle and low fracture toughness. Ceramic matrixes composite are designed to retain the ceramics important properties and compensating their weakness like brittleness and poor fracture toughness in the material. The main reason to develop ceramic matrix composite is to increase the materials toughness. [7]

Ceramic matrices are used in composite production with reinforcements of ceramic and metal alloys. Matrices used for ceramic matrix composite include alumina (Al2O3), boron carbide (B4C) and boron nitride (BN). While, mostly ceramic fibers, particle or whickers are used as reinforcement [1]

Ceramic matrix composite (CMC) are mostly used in high temperature application and where the environmental attack is an issue. For instance, TiC fiber reinforced alumina (Al2O3) and silicon carbide, zinc and calcium phosphate are the listed [40] [1]

2.5.8. Polymer matrix

Polymers are low density and good chemical resistant matrix that are suitable for aerospace applications especially in the fabrication of the fuselage and wings.

Advantages of polymer matrix

- ✓ low density
- ✓ low thermal conductivities
- ✓ translucence
- ✓ low electrical conductivities
- ✓ good corrosion resistance
- ✓ aesthetic color effects

Limitation

- ✓ Low transvers strength
- ✓ poor stiffness
- ✓ low operational temperature limit
- ✓ The poor mechanical properties of polymers are overcome by reinforcements with suitable particles, whiskers or fibers. [3] [36] [41]

2.6. Natural fiber

Natural fiber can add many environmental benefits when it compared with glass and other synthetic fibers. Natural fibers are green to environment from their extraction up to disposal. Especially those natural fibers, which are agricultural by-product totally has no impact to the environment even during producing, extracting, purifying, processing and disposing after use. [42]

Natural fiber reinforced composite have an increase in average annual production rate of around 18% in North America and 14% in Europe. It is also the most active areas in today's plastic industry. The demands of natural fiber in plastic industries have grown at 15-20 % annually in automotive application, 50%, and more in civil engineering works. [42]In north America use of natural fiber in automotive industries can save 3.07 million tons of CO2 emissions and 1.19 million m3 of crude oil could be saved by substituting 50% of synthetic fibers with natural fiber composite. [43] [44]

Plant and animal-based natural fiber have attracted researchers to use it as alternative to synthetic fiber such as glass and carbon fibers. These natural fibers reinforced composite has received much more in the structural application. For instance, interior parts such as door trim panels from natural fiber polypropylene, engine transmission cover and dashboard in automotive industry are the listed one. Based on its origin natural fibers are classified into three categories; these are plant fibers, animal fibers and mineral fibers. [45]

2.6.1 Mineral fiber

Asbestos is one of mineral based natural fiber which is used now mostly in composite industry due to its important feature of thermal and sound insulation, friction properties, adsorption capacity, inflammability and chemical inertness. In 2006, 2.3 million tons of asbestos were mined worldwide [46, 47] beside this, useful features it has many draw back specially with its silicate content it related to human health and environment pollution. These mineral-based fibers are drawn by electro spinning process and other modification. [46]

2.6.2 Animal fiber and their sources

Animal fibers like wool, silk, human hair and feathers contain proteins.

a) Silk fibers

Silk is collected from dried saliva of bugs or insects during the preparation of cocoons of the larvae. Example silk from silk worms [48], [49]

b) Human hair

Human hair is a filamentous biomaterial that grows from follicles found in the dermis. it is made up of 95% protein, is called keratin. [49]

c) Avian fiber or Feathers

Feathers are found in birds which formed in tiny follicles in the epidermis or outer skin layer, which contain keratin proteins. [50]

2.6.3 Plant fibers

Plant fibers are fibers extracted from plants. It is rigid and crystalline cellulose structure composed of cellulose, hemicellulose, lignin, waxes and some soluble compounds. Generally, the fiber contains 60-80% cellulose, 5-20% lignin and up to 20% moisture. [51] [40] [52]

Bast fiber

It is extracted from the ribbon of the stem of plant. Like jute fiber

Leaf fiber

Leaf fiber is scraped from the soft tissue of the plant by manually or machine. Such as sisal,

Seed fiber

In this type of fiber, seed fibers are extracted from seed of the plant. Hemp, Cotton, Flax and Ramie are listed

Fruit fibers

It is found from the husk of the fruit. Coir which originate from coconut fruit is the listed one

Stalk fiber

Stalk fiber are collected from the stalks of the plant and seeds. for example, rice, straws of wheat, grass and bamboo.

2.6.4 Natural Fiber and Its Characteristics

The manufacture of materials currently used is quite difficult in terms of energy consumption, raw materials and costs. Efforts are therefore being made to find suitable alternative material resources, while local, easily renewable resources are to be an advantageous alternative, on the condition that they are subsequently processed with low energy requirements. One solution method is the use of naturally available agricultural fibrous resources. Natural fiber is a type of renewable source and a new generation of reinforcements and complements for polymer-based materials see Table 2.1. The development of natural fiber composite materials or environmentally friendly composite materials has recently been a hot topic due to increasing environmental awareness.

Table 2. 1 Summary of Natural Fibers characteristics [56]

Fibers	Descriptions
Banana	Abaca, also known as manila hemp, is closely related to bananas. The plant of Abaca looks similar but, unlike bananas, its fruit is not for human consumption and is not economically viable. In contrast to bananas, abaca grows only for the production of fiber
Bamboo	Bamboo has received interest because it has a high strength to weight ratio, one

	of the fastest growing plants, requires less water, no use of pesticides or herbicides, and is harvested at its base, leaving the root untouched. Furthermore, the surface of the fiber is round and smooth and the ratio of l / d is high. It's lighter, stiffer and stronger than U.S. glass fiber.
Coir	Coir is very attractive because it is more durable than most natural fibers, free from chemical treatment, its high resistance to salt water and its availability.
Cotton	Cotton fiber has excellent absorbency, while Cotton accounts for 46% of the world's production of natural and chemical fibers.
Jute	Jute fiber has a high aspect ratio (l / d), a high strength to weight ratio and good insulation properties.
Kenaf	Kenaf fibers have low density and high specific mechanical properties.
Sisal	Sisal is easily cultivated with short periods of renewal. The fiber has a high tensile strength and tensile strength, abrasion resistance, salt water resistance, acid and alkali resistance.

There are several studies that point to the lower cost of natural fibers compared to synthetic fibers, but a proper comparison must be made in their application in part, considering the cost or impact of their production and life cycle as shown in Table 2.3. Different mechanical properties will require different mass of each fiber; different fiber quality and reliability will cause different waste and scrap during the production of composites and different needs for parts to be replaced during life.

Table 2. 2.Energy and cost of different fibers [56]

	Fibers	**Cost (US$/ton)**	**Energy (GJ/ton)**
A	Glass fiber	1200–1800	30
B	Carbon fiber	12,500	130
C	Natural fiber	200–1000	4

Following those authors natural fibers cost much less and require very less energy to produce which leads to cost and energy advantages over traditional reinforcing fibers such as glass and carbon fiber (Table 2.3)

Table 2. 3.Summary of characteristics of properties of natural and manmade fibers [56]

Fiber	Density(G/Cm)	Elongation (%)	Tensile Strength(MPa)	Elastic Modulus (GPa)
Cotton	1.5-1.6	7.0-8.0	400	5.5-12.6
Jute	1.3	1.5-1.8	393.773	26.5
Flax	1.5	2.7-3.2	500-1500	27.6
Hemp	1.47	2-4	690	70
Knaf	1.45	1.6	930	58
Sisal	1.5	2.0-2.5	511-635	9.4-22
Coir	1.2	30	593	4.0-6.0
E-Glass	2.5	0.5	2000-3500	70
S-Glass	2.5	2.8	4570	86

2.6.5 Mechanical performance of natural fiber composite

During developing natural fiber, reinforced composite material the main consideration is its mechanical performance. It depends on many factors. Such as

- ✓ Fiber type and its strength
- ✓ Fiber length
- ✓ Fiber orientation in the composite
- ✓ The amount of fiber in the composite (fiber weight fraction)
- ✓ Thickness of the laminate
- ✓ Fiber matrix interfacial bond strength (the interface) and so on [53], [54]

In addition of these, processing conditions, fiber extraction method, fiber's origin in the plant part have also undeniable impact on the strength of fiber reinforced composite. Several factors that significant to selecting suitable natural fiber for use in composites. Physical factors such as fiber dimension, structure, crystallinity, variability, and so on. Mechanical properties like fiber strength, bonding with matrix, environmental factor such as availability, cost and production are considered. [55]Sisal and sheep wool are chosen for this research because it is abundantly available in Ethiopia and a new fiber which are not get researchers focus. The matrix that used to adhere fibers plays a vital role in mechanical strength of the composite. Its main role is transferring the load to the stiff fibers through shear stresses at interface.

2.6.6 Production of natural fibers

Natural fibers such as sisal, Jute, pineapple, banana and coir are mostly used in today's composite material industry. Some studies stated that natural fibers like flax, jute, hemp and sisal have good strength and comparable with glass fiber in specific strength and modulus.

Table 2.1 Some natural fibers and their abundant origin **[56]**

Flax	**Borneo**
Hemp	Yugoslavia, china
Sun hemp	Nigeria, Sierra Leone, India
Jute	India, Egypt, Ghana, Malawi, Sudan
Kenaf	Iraq, Tanzania, Jamaica, South Africa, Cuba, Togo
Roselle	Borneo, Malaysia, sriylanka, Togo
Sisal	East Africa, Bahamas ,Tanzania, India
	Malaysia, Uganda, Philippines, Bolivia
Coir	India, lanka, Philippines, Malaysia

2.6.7 Manufacturing technique of composite material

Composite material manufacturing process is a goal-oriented process. The goal includes End use, production volume, size of product, economic targets, labor intensity, material involved, required skills, surface complexity and appearance, production rate, tools and required equipment are the factors that are considered while choosing a manufacturing process to produce composite with desired specification [57]For each type of application area it will done with different procedure. It depends on the availability of technology, facilities and personnel skills. It commonly produced in hand lay-up technique, press molding, injection molding and extrusion.

There are many fabrication techniques in manufacturing natural fiber reinforced thermoset composites. These are

- ✓ hand lay-up technique
- ✓ resin transfer molding (RTM)
- ✓ compression molding
- ✓ injection molding

Hand lay-up technique

Hand lay-up technique is the most widely used and simplest fabrication process for composite material. It is a process of placing the fibers in the mold manually and poring the resin followed by hand brush or rollers smearing. [41]

Four essential procedures in hand lay-up techniques

1. Mold preparation
2. Gel coating
3. Lay –up and
4. Curing

In otherwise, hand lay-up techniques are called wet lay-up techniques. However, in this technique high soluble resin is sprayed, poured or brushed in to mold then the reinforcement is wet with resin. After that, the wet reinforcement is placed in the mold, rolled or squeezed to distribute the resin and compact it, are followed respectively. However, additional fiber loading is not possible.

These hand lay-up techniques are suited for one offs or short production runs and used for large components such as mainly in the application of marine and aerospace structures.

easy to operate, low cost, versatile, efficient manufacturing method with no size limitations, and produces a high gloss finish on one surface are the listed advantages of hand lay-up techniques. On the other hand, the quality of the product is very much subjected to operator skill and only one finished surfaces are principal limitation of hand lay-up techniques. It is labor-intensive technique.

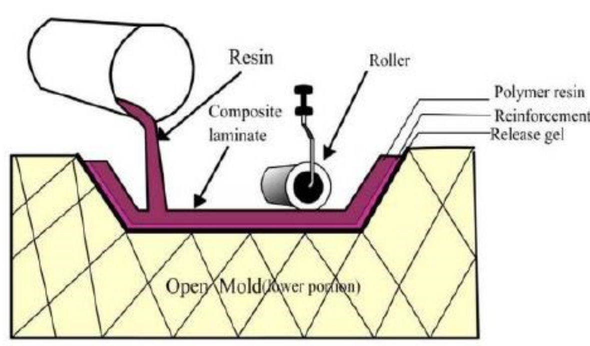


Figure 2. 3 hand lay-up method [4]

2.7 Advantages and Applications of Natural Fiber

The attraction of using natural fiber, such as distinctive wood fiber and plant fiber as plastics support has increased dramatically over the last few years. As regards the ecological point of view, it may be extremely intriguing if natural fibers could be used as a fortification rather than glass fibers in some structural provisions. Natural fibers have many points of interest as opposed to glass fibers, for example, of low thickness and are biodegradable and recyclable. They are also Renewable raw materials and generally have a high strength and rigidity [15]

2.8 Research gap

It was observed from literature reviewed many researchers were working on the fabrication of composite material for engineering application and determine the factor that affects some mechanical properties of composite materials. But, in this study attempts are made to develop hybrid composite materials from sisal-sheep wool fiber and unsaturated polyester resin to investigate the effect of fiber orientation, fiber weight ratio, and ply arrangement on mechanical properties like tensile, flexural, compression, hardness and impact strength and physical properties (water absorption and flammability) of sisal-sheep wool fiber reinforced composite material which is not done by other researchers.

CHAPTER – 3

3. Materials and Methods

3.1. Materials

This chapter deals with the different types of materials used in the preparation of composites. The composite manufacturing is also discussed. It also includes the different types of testing equipment needed to characterize the specimen. This chapter also discusses the methods used in the analysis of worn and destroyed specimens.

3.1.1 Matrix

The matrix phase is polymer in polymer matrix composites. The purpose of the polymer in PMCs is to convert the ductile property into a composite. Several functions are supported in the fiber reinforced composites matrix phase. The first function is that polymers bind the fibers together and act as a medium for stress transfer and distribution to the fibers. Second function, the matrix acts as shied around the fibers to protect against surface damage. This results in the improvement of mechanical properties and the protection of chemical reactions with the environment. Mainly polymers divided into two types:

I. Thermosetting polymers,

II. II. Thermoplastic polymers.

I. Thermosetting polymers

Thermosetting polymers are in a viscous state and during curing they alter the irreversibly insoluble polymer network. This process is usually called crosslinking. Thermoset polymers have a high dimensional accuracy. Because of the cross-linking, polymer molecules that are difficult to move/slide on each other's results make it strong and rigid. [58] [59]

General examples of thermoset polymers are epoxy, polyester, polyurethane, and silicone.

II. Thermoplastic polymers

Thermoplastic polymers are made to soften / melt on heating. These polymers are primarily suitable for the formation of liquid flow. Many thermoplastic polymers have a high molecular weight. Intermolecular force acting between polymer chains, which is rapidly weakened by temperature increases, produces a viscous liquid. Thermoplastics may be reformed by heating and are typically used to produce different parts by several polymer processing methods, such as injection molding, compression molding and extrusion. Examples of thermoplastic polymers include high- and low-density polyethylene, polystyrene and poly methyl methacrylate (PMMA). [58] [56]

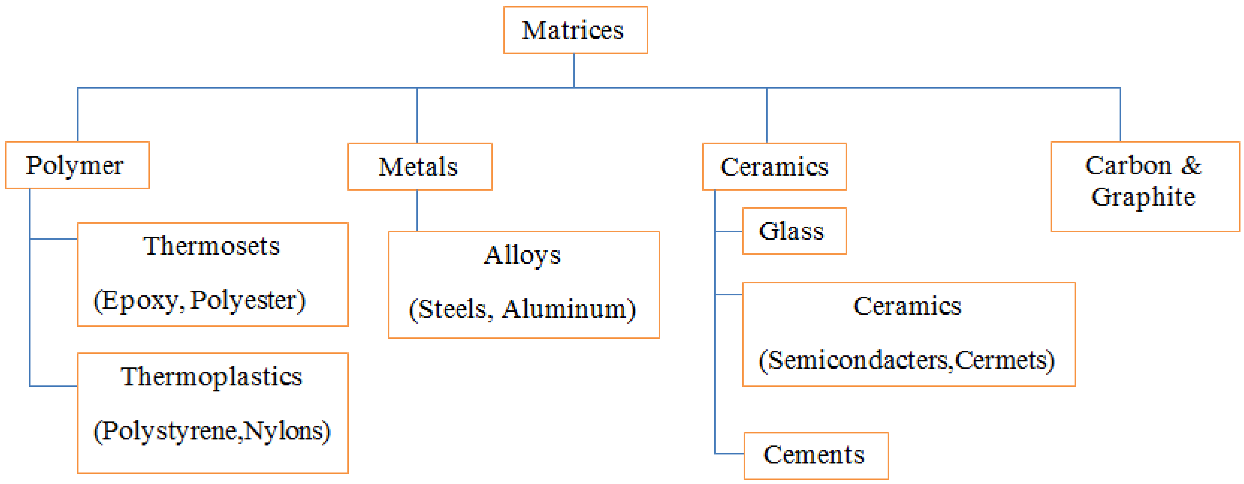


Figure 3. 1 Classification of matrices [64]

3.2 Preparation of raw materials

3.2.1 Reinforcement material preparation

Reinforcement materials are the dis-continues phase of composite material which is harder and load bearing element. Its main function is supporting the load and increasing the mechanical strength of the composite material. Sisal and Sheep wool fiber were used as reinforcement fiber during composite preparation.

3.2.2 Sisal Plant

Sisal or sisal hemp (Scientific name is Agave sisalana) is an agave. Agave sisalana of Agavaceae (Agave) that yields a stiff fiber used in making rope. Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East [15]a sketch of a sisal plant is shown in the figure 3.2 and sisal fibers are extracted from the leaves of this plant.

A good sisal plant has a 7-10 year life-span and typically produces or yields about 200-250 leaves with each leaf having a mass composition of 4% fiber, 0.75% cuticle, 8% other dry matter and 87.25% moisture (water). Thus a normal sisal plant leaf weighing about 600g yields about 3% by weight of fiber with each leaf containing about 1000 fibers [16]

The other important feature of sisal plant is that its cultivation process is very ease and also it can grow in all kinds of environment [17]

Figure 3. 2 Typical view of sisal fiber [65]

3.2.3 Extraction of Sisal fiber

Sisal fiber is extracted from the leaves by retting, scraping, or mechanical decortications. The sisal plant produces sword-like leaves with teeth and loses these teeth in maturity. Decortication is the most common method for extracting sisal fiber. In this process, the leaves are crushed between blunt knives and moisture and the fleshy pulp are removed from the fiber. Water is used to clean debris that is present in the leaves. The sisal fiber that is obtained is dried in the hot sun. The dried fibers will be spun and woven into a fabric with plain weave.

Figure 3. 3 (a) Picking the sisal plant (b) extraction process (c) the extracted fiber

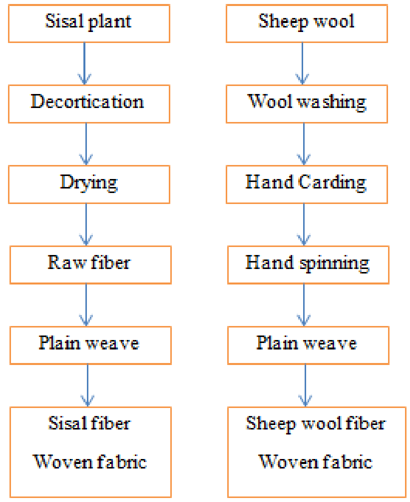


Figure 3. 4 Flow chart of processes in producing Sisal and sheep wool fibers woven fabric

3.2.4 Extraction of Sheep wool fiber

For sheep wool, the fiber was collected from Jimma area, Ethiopia. It was collected in the form of wool and yarn from Debrebrhan local market. Washing (scouring) of sheep wool fleece seeks to remove wool grease (lanolin), dirt, vegetation and chemicals from wool fleece. The proper washing is required to avoid felting the wool. Felting requires moisture, heat, and agitation of the wool. A good scour requires moisture, heat, and agitation as well, in the presence of a detergent. The clean, soft wool without felting can be obtained by concentrating on getting the temperature of the water right, using enough detergent, and limiting agitation. Some other things to be done to avoid felting are to never run water directly on the wool, and never vary the temperature of the wash and rinse baths. The clean wool fibers will be spun and woven into a fabric with plain weave (Fig.3.5, a). The flow chart of processes in producing sheep wool fibers woven fabric is shown in Fig.3.5, b

(a) (b)

Fig (a) washed sheep wool (b) Spinning of sheep wool

Figure 3. 5 Schematic representation of plain weave of fibers into fabric

3.2.5. Polyester resin

Commercially available unsaturated polyester resin is used for the investigation. Accelerator (Methyl Ethyl Ketone Peroxide) is used to cure the resin. Thermoset polyester resin is one of the economical resins due to its very low water absorbing capability and excellent bonding tendency as well as mechanical properties. [59]

3.3. Fiber and matrix mass fraction content of the composites

i. Fiber and matrix mass fraction ($\mathbf{M}_F$ $\mathbf{M}_M$)

Total mass of composite = mass of fiber + mass of matrix

$$M_C = M_f + M_m$$

Fiber mass fraction = $\frac{mass\ of\ fiber}{total\ mass}$ (3.1)

$$M_F = \frac{M_F}{M_f + M_m}$$

Matrix mass fraction = $\frac{mass\ of\ matrix}{total\ mass}$ (3.2)

$$M_M = \frac{M_M}{M_f + M_m}$$

$$\text{And; } M_F + M_M = 1$$

ii. Fiber and matrix volume fraction (V_F V_M)

Volume of fiber = $\frac{mass\ of\ fiber}{density\ of\ fiber}$ (3.3)

$$V_f = \frac{M_m}{\rho_m}$$

$$V_C = V_m + V_f$$

Fiber volume fraction = $\frac{Volume\ of\ fiber}{total\ volume}$ (3.4)

$$V_f = \frac{V_f}{V_{f+V_m}}$$

Matrix volume fraction = $\frac{Volume\ of\ matrix}{total\ volume}$ (3.5)

$$V_m = \frac{V_m}{V_{f+V_m}}$$

Let ρ_f and ρ_m density of fiber and density of matrix respectively. Then we have

$$V_F = \frac{M_{f} + \rho_m}{M_f \times \rho_m + M_m \times \rho_f} \quad (3.6)$$

Similarly;

$$V_M = \frac{M_{m} + \rho_f}{M_f \times \rho_m + M_m \times \rho_f} \quad (3.7)$$

i. Density of ply(ρ)

$$\rho = \frac{Total\ mass}{Total\ volume} = \frac{mass\ of\ fiber}{total\ volume} + \frac{mass\ of\ matrix}{total\ volume}$$

$$\rho = \frac{volume\ of\ the\ fiber}{total\ volume}(\rho_f) + \frac{volume\ of\ the\ matrix}{total\ volume}(\rho_m)$$

$$\rho = \rho_f \times V_F + \rho_m \times V_M \quad (3.8)$$

ii. Ply thickness, h

The thickness of plies is simply the number of grams of fibers (W_f) per unit area.

$$\text{Total volume} = h \times 1(m^2)$$

$$h = \frac{total\ volume}{1(m^2)}$$

$$h = \frac{M_f}{V_F \times \rho_f} \quad (3.9)$$

In terms of mass of fraction of fibers thickness expressed as

$$h = M_f \left[\frac{1}{\rho_f} + \frac{1}{\rho_m}\left(\frac{1 - M_f}{W_F}\right)\right] \quad (3.10)$$

Where:-

h- Lamina (ply) thickness (mm) ρ_f- Density of fiber (gm/cm^3)

ρ_m- Density of matrix (gm/cm^3) V_F – Fiber volume fraction

V_m – Volume of matrix (cm^3) M_M – Matrix mass fraction

M_F – Mass of fiber (gm) M_f – Mass of fiber (gm)

V_m – Matrix volume fraction V_f- Volume of fiber (cm^3)

M_m – Mass of matrix (gm) M_C – Mass of composite (gm)

3.4. Preparation of hybrid Composite

The Hybrid fiber composite materials were prepared by using hand lay-up technique. Hand layup method is the simplest processing step. It needs minimal infrastructure with easy procedure. It includes design of fiber orientation and casting of composite material. In hand lay-up molding techniques, the fiber were arranged in the mold by hand then pour the resin into the fiber and smear it throughout the mold. Unsaturated polyester resin (UPR) and hardener (MEKP) mixed in a ratio of 1:0.02 s and stirred thoroughly. Sisal and sheep wool fibres woven fabric weighed using a calibrated digital analytical balance based on their weight percentages in the hybrid for each experimental setup. Sisal fiber and sheep wool fiber woven fabric will be placed on the mold. The resin will then be poured into the mold and then spread gently to ensure uniform thickness of the resultant composite. After that it was compacted with lightweight press. [60]For the second layer of the reinforcement the fibers were placed on the resin surface then rolling a roller thoroughly, and pour and smear the resin then compress it. These processes were repeated for all plies of the reinforcement and resin until getting the desired thick composite. The compression process was done by using Ageo Screw press machine for 6 hours at room temperature. After that, open the mold and taken out the composite and placed outside to dry with room temperature for 24 hours. This process was appropriate for lower volume of production and difficult to high volume fraction of reinforcement. It is also easy to tailor the reinforcement with different orientation and to gate good surface finish. Generally, hand lay-up processes are more flexibility in composite design.

i. measure the weight of fibers and matrix as desired
ii. Stir the polyester as per company instruction carefully to avoid the formation of air bubbles.
iii. Putting releasing film on the mold surface and coated with plastic film
iv. Properly placing the designed fiber in the mold
v. Pour the resin and smear it gently on the fiber
vi. Again placing the designed fiber ply and pour polyester and smear it for HFC preparation as design requirement unless finish it here
vii. On the top of the last play cover with plastic film and do rolling

viii. Finally close the mold by designed plate with releasing agent then followed by light weight compression step

The thin plastic film was required to prevent the mold from air entry and to get good surface finish at end product. The lightweight compression step also performed with Ageo Screw press machine for 6 hours.

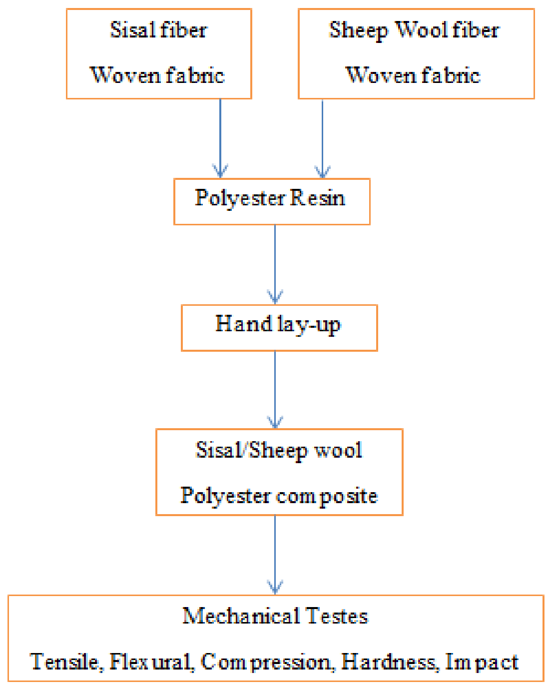


Figure 3. 6 Flow chart of Experimental methods

(a) (b) (c)

Figure 3. 7 (a) Polyester risen (b) Adding the hardener (c) Mixing the hardener with Risen

The experimental design for the amount of matrix material and the reinforcements used in the polymer composite are summarized in Table 3.2.

The fiber was tailored with different orientation. These are categorized in to Random and geometrical orientation. Random orientation includes random discontinuous (chopped) fibers. In random discontinuous orientation, it uses short randomly oriented (chopped) fibers. Whereas, in geometrical orientation include multidirectional orientation of fibers. In multi direction orientation woven orientation were used.

Multidirectional orientation

The fibers are arranged in many directions as desired either geometrically systematic or randomly oriented.

Geometrically systematic (bidirectional orientation)

In this orientation, the fibers were placed by consideration of geometrical axis. The fibers were oriented in two directions (warp 90 and weft 0) to form woven type structure. It uses the same ratio of fibers in both directions.

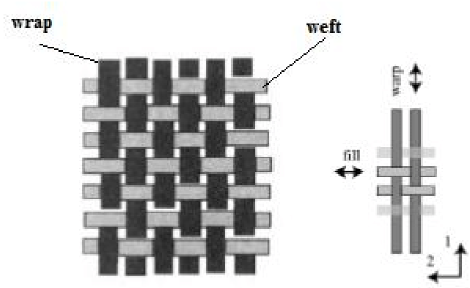


Figure 3. 8 Schematic representation of plain weave of fibers into fabric [32]

Random orientation

In random orientation, the fibers were arranged casually but with uniform distribution of fiber throughout the mold. Random discontinuous fibers were used.

Random discontinuous (chopped) fiber

Chopped fibers were used and placed thoroughly in the mold with uniform distribution. Then pour the resin carefully to avoid redundant assemblage of fibers due to flow pressure of poured resin. After that, followed with lightweight compression process.

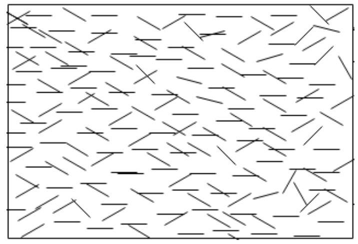


Figure 3. 9 Random discontinuous fiber orientations [32]

Layer or sandwich orientation

In this orientation use layer by layer of the above listed orientation as desired.

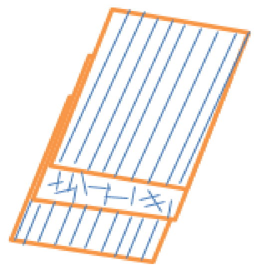


Figure 3. 10 Layer or sandwich orientation [32]

3.5 Hybrid fiber composite development

The required hybrid fiber composite material was manufactured with different type of fiber orientation, plies arrangement and constitutes composition as presented below in the table.

Table 3. 1 Designed HFCM

Orientation	*Arrangements (m/v) %*	*Composition*			*No. of Samples*
		SW (%)	S (%)	Poly	
Chopped	CSW	15	15	70ml	5
	CSW	10	10	80ml	5
	CSW	5	5	90ml	5
Continuous (Mat)	S	20	-	200ml	5
	W	-	20	200ml	5
	SW	10	10	200mi	5
	SWS	10	10	200ml	5
	WSW	10	10	200ml	5

3.6 Laboratory Test

After preparing the composite, the next step was spacemen preparation and followed by lab testing and recording.

3.6.1 Spacemen preparation

During composite preparation, the prepared composites were with a dimension of length 300 mm width 260 mm and thickness of 15 mm equal with mold dimension. It was cute by using electrical saw machine to standard specimen dimensions.

(a) (b) (c)

Figure 3. 11 a) Casted composite b) cutting of composite with electrical saw c) specimens

3.6.2. Specimen preparation for tensile test

The dimensions of the samples are according to the ASTM standard D-3039. For each designed composite, it was prepared five specimens with rectangular shape with a dimension of length 250 mm, width 20 mm and variable thickness. Sheet metal taps were attached at both end of specimen during griping in order to minimize the premature failure of the specimen.

The most commonly used specimen geometries such as the dog- bone specimen and straight-sided specimen with end tabs were prepared from flat samples. Square cut tabs were mounted on the specimens according to the specifications given by ISO 527. It used to minimize the complicated stress field in the gripping area that causes premature failure. That leads to underestimation of the ultimate tensile strength of the composites. [51]

The failure should be occurred inside the gauge section. Mostly the stress strain curves obtained not are used to determine the true ultimate tensile strength of the composite since failure occurred outside the gauge section in the tab region.

Figure 3. 12 Specimen prepared for tensile test

3.6.3. Specimen preparation for flexural test

Three point bending flexural test provides the modulus of elasticity in bending, and bending stress- strain response of the material. The specimens were prepared according to ASTM D 790. It have rectangular shape having a dimension of length 250mm, and width 20 mm. the span (center to center) distance for each specimen is 100mm.

Figure 3. 13 Specimen prepared for flexural test

From each designed composite material three rectangular specimen with a dimension of L=250mm, W=20mm, T=13mm were cut out by using electrical saw machines.

3.6.4. Specimen preparation for Impact test

The impact strength of the material or the material resistance to sudden load before fracture was determined by dividing the measured fracture energy with the specimen cross-sectional area.

Avery Denison pendulum Izod testing machine were used to determine the resistance of impact or sudden load of composite material. The specimens were prepared according to ISO 179: 1997 standards. Three un-notched specimens with a dimension of 55 mm length and 10 mm width were tested for each type of designed composite.

The tests was conducted at impact speed of 4m/s and incident energy of 15J and the span lengths of 20 mm and with 0.6Kg hammer weight.

Table 3. 2 ASTM Standards

S.No	Mechanical Test	ASTM Standard	Sample Dimension(mm)	Testing Facility
1	Tensile	ASTM D638 ISO 527-4	200×20×10	DUCE
2	Flexural	ASTM D790 ISO 178	200×20×10	DUCE
3	Compression	ASTM D3410	50×10×4	DUCE
4	Impact	ISO 179 ASTM D 6110	55×10×3	DUCE
5	Hardness	ASTM E10	30×30×5	JIT
6	Water Absorption	ASTM D570	40×10×10	JIT

Source: Materials testing standards for Additive Manufacturing of polymer materials, Aaron M. Forster, National Institute of standards and Technology 2015.

3.7. Testing and recording

3.7.1 Physical properties test

It covers length, diameter, density, water absorption etc. [41]

3.7.2 Length measurement

After washing and drying the fibers, 10 fibers were randomly chosen and their length measured with a meter. Then the average fiber length was reported.

The average length of Sisal fiber was 80 cm the shortest fiber 60 cm and the longest 105 cm. it shows a wide length distribution. The average length of wool fiber was 3 cm the shortest fiber 2cm and the longest 4.5cm.

3.8. Physical Test

3.8.1. Water absorption test

Water absorption test objective was to determine the capability of the fiber to absorb the water and measured with the weight gaining of the sample which is dipped in the water. Water absorption tests were carried out according to ASTM D570-81. [61]For water absorption test the procedure were first prepare three specimen with dimension of 40mm length * 20 mm width for each factor. From both Sisal and wool fiber the specimen was prepared. Then dip it in distilled water at room temperature. The dipping is done consequently with the interval of every 24 hr. At every 24 hours the specimen were removed and the wiped the surface moisture with hanky and measure the weight and dimension. Then again, dip it until the samples reached their saturation limit.

Table 3. 3 Water absorption test specimen and weight measurement apparatus

3.8.2 Flammability test.

The flammability test was carried according to ASTM D635 standard. The flammability test carried out to determine the rate at which a material will burn when placed near a flame**.** [62]

3.9. Mechanical test

During the development of new material, the main thing is recognizing its mechanical performance to withstand and tolerate stresses for the intended application.

Different types of Mechanical tests have been conducted in order to investigate mechanical performance of composite material. Such as tensile strength test, flexural strength test, and impact strength test. Most of these testing results are expressed in terms of stress strain correlation.

$$\text{Stress} = \frac{Force}{Area} \qquad \sigma = \frac{F}{A} \tag{3.11}$$

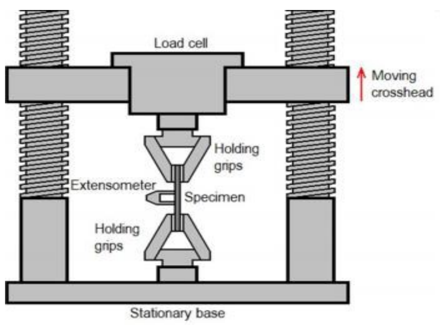
$$\text{Strain} = \frac{Deformation}{Orginal\ Area} \qquad \varepsilon = \frac{\Delta L}{l_o} \qquad \Delta L = l_f - l_o \tag{3.12}$$

3.9.1 Tensile test

Tensile test is conducted in order to investigate the tensile strength of the composite material. Material’s tensile strength is defined by measuring of the force that pulls a specimen to the point where it will break. The maximum tensile stress where before specimen failure or breaking is defines the tensile strength of the material.

Test procedures

Tensile test was performed based on ASTM D790 testing standard by using UTM with a load cell of 50KN and fixed crosshead of 5 mm/min. Before conducting the test, the end edge of specimen was tap with sheet metal, in order to prevent it from premature failure during gripping.



(a) (b)

Figure 3. 14 a) Tensile test diagram and b) Tensile test set up

Calculation

During tensile test, ultimate tensile strength and young's modulus are the main properties to be evaluated. The tensile strength of fiber reinforced composite material highly dependent on fiber concentration and orientation.

Ultimate tensile strength

$$\boldsymbol{\sigma_{ut}} = \frac{\boldsymbol{p_{max}}}{\boldsymbol{bh}} \tag{3.13}$$

Where $pmax$is the maximum load before failure, b is the specimen width and h is the specimen thickness.

Tensile modulus

$$\boldsymbol{E_t} = \frac{\Delta\boldsymbol{\sigma}}{\Delta\boldsymbol{\varepsilon}} \tag{3.14}$$

Where Et is the tensile modulus of elasticity, $\Delta\sigma$ is the difference in applied tensile stress between the two strain points and $\Delta\varepsilon$ is the difference between the two strain points within the elastic region.

3.9.2 Flexural test

Flexural test is conducted in order to investigate the flexural strength of the composite material. Flexural strength is expressed as modulus of rupture (MR) in psi (MPa) that defined by the measure of stress in a material just before it yields in bending test.

Test procedure

Flexural test of a material is performed using center point loading in three-point bend test. Based on ASTM D790 testing standard, flexural or three-point bend test ware carried out by using universal testing machine. Specimen with a dimension of 250mm*20mm*13mm hooked on the grip then apply the load with central grip that was fixed at center of the specimen. When, the specimen start bending the onboard computer generates the required data and graphs. The flexural test was conducted at strain rate of 2mm/min and span of 100mm was kept up. The detail of test setup and procedure are presented below in figure.

Natural fibers are high modulus material, so increase fiber concentration highly affects the material deformation. Therefore, flexural strength and flexural modulus depend on the fiber concentration and fiber- matrix adhesion.

Figure 3. 15 Flexural test set up

Calculation

Flexural stress

$$\sigma = \frac{3ps}{2bh^2} \tag{3.15}$$

Where σ is the normal stress on the outer surface of the specimen, p is the applied load and b is the specimen width h is the thickness of the specimen

Flexural modulus

$$E_{flex} = \frac{ms^3}{4bh^3} \quad (3.16)$$

Where m is the slope of the tangent of the initial load deflection curve

3.9.3 Compressive strength test

The compressive strength test was carried out based on the ASTM D3410 standard by using UTM. The test was conducted to investigate the compressive strength of the developed composite material. It tells us the load-carrying capability of the material. The samples were placed between the compression anvils to start compression testing. It was conducted with a crosshead speed of 5 mm/min and carried out at room temperature. A typical specimen under the compressive strength test is shown in Figure 3.16.

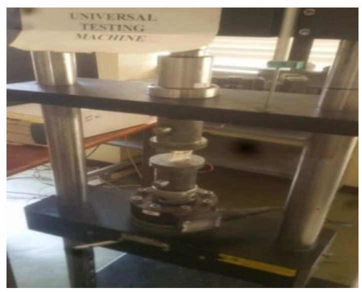


Figure 3. 16 specimens under compressive test

3.9.4 Impact test

Impact test is used to measure the materials capability to resist the fracture under high speed stress or impact load. It is related to the materials toughness under high strain rate deformation.

The test was carried as per ASTM D 256 using a Izod manual impact tester. The specimen with MMM and C, with S, W, SW, SWS,WSW,SW-10, SW-20 and SW-30 hybrid reinforced composite materials were used to investigate the impact strength of the material. The initial energy of the impactor was 7.5J at the initial height and released at 2.9 m/s speed. Thee specimen with 55 *10 *3 mm, with a V-notch 2mm deep at 45° on one side at the center were prepared at each sample.

$$Impact\ strength = \frac{E}{A} \qquad E = j_0 - j_1 \quad (3.17)$$

Where

j_0 = initial energy at the initial height

J_1= Resultant energy

A= area of the specimen

3.9.5 Hardness test

Hardness test is used to evaluate a material properties, such us strength, ductility and wear resistance therefore it helps to determine whether a material is suitable for the purpose of required. The test was carried as per ASTM E10 using a Brinell hardness tester. The specimen with 30*30*5 mm with indenter size 1mm.

Figure 3. 17 Brinell hardness tester

CHAPTER 4

4. RESULT AND DISCUSSION

In this section, the result of the experiment and its analytical analysis of data are presented. The result of the model also compared with the related literature review result and inspected with real world area of applications.

The first thing during developing new material is investigating its physical and mechanical properties with experiment. Both physical and mechanical investigation has been conducted. Physical properties like length, shape, density, diameter water absorption, and burning test. Whereas investigating mechanical properties include mechanical strength (flexural, tensile, impact).

4.1 Physical characterization

a) Length of the fibers

The average length of Sisal fiber was 80 cm the shortest fiber 60 cm and the longest 105 cm. it shows a wide length distribution. The average length of wool fiber was 3 cm the shortest fiber 2cm and the longest 4.5cm.

b) Diameter of the fibers

The diameter of sisal fiber is around $121.6 - 411.0\ \mu$m and the smallest wool fiber diameter is 24.9 μm and the biggest sheep wool fiber is 32.5 μm. The average diameter of sheep wool fiber is 28.99 μm [63]

c) Density of the fibers

The density of the sheep wool fiber is 1.3 kg/m^3 and the sisal fiber has a density of 1.45 g/cm^3. [64]

d) Water absorption of the composite

The HFCM with highest mechanical strength were demonstrated in water absorption test. In this test Chopped SW-10, SW-20, SW-30 fiber volume ratio and Mat type SW, SWS, WSW with 20% fiber volume ratio HFCM were inspected. In addition to that individual fibers composite i.e. S and W fiber composite are investigated for four 24 hours. The result Percent of water absorption were used to analyses the capacity of HFCM that absorb water.

The result shows that Mat type SWS, HFCM absorbed more water at the 24 hour than the other with 13.33 %. The cause was in this composite material the Sisal fibers are more concentrated. Due to the amorphous nature of Sisal, it is highly moisture absorbent than plant based fibers.

In addition to that individual fibers composite the result shows that Mat type sisal fiber is more moisture absorbent than the other with 20%.

$$\%W = \frac{w_f - w_i}{w_f} \times 100 \quad \textbf{(4.1)}$$

Where:

w_f:-Weight after time‘t’

$\%W$:- Percentage of water absorption

w_i:-Weight dry samples before test

Table 4. 1 Water absorption test result

Sample Type	Ordination	Initial Weight	Final Weight	Moisture Absorption (%)
Chopped	S	3.3	3.5	6.06
	W	2	2	0
	SW-10	4	4.2	4.7
	SW-20	5.5	5.7	2.9
	SW-30	6.5	7.5	13.3
Mat	S	2	2.5	20
	W	2	2	0
	SW	5	5.5	9.09
	SWS	7.5	8	6.25
	WSW	7.5	7.58	1.05

e) Burning test.

The performance of burning of the composite at various fiber layers was observed according to ASTM D 635-76 standard. The results of duration of burning are given in Table 4.2.

The following observations were made during the burning:

- ✓ The composite burnt with an orange flame producing a black soot with a chocking polyester smell
- ✓ The composite did not easily catch fire as it took 6-10 s but burnt easily after catching fire.
- ✓ The remains were black in color with hard black particles as shown in Fig. 4.1

Wood partitions are disposed to fire hazards. They quickly catch fire and burn freely leaving white ashes. With the composite, it is slow at catching fire and the burning characteristics shows that it takes longer for the fire to spread.

Table 4. 2 Results of the burning test.

Sample	Chopped					Mat				
	S	W	SW-10	SW-20	SW-30	S	W	SW	SWS	WSW
Duration (min)	3.28	3.26	3.36	5.31	5.02	4.14	2.49	5.30	4.32	7.28
Speed (mm/Min)	1.92	2.16	3.15	3.0	3.06	2.14	1.10	2.58	1.37	4.39

Figure 4. 1Remains of the samples after the burning test.

4.2 Mechanical characterization of the developed composites

Tensile strength, flexural strength and impact strengths are significant to recommend the suitability of any composite material for structural application.

4.2.1 Tensile test results of HFCM

Tensile test result of the prepared HFCM is presented below with tabulated form and with graph interpretation.

Ply arrangement, orientation, fiber volume ratio are factors considered during HFCM specimen. Ply arrangement is lying of respective lamina in the sandwich model of HFCM. These arrangements are grouped in two levels these are Sisal–Wool- Sisal (SWS) and Wool-Sisal-Wool (WSW). In fiber orientation the orientation of fibers in the lamina, which are Chopped, Mat fiber orientations are considered. These orientations were grouped in to five levels. These are for the copped one CS, CW, CSW A, CSW B, and SW D Also for the mat MS, MW, MSW, MSWS and MWSW. M stands for Mat or Woven fiber orientation, C stands for Chopped fiber orientation. Whereas, A, B, and D are used for fiber volume ratio designation. A designated for 30 % of fiber in the composite, B designated for 20 % of fiber and D designated for 10% of fiber in the composite the remaining were matrix.

From these, for each designed HFCM three specimen were prepared. The mean value of the results are presented and used for further analysis.

a) Effect of fiber arrangement on tensile strength of HFCM

Tensile strength of the material is expressed in terms of tensile modulus and ultimate tensile strength obtained from tensile test. Tensile modulus is an indication of the relative stiffness of a material and obtained from stress strain diagram.

The result of the measured tensile strength of HFCM is presented below with respect to its ply arrangement.

The tensile test is done as per universal machine which was shown in Fig 4.3, the load applied for such case was 50KN, and the specimen size was 250mm, 20mm width, 13mm thickness.

Table 4. 3 Tensile test experimental result of HFCM with respect to parameters

No	Volume (m/v)%	Ply arrangement	Tensile strength MPa	Force @ peak N	Younges modules MPa
1	10/90	CW	7.33	220	46.18
2	10/90	CS	27.33	820.27	191.9
3	10/90	CSW	41.62	1180	216.6
4	20/80	CSW	50.22	1420	242.5
5	30/70	CSW	38.54	1080	180.56
6	20	MS	6	180.03	37.80
7	20	MW	4.46	133.86	20.09
8	20	MSW	13.77	413.28	86.75
9	20	MSWS	20.16	605.07	127.01
10	20	MWSW	16.07	2618.05	101.24

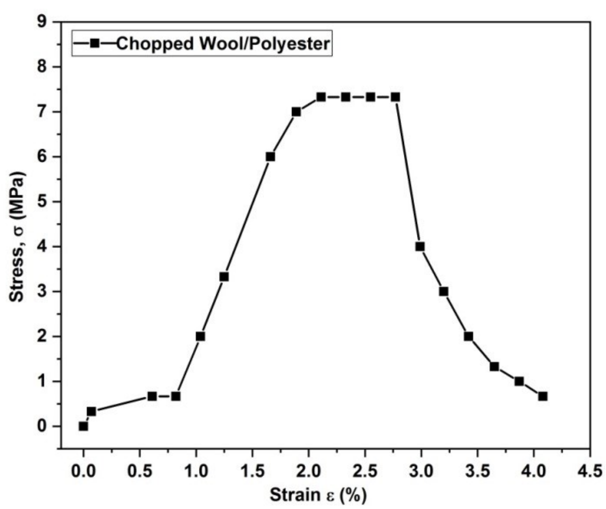


Figure 4. 2 Stress-strain curve for sample Chopped Wool

Figure 4.2, Shows that tension test result of Chopped Wool fiber polyester composite stress versus strain curve of test the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (7.33MPa) of the specimen, which means failure will happen beyond this limit.

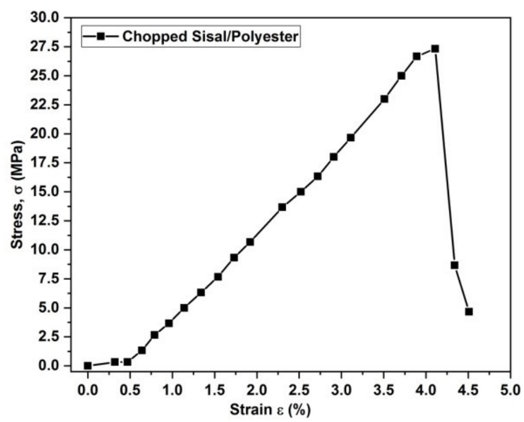


Figure 4. 3 Stress-strain curve for sample Chopped Sisal

Figure 4.3, Shows that tension test result of Chopped Sisal fiber polyester composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (27.33MPa) of the specimen then failure will happen beyond this limit.

The above data implies that the ultimate tensile strength (UTS) for the developed fiber composite is affected by the arrangement in the composite.

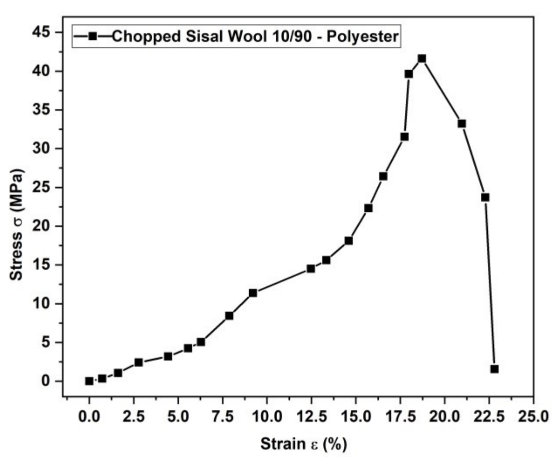


Figure 4. 4 Stress-strain curve for sample Chopped Sisal- Wool 10/90

Figure 4.4, Shows that tension test result of Chopped Sisal Wool 10/90 fiber polyester composite stress versus strain curve of test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (41.62MPa) of the specimen.

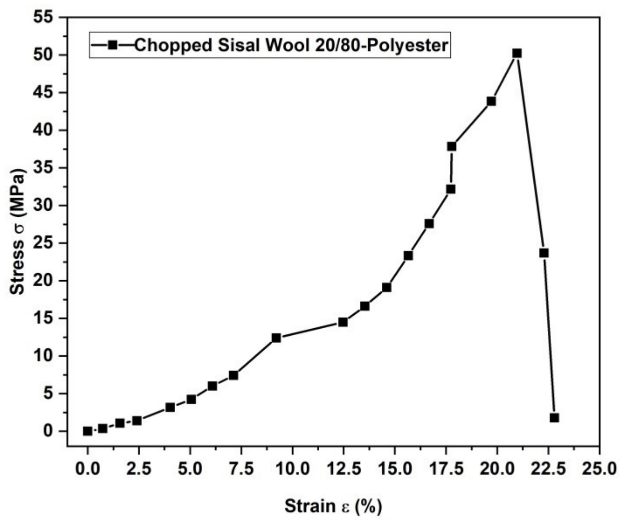


Figure 4. 5 Stress-strain curve for sample Chopped Sisal Wool 20/80

Figure 4.5, Shows that tension test result of Chopped Sisal Wool 20/80 fiber polyester composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (50.22 MPa) of the specimen then failure will happen beyond this limit. The fiber with Chopped Sisal arrangement shows preferable tensile strength.

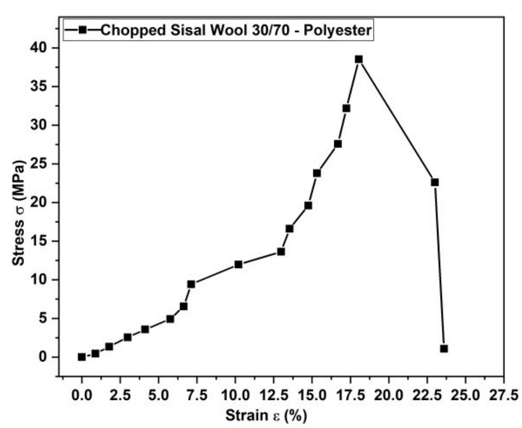


Figure 4. 6 Stress-strain curve for sample 30/70 percent ratio

Figure 4.6, Shows that tension test result of Chopped Sisal Wool fiber polyester composite stress versus strain curve of test, the curve shows as stress and strain is directly proportional until the ultimate stress limit is obtained (38.54 MPa)of the specimen then the specimen will failed to withstand the stress acting on the specimen.

The above data implies that the ultimate tensile strength (UTS) for the developed HFCM is affected by the ply arrangement in the sandwich model of the composite. HFCM with Chopped Sisal Wool 20/80 (CSW 20/80) ply arrangement shows preferable tensile strength. Since in this arrangement Chopped Sisal and Wool fiber were used with volume ratio of 20/80. Concentrating mixture volume ratio of fiber and matrix in the composite gives better strength than concentrating Sisal sheep wool fiber type in HFCM.

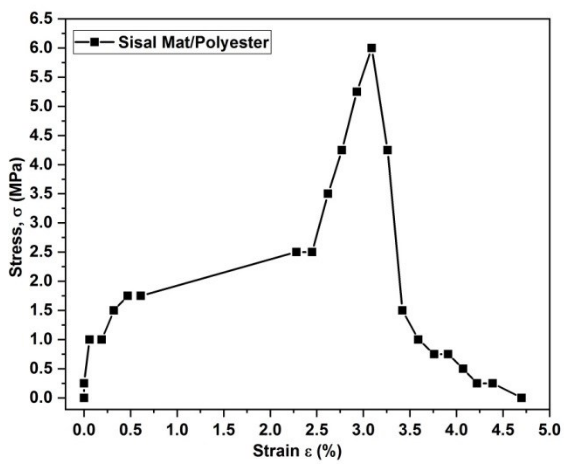


Figure 4. 7 Stress-strain curve for sample Mat Sisal

Figure 4.7, Shows that tension test result of Mat Sisal fiber polyester composite stress versus strain curve of test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (6 MPa) of the specimen.

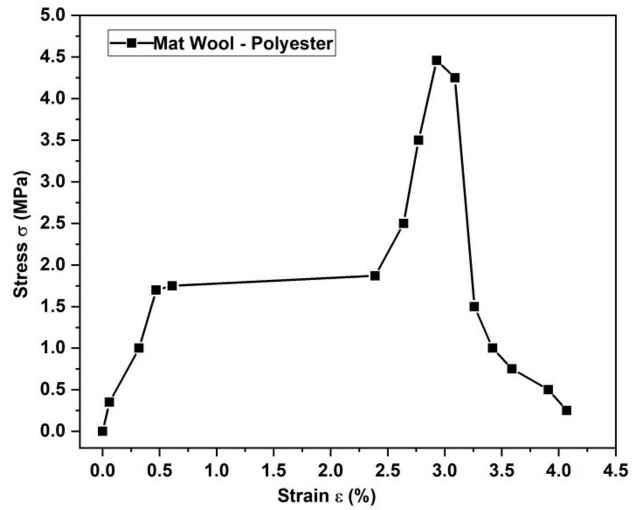


Figure 4. 8 Stress-strain curve for sample Mat Wool

Figure 4.8, Shows that tension test result of Mat Wool fiber polyester composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (4.46 MPa) of the specimen then failure will happen beyond this limit.

The above data implies that the ultimate tensile strength (UTS) for the developed fiber composite is affected by the arrangement in the composite.

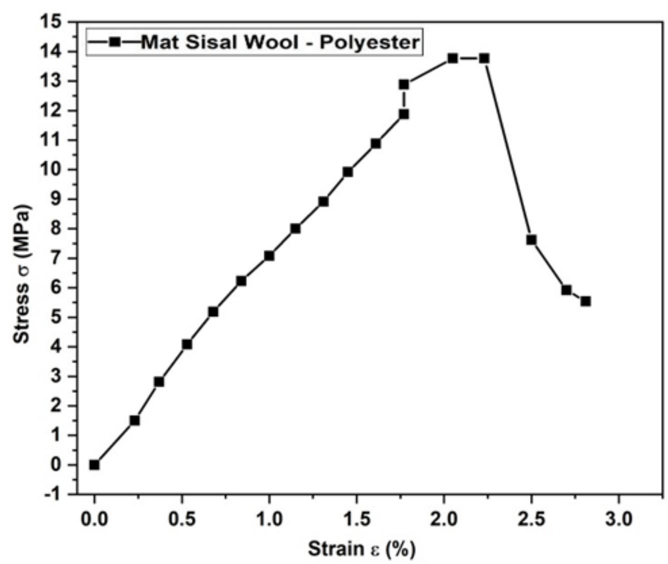


Figure 4. 9 Stress-strain curve for sample Mat Sisal Wool HFCM

Figure 4.9, Shows that tension test result of Mat Sisal Wool fiber polyester composite stress versus strain curve of test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (13.77 MPa) of the specimen.

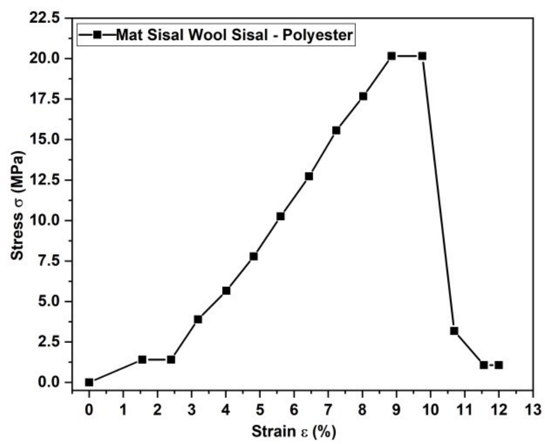


Figure 4. 10 Stress-strain curve for sample Mat Sisal-Wool-Sisal HFCM

Figure 4.10, Shows that tension test result of Mat Sisal Wool Sisal fiber polyester composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (20.16 MPa) of the specimen then failure will happen beyond this limit.

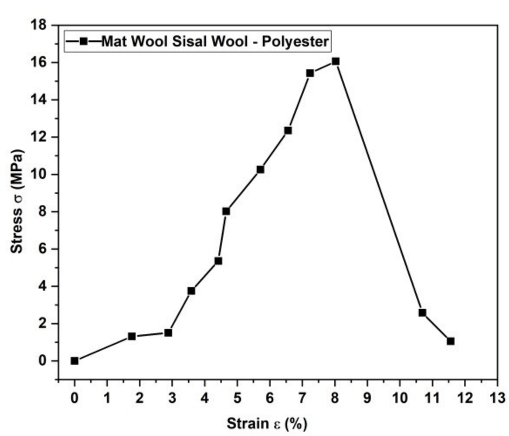


Figure 4. 11 Stress-strain curve for sample Mat Wool-Sisal-Wool HFCM

Figure 4.11, Shows that tension test result of Mat Wool Sisal Wool fiber polyester composite stress versus strain curve of test, the curve shows as stress and strain is directly proportional until the ultimate stress limit is obtained (16.07 MPa) of the specimen then the specimen will failed to withstand the stress acting on the specimen.

The above data implies that the ultimate tensile strength (UTS) for the developed HFCM is affected by the ply arrangement in the sandwich model of the composite. HFCM with Sisal-Wool-Sisal (SWS) ply arrangement shows preferable tensile strength. Since in this ply arrangement more Sisal fiber lamina were used than wool fibers lamina. Concentrating Sisal fiber in the composite gives better strength than concentrating sheep wool in HFCM.

For the Chopped one, Fiber matrix volumetric ratio in the composite also had their own impact on the tensile strength of the composite. When the fiber ratio increased from 10% to 20%, it shows the tensile strength of the Chopped fiber also increases. Whereas, in increasing from 20% to 30 % fiber volume ratio the tensile strength was not superior as expected rather fiber was pullout instead of bearing the load was shown during failure. Since in this concentration of fiber, the matrix cannot impregnate completely the fibers or there was a formation of Fiber Bridge in the composite. It indicates there is the poor interface contact between fibers. This follows a weak load transfer and under estimated strength of the composite. Therefore, in order to get optimum tensile strength of the composite the fiber to matrix ratio should be proportional.

The SWS ply arrangement of the Mat composite and 20% fiber volume ratio of Chopped SW composite had superior tensile strength than the other with a tensile strength of 20.16 MPa and 50.22 MPa with modulus of elasticity of 127.01 and 242.5 MPa respectively. This result provides there is excellent adhesion between the reinforcement and the matrix and within the plies.

b) Tensile Test Comparison of mono fiber and hybrid fiber Composite with polyester

Investigating tensile strength of Mono and hybrid fiber type with keeping its fiber volume fraction constant and with similar woven fiber and Chopped fiber orientation. For the woven one Wool fiber observed to have a tensile strength and tensile modules of about 4.46 N/mm2 and 20.09 N/mm2 and Sisal fiber observed to have a tensile strength and tensile modules of about 6 N/mm2 and 37.8 N/mm2. Sisal-Wool-Sisal fiber composite shows a better tensile strength and observed to have a tensile strength and tensile modulus of about 20.16 N/mm2 and 127.01 N/mm2 respectively. This is because of the reason that the Hybrid fiber composite improved mechanical properties than the mono fiber composite. For the Chopped one hybrid fiber composite shows better tensile strength. Mono fiber composite observed to have a tensile strength and tensile modulus of about 27.33 N/mm2 and 658.39 N/mm2 respectively whereas the hybrid one shows about 50.22 N/mm2 and 3299.9N/mm2 respectively.

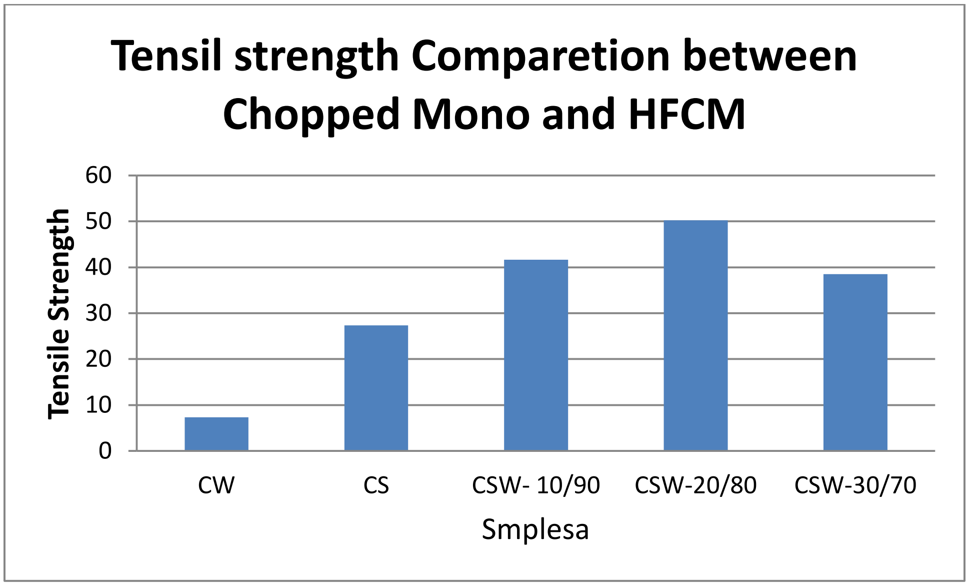


Figure 4. 12 Tensile Strength Comparison between Chopped HFCM

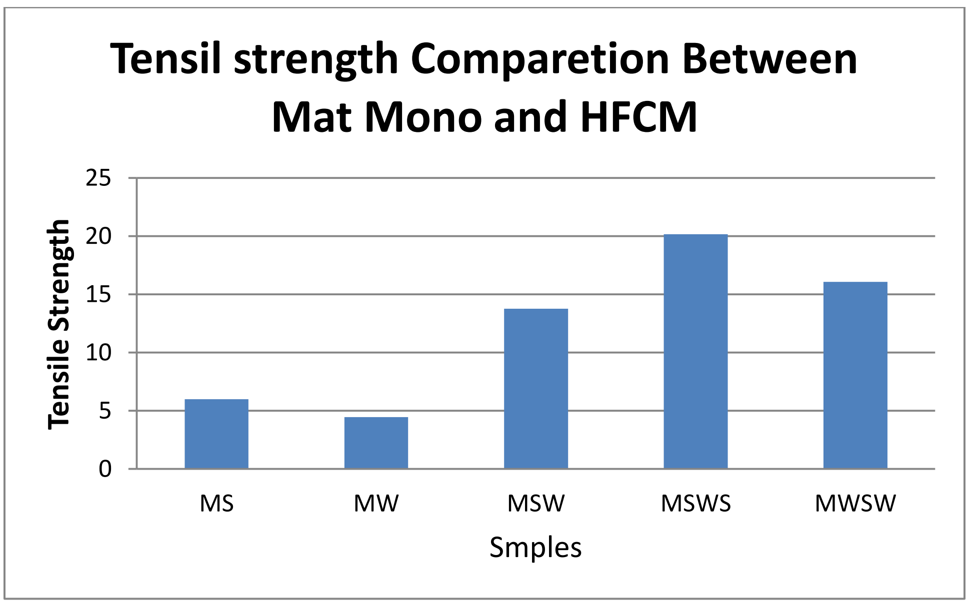


Figure 4. 13 Tensile Strength Comparison between Mat HFCM

4.2.2 Flexural or three-point bending test result of HFCM

For this test, three specimens were taken for each designed HFCM sample test but the mean values of the test result were presented as below. The samples were grouped according to play arrangement and fiber volume ratio.

Table 4. 4 Three-point bending test result

No	**Volume (w/v) %**	**Ply arrangement**	**Flexural strength (MPa)**	**Force @ peak N**
1	10/90	CW	9.99	90
2	10/90	CS	21.08	190
3	10/90	CSW	12.2	110
4	20/80	CSW	62.5	80
5	30/70	CSW	41.67	62
6	20	MS	22.19	200
7	20	MW	20.83	10
8	20	MSW	44.63	70
9	20	MSWS	62.5	30
10	20	MWSW	35.5	160

Flexural test or three-point bend test from table 4.4 shows that for each measured parameters the required load to bend the specimen were changing for every change of parameters. This indicates the factors for example fiber orientation, ply arrangement and fiber volumetric ratio are the main factor to be considered in flexural strength of designed HFCM.

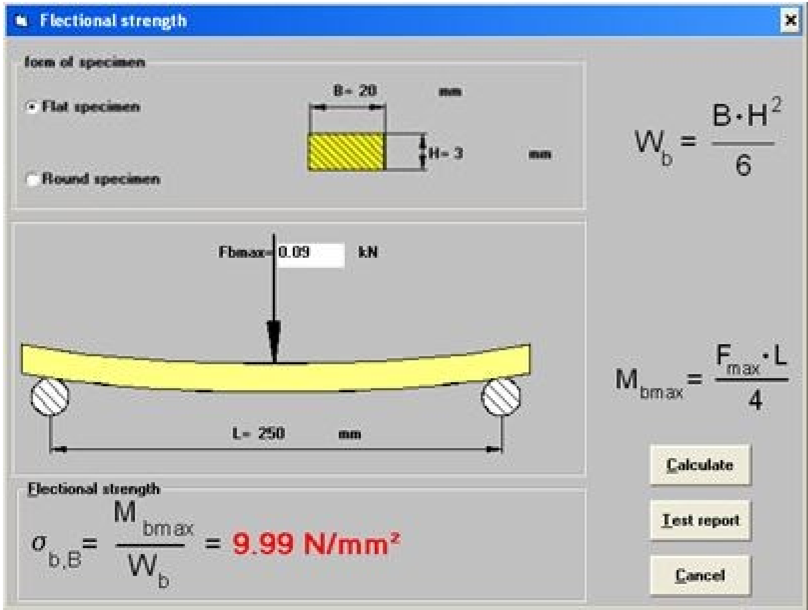


Figure 4. 14 Bending strength of Chopped wool

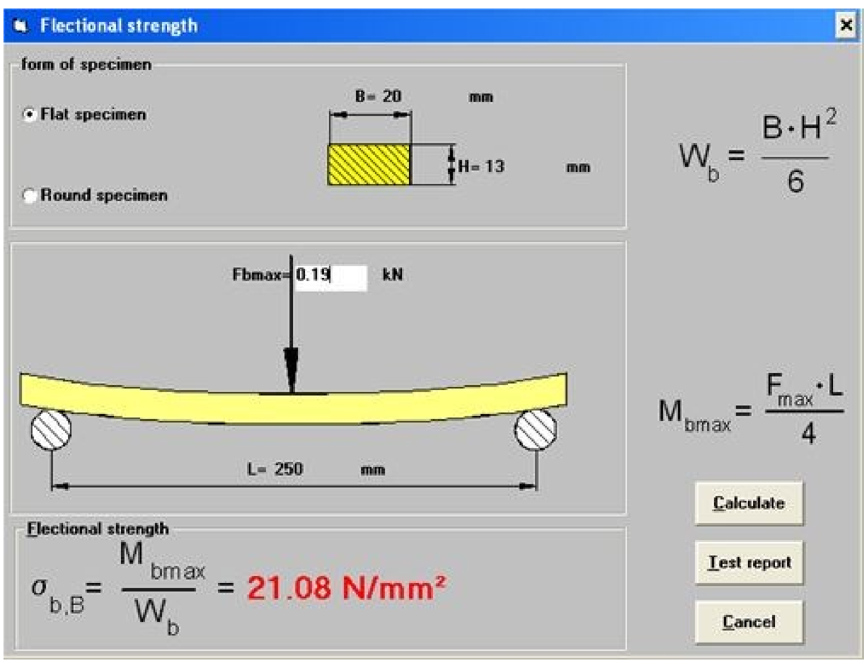


Figure 4. 15 Bending strength of Chopped Sisal

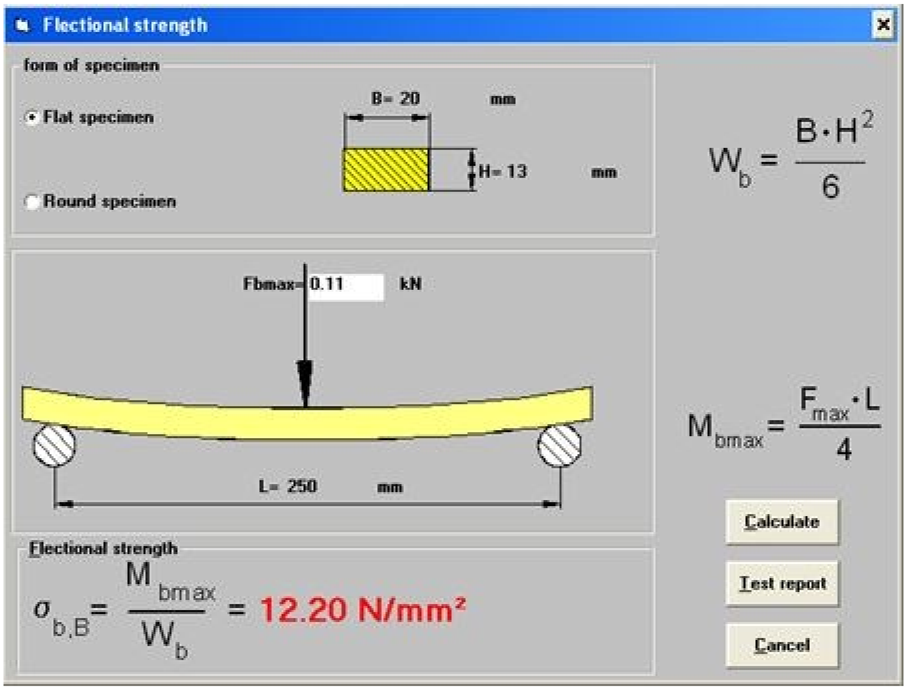


Figure 4. 16 Bending strength of Chopped Sisal Wool 10/90

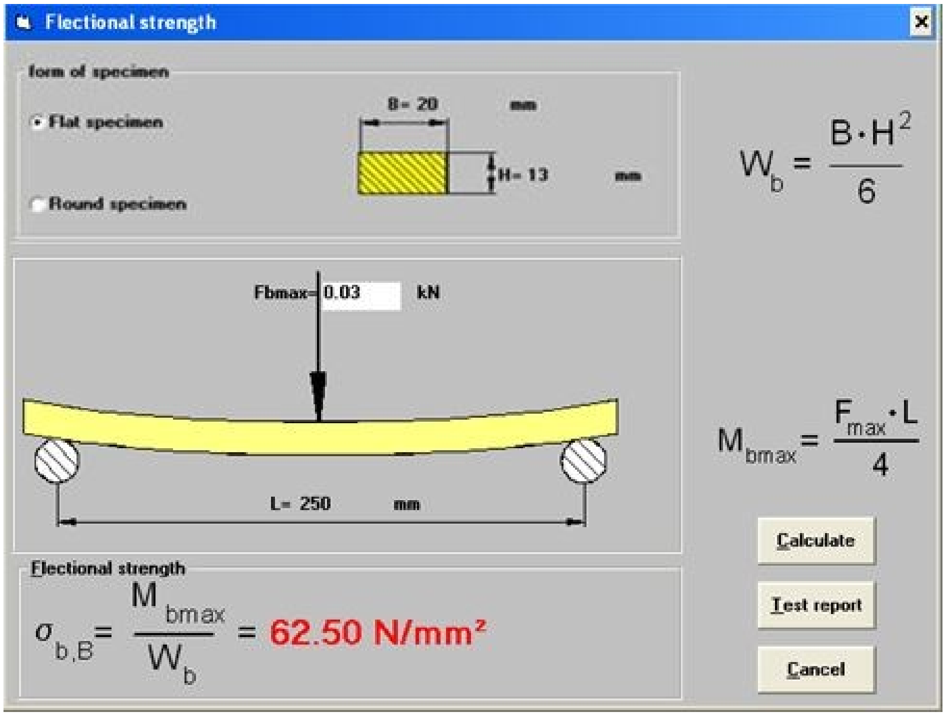


Figure 4. 17 Bending strength of Chopped Sisal Wool 20/90

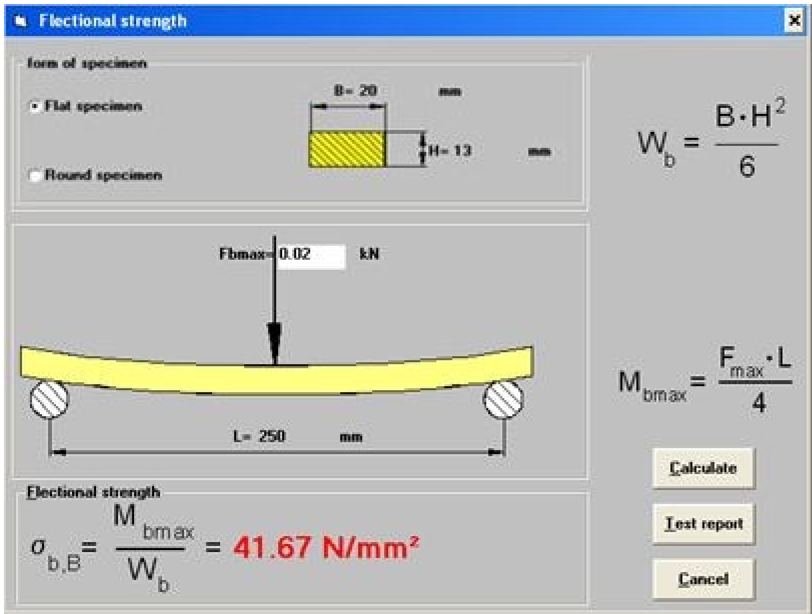


Figure 4. 18 Bending strength of Chopped Sisal Wool 30/90

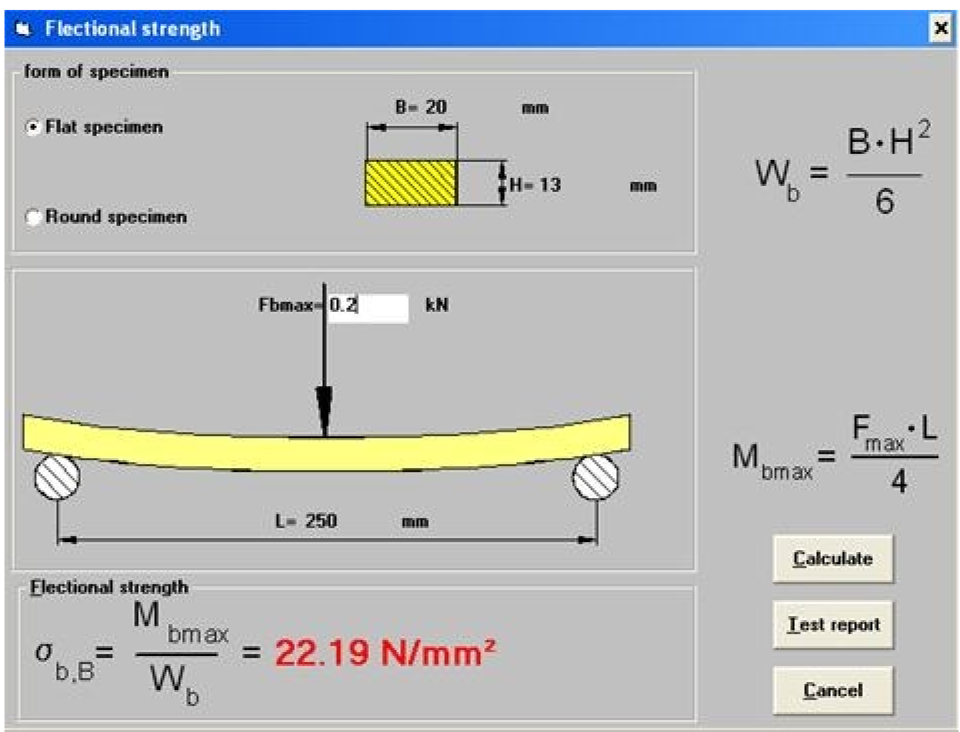


Figure 4. 19 Bending strength of Mat Sisal

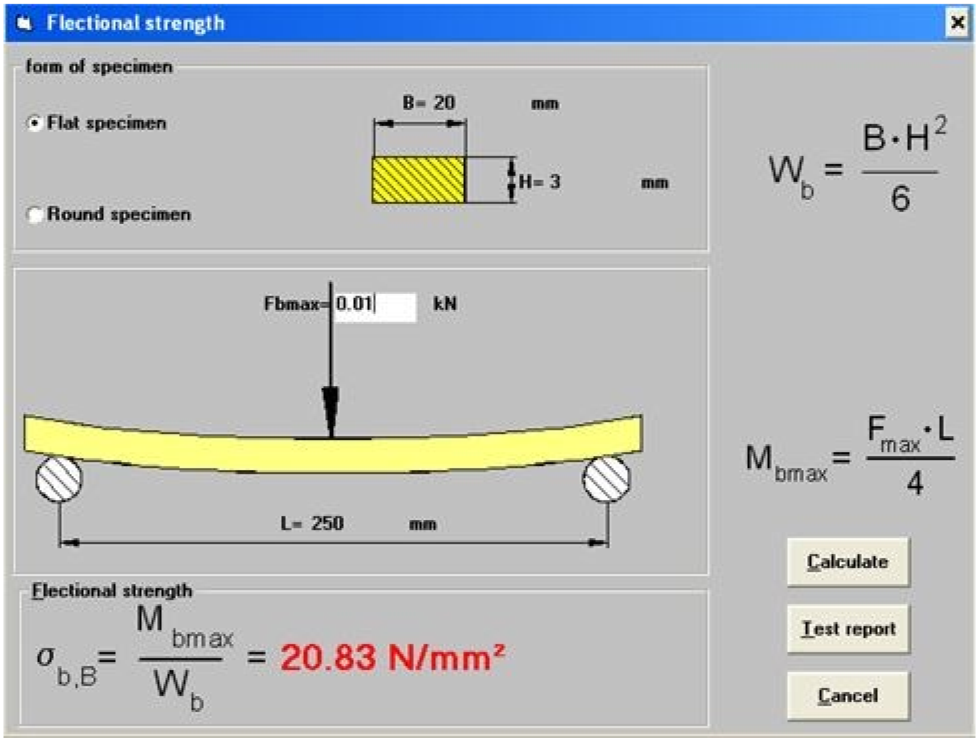


Figure 4. 20 Bending strength of Mat Wool

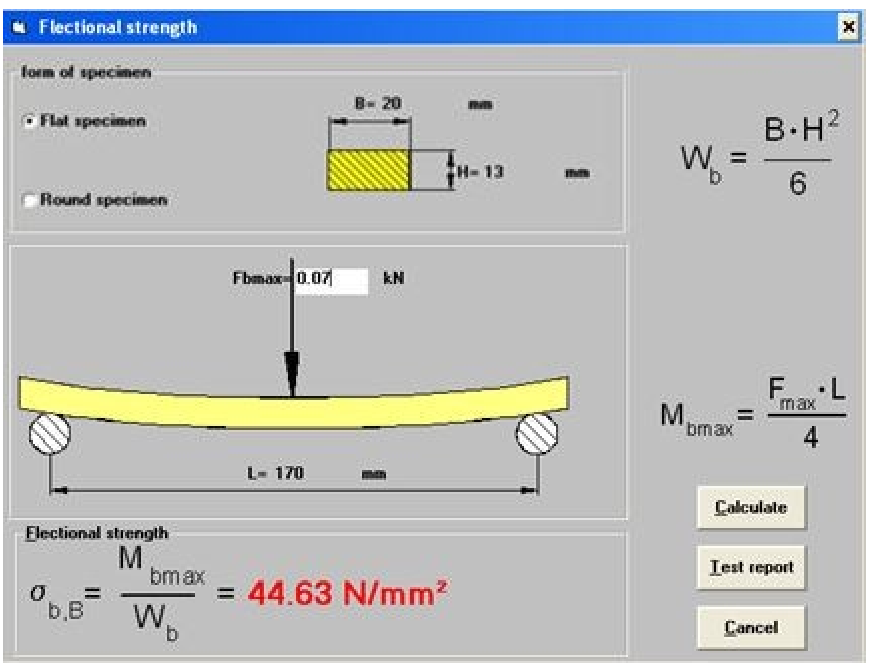


Figure 4. 21 Bending strength of Mat Sisal Wool

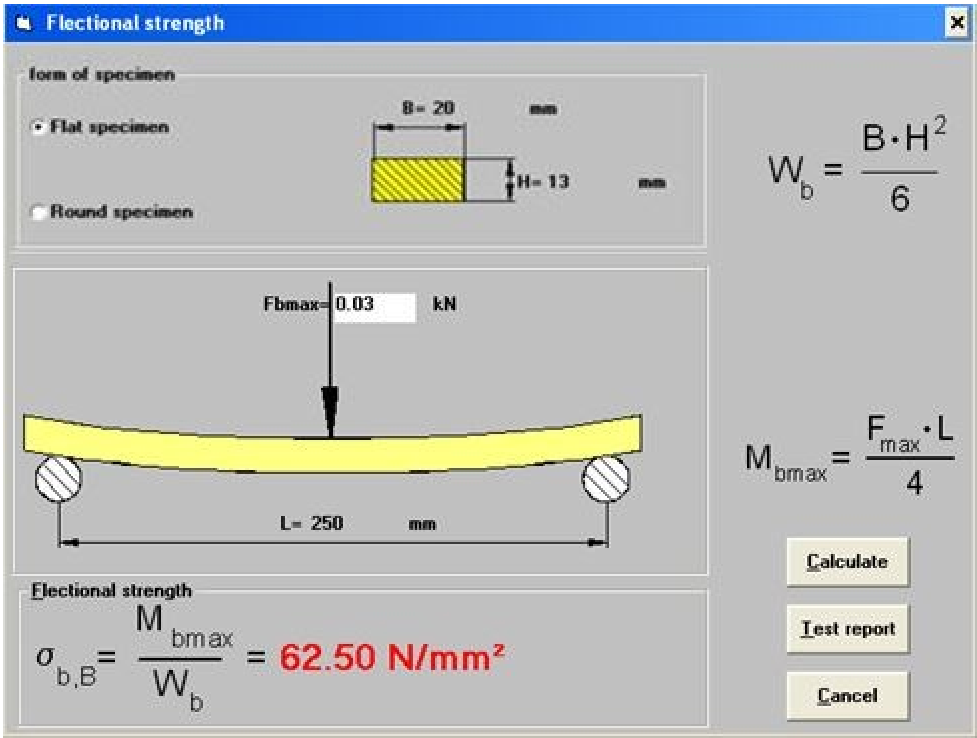


Figure 4. 22 Bending strength of Mat Sisal Wool Sisal

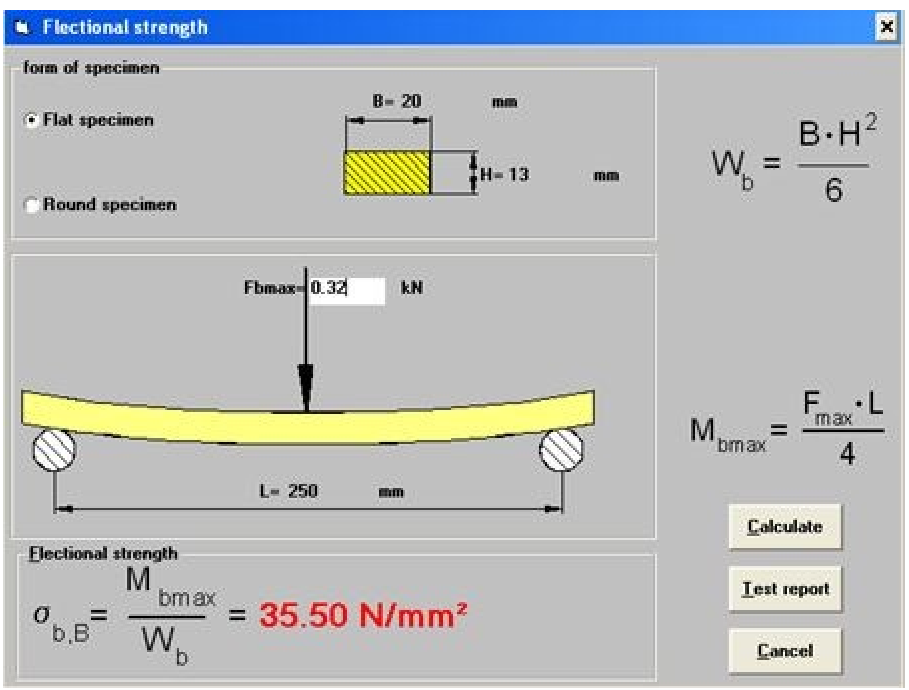


Figure 4. 23 Bending strength of Mat Wool Sisal Wool

This implies, from these design parameters, HFCM with ply arrangement, fiber volumetric ratio and fiber orientation [MMM] and C required maximum force during deforming in three-point bend test. For the Mat type, since in this SWS ply arrangement more Sisal fibers with mat or fabric orientation were used and fiber volumetric ratios the matrixes to fiber interaction were strong that means the fiber and the ply were fully soaked in the matrix.

For the Chopped type, since in this CSW-20/80 ply arrangement fiber volumetric ratios the matrixes to fiber interaction were strong that means the fiber and the ply were fully soaked in the matrix.

In those woven or Mat SWS ply arrangement and chopped CSW-20/80 ply arrangement fiber orientation the bending force were maximum. Since, this inter woven orientation of fiber protect the composite from quick crack propagation or failure during flexural loading than others ply arrangements.

The possible reasons will be (1), there is strong ply-to-ply interaction due to adequately impregnation of the lamina in the matrix and the fiber also strongly bonded with each other in these orientations. (2), for woven or mat one, the waviness of these fibers in the lamina significantly increases the load transfer capability properties of the lamina in the HFCM.

4.2.2.1. Flexural Test Comparison of S and W with polyester

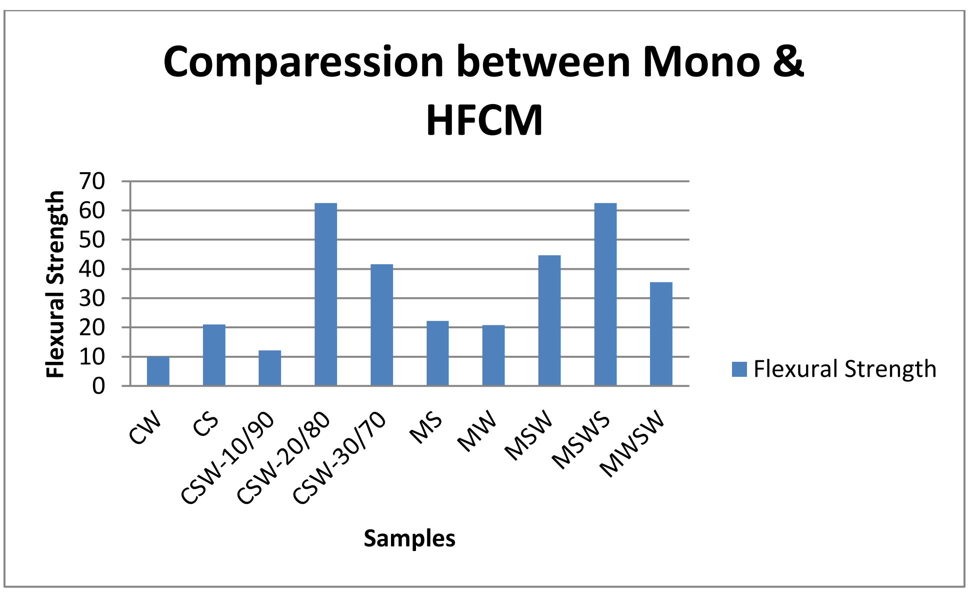


Figure 4. 24 Flexural Test Comparison of S and W with polyester

b) Flexural Test Comparison of mono fiber and hybrid fiber Composite with polyester

Investigating Flexural strength of mono and hybrid fiber type with keeping its fiber volume fraction constant and with similar woven fiber and Chopped fiber orientation. For the woven one Sisal-Wool-sisal fiber shows better tensile strength and observed to have a flexural strength of about 62.5 N/mm2. This is because of the reason that for, the waviness of these fibers in the lamina significantly increases the load transfer capability properties of the lamina in the HFCM. For the Chopped one, the hybrid fiber composite shows better flexural strength. Mono fiber composite observed to have a flexural strength of about 21.08 N/mm2 whereas the hybrid one shows about 62.5 N/mm2.

4.2.3 Compression strength test result

The compressive strength of prepared composite materials for different fiber weight ratio, fiber orientations, and ply arrangements is presented in Table 4.5. The test was carried out in a UTM.

Table 4. 5 Compression test experimental result of HFCM with respect to parameters

No	Volume (m/v)%	Ply arrangement	Compression strength MPa	Force @ peak N
1	10/90	CW	2.52	194.31
2	10/90	CS	9.39	724.06
3	10/90	CSW	14.31	1103.45
4	20/80	CSW	17.27	1331.7
5	30/70	CSW	13.25	1021.71
6	20	MS	2.06	158.84
7	20	MW	1.53	117.97
8	20	MSW	4.73	364.7
9	20	MSWS	6.93	534.37
10	20	MWSW	5.53	426.42

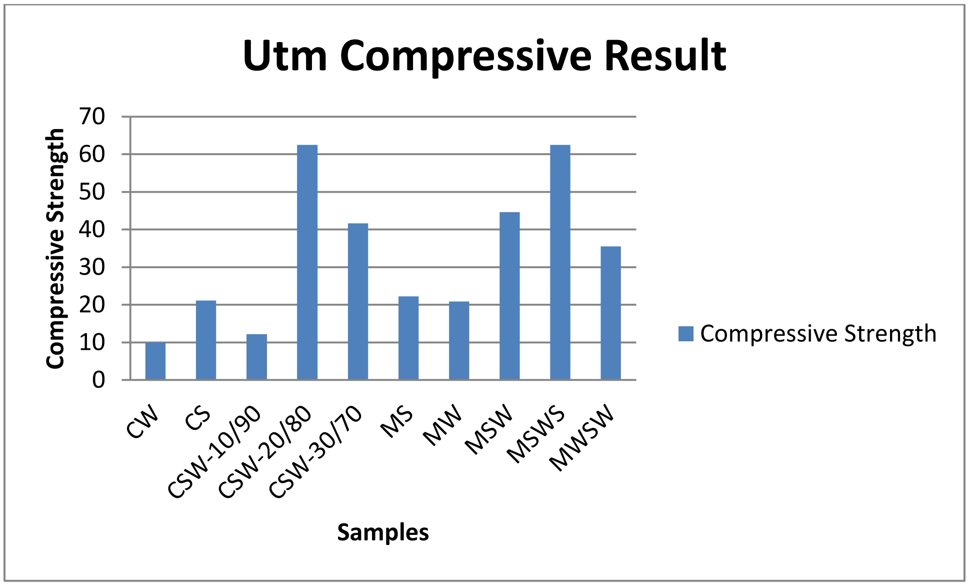


Figure 4. 25 Compressive strength of different laminates

The difference in compressive strength for various ply arrangement is shown in Figure 4.25. It is observed that the Chopped fiber orientation with Chopped Sisal Wool 20/80 (CSW-20/90) ply arrangement and 20% fiber weight ratio composite material shows the highest compressive strength as compared to other composite materials.

It is observed that the lowest values of compressive strength are recorded on MMM fiber orientation of composite with Mat sisal-Wool (MSW) ply arrangement and 20% fiber weight fraction composite material than other composite materials.

This implies that the stiffness of composite material is higher when there is a well mix between the reinforcement and matrix. Also it implies that in compressive the stress is acting on the matrix whereas the role of reinforcement is negligible. Therefore, the well Mix between the reinforcement and the matrix in the composite can improve the compressive strength of the material.

4.2.3 Impact test result of HFCM

Impact test is used to measure the materials capability to resist the fracture under high speed stress or impact load. It is connected to the materials toughness under high strain rate deformation. The initial energy of the impactor was 7.5J at the initial height and released at 2.9 m/s speed to strike the specimen. The result has been presented in table and graph.

Table 4. 6 Impact test result

No	Ply arrangement	Degree	Impact strength (J)
1	CW	140	4.5
2	CS	145	4
3	CSW 10/90	148	6
4	CSW 20/80	126	9
5	CSW 30/70	138	5
6	MS	140	4.5
7	MW	145	3
8	MSW	131	7
9	MSWS	78	29
10	MWSW	128	8.5

Ply arrangement of the HFCM can have a great effect on impact strength of the specimen. SWS ply arrangement has preferred impact strength than chopped one and other arrangement. The maximum impact strength of 29 J is obtained in case of MMM fiber orientation with SWS ply arrangement.

Generally, impact strength suggests about material toughness under high strain rate deformation. It is all about a measure of the materials energy absorption during failure. Form experimental investigation, the impact strength of the developed HFCM improved with respect to ply arrangement and fiber orientation. In Mat wool (MW) ply arrangement HFCM the crack propagates more easily and with less energy than SWS. In MMM the stress distribution is not only in transverse direction but also on longitudinal direction. Due to that the crack growth and propagations in the specimen are less.

4.2.3.1 Comparison of Impact test

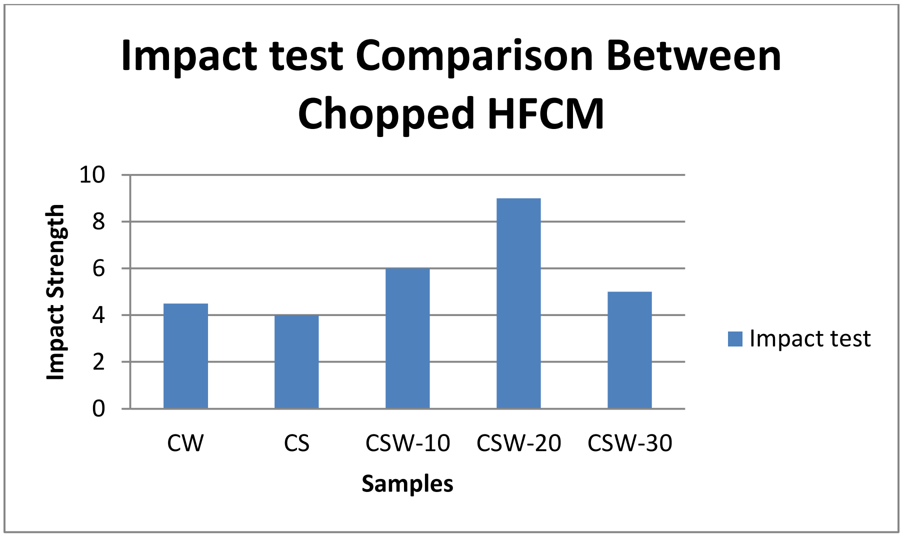


Figure 4. 26 Impact test Comparison between Chopped HFCM

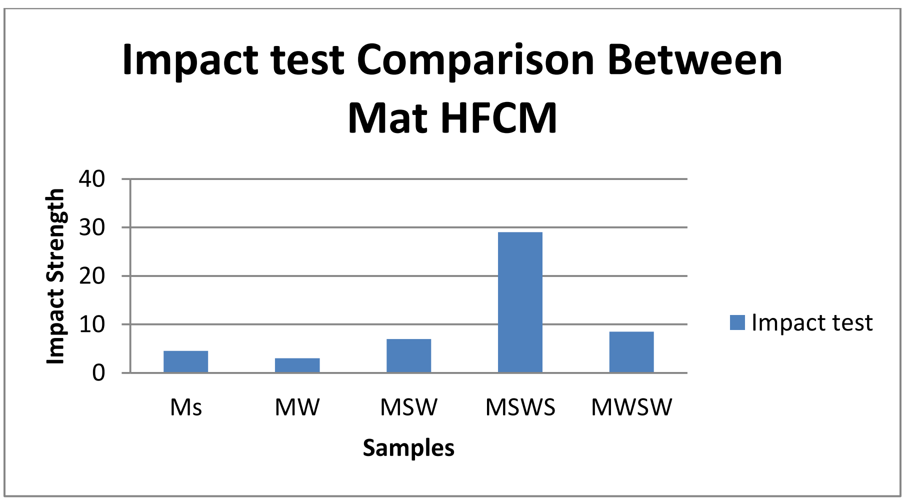


Figure 4. 27 Impact test Comparison between Mat HFCM

4.2.4 Hardness test result of HFCM

Hardness test is used to evaluate a material properties, such us strength, ductility and wear resistance therefore it helps to determine whether a material is suitable for the purpose of required. The test was carried as per ASTM E10 using a Brinell hardness tester. The specimen with 30*30*5 mm with indenter size 1mm. The result has been presented in table.

Table 4. 7 Hardness test result

No	Ply arrangement	Hardness(HB)
1	CW	2.42
2	CS	7.92
3	CSW 10/90	12.06
4	CSW 20/80	14.55
5	CSW 30/70	11.17
6	MS	1.73
7	MW	1.29
8	MSW	3.99
9	MSWS	5.84
10	MWSW	4.65

Ply arrangement of the HFCM can have a great effect on hardness of the specimen. In the case of Mat orientation SWS ply arrangement has preferred hardness strength whereas in the chopped one CSW-20 arrangement preferred hardness strength. The maximum hardness strength of 14.55 HB is obtained in case of C fiber orientation with CSW-20 ply arrangement.

Generally, Hardness test is used to evaluate a material properties, such us strength, ductility and wear resistance therefore it helps to determine whether a material is suitable for the purpose of required. Form experimental investigation, the hardness of the developed HFCM improved with respect to ply arrangement and fiber orientation.

4.3 Comparison with previous works

Table 4. 8 Comparison with previous works

Author	Title	Test Type	Result	Reference	Current work
Madhukiran.J Dr.T.Venkateswara Rao,Dr.S.Madhusudan Dr.R.Umamaheswara Rao	Evaluation of the mechanical properties on sisal coir Hybrid Natural Fiber Composite	Tensile	17.92 MPa	[65]	Tensile Test Result 50.22 MPa
		Flexural	62.66 MPa		
G.Dharmalingam,V.K umar A.Senlolerayan	Mechanical Behavior of treated and untreated sisal kenaf Hybrid composite material	Tensile	24.17 MPa	[66]	
		Flexural	39.88 MPa		
		Impact	7 J		
Kumaresan.M,Sathish and Karthi.N	Effect of fiber orientation on mechanical properties of sisal fiber reinforced epoxy composites	Tensile	16.74 MPa	[67]	Flexural Test Result 62.5 MPa
		Impact	3.65 J		
J.manivannam, S.Rajesh, K.Mayandi MTH sultan	Tensile and Hardness properties of wool fiber Reinforced Polyester composite	Tensile	9.5 MPa	[68]	
J.Tusnim, N.S.Jenifar, M.Hasan	Properties of Jute and sheep wool fiber reinforced Hybrid polypropylene composite	Tensile	27.6 MPa	[20]	Impact Test Result 29 J
		Flexural	42.3 MPa		
		Impact	0.57		
S.Goncalves, P.Vieira, J.L.Esteves	Mechanical Characterization of wool fiber for reinforcing of composite Materials	Tensile	34.93	[69]	

As shown on table the current study is compared with some of the other previous researcher's studies. From Table 4.8 the tensile strength obtained from the current work is higher when compared to [69] work, and the current work clearly shows that hybrid composite fibers with natural fibers and fiber orientation have a significant effect on the tensile strength of materials. It can be concluded that the results obtained from the current work are good.

A flexural strength of the current work is compared with some of the other researcher's work. From Table 4.8 the flexural strength obtained from the current work is equal with compared to [65] work, and the current work clearly shows that a hybrid composite fiber with natural fibers and fiber orientation has an effect on the flexural properties of materials. It can be concluded that the flexural strength results obtained from the current study are acceptable.

Impact strength of the current work is compared with some of the other researcher's work. From Table 4.8 the Impact strength obtained from the current work is greater than compared to [66] work, and the current work clearly shows that a hybrid composite fiber with natural fibers and fiber orientation has an effect on the impact properties of materials. It can be concluded that the flexural strength results obtained from the current study are batter.

4.4 Automotive door internal panel

The design of the vehicle body has evolved from a simple, all-steel structure that meets the basic requirement of strength and functionality, to the current day complex and efficient structure. Deep drawing steel sheets with good formability were developed in the 1950s, followed by the development of anti-corrosive steel sheets in the 1960s. In the 1970s and 1980s, low fuel consumption was a strong issue because of the oil crisis. High-strength steel sheets were developed in response to this issue and have contributed to lightning vehicles by reducing sheet thickness. In the 1990s, safety and environmental issues became primary concerns in the automotive industry, and further work was done on developing technologies for weight reduction. Aluminum alloy sheets were developed in this connection and applied to various body panels such as the engine hood, and have contributed to achieving lighter vehicles [70]

According to [70] automobile body panels consist of a double structure with an outer panel and an inner panel. For the outer panels, higher strength materials are especially required to provide sufficient damaging resistance. For the inner panels, higher deep drawing capacity materials are especially required to allow the manufacture of more complex shapes.

Lightweight composite materials, such as natural fiber-reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness, and energy absorption, combined with weight reduction, and low oil consumption [71]

From all the results and comparisons, the current study gives the confidence to utilize fabricated composite material in automotive door internal panel body parts application which does not need a very high mechanical performance also it uses for structural application such as panel, tables, Partition, boards, tables and chairs, but need lightweight.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

HFCM are successfully fabricated by using hand lay-up manufacturing technique with Sisal and wool fiber as reinforcement and polyester (Methyl Ethyl Ketone Peroxide) as binding material.

Fiber volume ratio (10%, 20% and 30%), ply arrangement (CW, CS, CSW-10, CSW-20, CSW-30, MS, MW, MSW, MSWS, MWSW) and fiber orientation (MMM, C) are the design parameters with respective level to develop the HFCM.

Different fiber volume ratio was used, in chopped one increasing fiber volume ratio from 10 - 20 % results increasing the strength of the composite. Whereas, increasing its volume above 20 % shows the strength of the composite decline. Since, excess fibers in composite materials create less wettability of fiber that means there is poor interfacial strength of fiber and matrix. This affects the stress transferring between fibers during tensile and flexural loading.

Mechanical strength of the HFCM is influenced by several factors. Fiber orientation, fiber volume ratio and ply arrangement are the considered parameters in this research.

From (MMM, C) fiber orientation MMM shows better flexural strength and Chopped shows better tensile strength than the other. The possible reason is for MMM fiber orientation the stress is transferred to both longitudinal and transverse fibers.

From SW, SWS and WSW ply arrangement, SWS ply arrangement has better flexural and tensile strength. Since the mechanical strength of Sisal fiber is better than wool fiber therefore, concentrating Sisal fiber will result better strength than concentrating wool in HFCM.

Fiber orientation, ply arrangement and fiber volume ratio are significant parameters that affect the mechanical performance of the developed HFCM.

5.2 Recommendation for future work

From the conclusions of this research the following recommendation are made for further studies in the future.

- In this work, hand lay-up manufacturing technique was used to develop HFCM. By using other manufacturing process, it will be analyzed.
- Categorization of fibers furthermore is complete by different manufacture methods.
- The physical, chemical, crystalline, and thermal stability analyses were not discussed.
- Testing like fatigue test, shear test, moisture content test and thermal test.

REFERENCE

[1] A. Ticoalu, T. Aravinthan & F. Cardona, "A review of current development in natural fiber composites for structural and infrastructure applications," *Southern Region Engineering Conference,* pp. 1-5., 2010.

[2] K. Srinivas, A. Lakshumu Naidu and M. V. A. Raju Bahubalendruni, "A Review on Chemical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites," *International Journal of Performability Engineering,* pp. 189-200, 2017.

[3] Furqan Ahmad, Heung Soap Choi, Myung Kyun Park, "A Review: Natural Fiber Composites Selection in View of Mechanical, Light Weight, and Economic Properties," *Macromol. Mater. Eng,* p. 10–24, 2015.

[4] Dr. Navdeep Malhotra, Khalid Sheikh and Dr. Sona Rani, "A review on mechanical characterization of natural fiber reinforced polymer composites," *Journal of Engineering Research and Studies,* pp. 75-80, 2012.

[5] A. Lakshumu Naidu and P. S. V. Ramana rao, "A review on chemical behaviour of natural fiber composites," *Int. J. Chem. Sci,* no. 4, pp. 2223-2238, 2016.

[6] TP Sathishkumar, P Navaneethakrishnan, S Shankar, R Rajasekar and N Rajini, "Characterization of natural fiber and composites," *A review, Journal of Reinforced Plastics and Composites,* vol. 32, no. 19, p. 1457–1476, 2013.

[7] Michael A. Fuqua, Shanshan Huo, and Chad A. Ulven, "Natural Fiber Reinforced Composites," *Polymer Reviews,* vol. 52, p. 259–320, 2012.

[8] Kamrun N. Keya, Nasrin A. Kona, Farjana A. Koly, Kazi Madina Maraz, Md. Naimul Islam, Ruhul A. Khan,, "Review - Natural fiber reinforced polymer composites: history, types, advantages and applications," *Mater Eng Res,* vol. 1, no. 2, pp. 69-85, 2019.

[9] Fatin I. Mahir, Kamrun N. Keya, Bijoyee Sarker, Khandakar M. Nahiun, Ruhul A. Khan, "Review - A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites," *Mater Eng Res,* vol. 1, no. 2, pp. 86-97, 2019.

[10] Paulo Pecas, Hugo Carvalho, Hafiz Salman and Marco Leite, "Natural Fibre Composites and Their Applications," *A Review, J. Compos. Sci,* vol. 2, p. 66, 2018.

[11] Mohammad Affan Usmani, Mohd. Anas, "Study of Natural Fibre Reinforced Composites," *IOP Conf. Series: Materials Science and Engineering,* vol. 1, no. 404, pp. 12-48, 2018.

[12] Maya Jacob John, Rajesh D. Anandjiwala, "Recent Developments in Chemical Modification and Characterization of Natural Fiber-Reinforced Composites," *Polymer Composites,* pp. 187-207, 2008.

[13] T.P. Sathishkumar, P. Navaneethakrishnan, S. Shankar, "Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites," *Composites Science and Technology,* no. 72, p. 1183–1190, 2012.

[14] Duppala Ajay Kumar, Ch. Bharath Kumar, "Processing and mechanical behaviour of human hair fiber reinforced polymer composites,," *International Journal of Mechanical and Production, Engineering Research and Development,* vol. 8, no. 5, pp. 107-116, 2018.

[15] "Novel composites utilizing raw wool and polyester resin," *Journal of materials science letters,* vol. 16, pp. 1417-1419, 1997.

[16] Kuruvilla Joseph, Sabu Thomas, and C. Pavithran, "Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites," *Polymer,* vol. 37, no. 23, pp. 5139-5149, 1996.

[17] Puneet Gondal, Abhishek Verma, Yogesh Iyer Murthy, Uddeshya Mishra, "Experimental Study of Sisal and Jute Fiber Based Biocomposite," *International Journal of Interdisciplinary Research and Innovations,* vol. 6, no. 4, pp. 398-404, 2018.

[18] Silas M. Mbeche, Paul M. Wambua, and David N. Githinji, "Mechanical Properties of Sisal/Cattail Hybrid-Reinforced Polyester Composites," *Advances in Materials Science and Engineering,,* pp. 1-9, 2020.

[19] Franciszek Pawlak, Miguel Aldas, Francisco Parres, Juan López-Martínez and Marina Patricia Arrieta, "Silane-Functionalized Sheep Wool Fibers from Dairy Industry Waste for the Development of Plasticized PLA Composites with Maleinized Linseed Oil for Injection-Molded Parts," *Polymers,* vol. 12, p. 2523, 2020.

[20] J. Tusnim, N.S. Jenifar and M. Hasan, "Properties of Jute and Sheep Wool Fiber Reinforced Hybrid Polypropylene Composites," *IOP Conf. Series: Materials Science and Engineering,* no. 438, p. 12029, 2018.

[21] Flávio de Andrade Silva, Nikhilesh Chawla, and Romildo Dias Toledo Filho, "Mechanical

behavior of Natural sisal fibers," June 2010..

[22] Franciszek Pawlak, Miguel Aldas, Francisco Parres, Juan López-Martínez and Marina, "Silane-Functionalized Sheep Wool Fibers from Dairy IndustryWaste for the Development of Plasticized PLA Composites with Maleinized Linseed Oil for Injection-Molded Parts," October 2020.

[23] Puneet Gondal, Abhishek Verma, Yogesh Iyer Murthy, Uddeshya Mishra, "Experimental," December 2018.

[24] K. L. Pickering, m. G. A. Efendy, and t. M. Le,, "composites : part a a review of recent developments in natural fibre composites and their mechanical performance," vol. 83, p. 98–112, 2016.

[25] H. B. kahla, "Models for bending stiffness in laminates with intralaminar and interlaminar damage," 2014.

[26] H.Khang, "Biodegradable natural fiber composites : Fabrication and characterization of hemp fiber with pla powder composites," 2016.

[27] M. N. Yahya, D. Daniel, V. S. Chin,S. H. Kamarudin, and I. Chuah, "Review the potential of natural fibres for automotive sector - review -," 2017.

[28] R. Sangamesh, n. Kumar, k. S. Ravishankar, and s. M. Kulkarni, "mechanical characterization and finite element analysis of jute-epoxy composite," vol. 02014, p. 1–6, 2018.

[29] A. Lahti, "handbook composite materials handbook volume 3," *Polymer matrix composites,* June 2002.

[30] A. Palanivel, "Evaluation of mechanical properties of natural fibre reinforced composites – a review,," July 2017, 2018..

[31] K. Srinivas, A. Lakshumu, and A. Pradesh, "A review on chemical and mechanical properties of natural fiber reinforced polymer composites," vol. 13, no. 2, p. 189–200, 2017.

[32] M. Al-maamori, "Study the effect of adding wool fiberwaste on the mechanical properties of composites," vol. 14, no. 4, p. 2450–2460, 2016.

[33] S. Tyagi and S. Kumar, "Experimental and numerical analysis of tensile strength of unidirectional glass / epoxy composite laminates with different fiber percentage," vol. 13,

no. 15, p. 12157–12160, 2018.

[34] G. Sreevani and S. B. Ajitha, "human hair as fibre reinforcement in concrete," vol. 7, no. 5, p. 11358–11364, 2017.

[35] M. N. Yahya, D. Daniel, V. S. Chin,S. H. Kamarudin, and I. Chuah, "Review the potential of natural fibres for automotive sector - review -," 2017.

[36] H. Arjun and l. M. J, "A study on hair and coir reinforced polymer composite," January 2016.

[37] H. Kim, "Hybrid composites with natural fibres," November 2014.

[38] F. Sciences, a. H. Barbhuiya, k. Ismail, and k. Road, "natural fiber reinforced polymer," p. 17–26, May 2017.

[39] K. Rajasekar, "Experimental testing of natural composite material (jute fiber)," vol. 11, no. 2, p. 1–9, 2014.

[40] C. Ampri, "Advances in composite materials - analysis of natural and man-made materials," May 2016.

[41] S. R. Sethy, "A study on mechanical behavior of surface modified natural fiber based polymer composites," May 2011.

[42] W. Wang, "Forming analysis of natural fibre composites," December 2015.

[43] U.S.Bongarde, V.D.Shinde, "Review on natural fiber reinforcement polymer composites," vol. 3, no. 2, p. 431–436, 2014.

[44] D. Shringi, r. Kumar, and p. Sharma, "a thermo-mechanical analysis on fiber reinforced composite by numerical method," vol. 3, no. 3, p. 114–122, 2014.

[45] D. R. Kumar and P. Mohanraj, "Filler material reinforced with natural fiber of mechanical properties and microstructure analysis for preparing perfect fiber," vol. 1, no. 2, p. 79–95, 2017.

[46] C. C. Ihueze, C. E. Okafor, and C. I. Okoye, "Natural fiber composite design and characterization for limit stress prediction in multiaxial stress state," *j. King saud univ. - eng. Sci,* vol. 27, no. 2, p. 193–206, 2015.

[47] D. R. Kumar and P. Mohanraj, "Filler material reinforced with natural fiber of mechanical properties and microstructure analysis for preparing perfect fiber," vol. 1, no. 2, p. 79–95, 2017.

[48] T. H. Shubhra, E. Commission, and S. Shamsuddin, "Characterization of plant and animal based natural fibers reinforced polypropylene composites and their comparative study," May 2014,.

[49] A. Kumar, "a study on mechanical behaviour of hair fiber reinforced epoxy composites," p. 110, 2014.

[50] P. D. Rao, c. U. Kiran, and k. E. Prasad, "effect of fiber loading and void content on tensile properties of keratin based randomly oriented human hair fiber composites," vol. 7, no. 5, p. 136–143, 2017.

[51] F. Bent, "sources of materials characterisation of flax fibres and flax fibre composites being cellulose based sources of materials," 2012.

[52] M. Saxena and A. Pappu, "Composite materials from natural resources : Recent trends and future potentials," 2011.

[53] B. M. Techapaitoon, "Tough natural-fibre composites," January 2015.

[54] O. Gabrielsson, "Manufacturing of pla-based composites reinforced with cellulose fibers and fibrils," 2013.

[55] M. R. H. Mazumder, f. Numera, and m. Hasan, "Mechanical properties of silk and glass fiber reinforced hybrid polypropylene composites," 2018.

[56] H. B. Vinay, H. K. Govindaraju, and P. Banakar, "A review on investigation on the influence of reinforcement on mechanical properties of hybrid composites introduction fibers / reinforcement materials," vol. 24, no. 2, p. 39–48, 2014.

[57] H. Banga, V. K. Singh, and s. K. Choudhary, "Fabrication and study of mechanical properties of bamboo fibre reinforced bio-composites," vol. 6, no. 1, p. 84–99, 2015.

[58] S. Ahmad, "Preparation of eco-friendly natural hair fiber reinforced polymeric composite (frpc) materials by using of polypropylene and fly ash," vol. 5, no. 11, p. 969–972, 2014.

[59] S. P. Shukla, "Investigation in to tribo potential of rice husk (rh) char reinforced epoxy," vol. 008, 2011.

[60] A. M. Kanerva and O. R. Ulla, "Design handbook of composite material: acase study of compsite materail," 2017.

[61] A. Osman, "the mechanical properties of natural fiber composites," 2013.

[62] Rivalani B. Baloyi, Sizo Ncube , Mufaro Moyo, Londiwe Nkiwane & Pethile Dzinga, "Analysis of the properties of aglass/sisal/polyester composite," vol. 11, p. 361, 2021.

[63] T.Harizi, F.Abidi, R.Hamdaoui,Y.ben Ameur, "Variation in Fleece Characteristics of Tunisian Sheep," *International Jouranal of Textile Science,* vol. 4, no. 5, pp. 97-101, 2015.

[64] J. Naveen, M.Chandrasekar, "Mechanical and physical properties of sisal and hybrid sisal fiber reinforced polymer composite," *Woodhead Publishing Series in Composite Science and Engineering,* pp. 427 - 440 , 2019.

[65] Madhukiran. J,Dr.T.venkateswara Rao, "Evaluation of the Mechanical properties on sisal coir Hybrid Natural Fiber composite," vol. 13, no. 9, pp. 43-49, 2017.

[66] G.Dharmalingam, V.Kumar, A.Senlolerayan, "Mechanical behaviour of treated and untreated sisal kenaf Hybrid composite material," vol. 8, no. 3, pp. 39-50, jan 2018.

[67] Kumaresan.M,Sathish and Karthin, "Effect of fiber orientation on mechanical properties of sisal fiber reinforced epoxy composites," vol. 18, no. 3, pp. 289-294, 2015.

[68] J.maultannivannan, S.Rajesh, K.Mayandi,MTH s, "Tensile and hardness properties of Sheep wool fiber reinforced polyester composite," pp. 266-270, 2019.

[69] S.Goncalves, P.vieria, J.L.Esteves, "Mechanical characterisation of wool fibers For Reiforcing of composite materials," 2019.

[70] Carlsson LA, Adams DF, Pipes RB., "Experimental characterization of advanced composite materials," *CRC press,* 5 march 2014.

[71] Cantor B, Grant P, Johnston C,, "Automotive engineering: lightweight, functional, and novel materials," *CRC press,* 19 Feb 2008.

[72] N. Fiber, c. As, a. N. Alternative, and e. Hause, "Decleration mechanical characterization of natural fiber composite as alternative ethiopian house roofing acknowledgment".

[73] N. Fiber, c. As, a. N. Alternative, and e. Hause, "Decleration mechanical characterization of natural fiber composite as alternative ethiopian house roofing acknowledgment".

[74] E. Jayamani, S. Hamdan, R. Rahman, and M. Khusairy, "Investigation of fiber surface treatment on mechanical , acoustical and thermal properties of betelnut fiber polyester composites," *procedia eng,* vol. 97, p. 545–554, 2014.

[75] T. CIRI SATYA DEVA,D.Venkata Rao,A. Lakshumu Naidu,MVA Raju Bahubalendruni, "A REVIEW ON MECHANICAL, PHYSICAL AND CHEMICAL PROPERTIES OF sisal REINFORCED FIBER," *international journal for research & development in technology,* vol. 8, no. 5, pp. 2349-3585.

[76] "http://www:youtube.com/watch?v=ijHvfn2vcss," [Online].

[77] "www.Survivopedia.com," [Online].

[78] "www.pdfprof.com," [Online].

[79] "link.spriger.com," [Online].

[80] "link.springer.com," [Online].

Appendix A

Experimental Test data's for both Tension and Bending Test

Output force-elongation-table

Material: s
Free Text:
Initial measurement length: 165mm
Specimen diameter: 20mm
Date: 18.08.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.13	0.00
2	0.01	0.00
3	0.04	0.10
4	0.04	0.31
5	0.08	0.53
6	0.07	0.77
7	0.07	1.00
8	0.07	1.24
9	0.06	1.48
10	0.04	1.73
11	0.02	1.98
12	0.00	2.24
13	0.02	2.50
14	0.03	2.75
15	0.05	3.01
16	0.06	3.27
17	0.10	3.76
18	0.10	4.05
19	0.14	4.32
20	0.17	4.58
21	0.21	4.84
22	0.24	5.10
23	0.17	5.38
24	0.06	5.65
25	0.04	5.92
26	0.03	6.20
27	0.03	6.46
28	0.02	6.72
29	0.01	6.97
30	0.01	7.24
31	0.00	7.76
32	0.00	8.04
33	0.00	8.31
34	0.00	8.57

Output force-elongation-table

Material: sw
Free Text:
Initial measurement length: 165mm
Specimen diameter: 20mm
Date: 18.08.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.01	10.41
2	0.00	0.00
3	0.01	0.25
4	0.04	0.50
5	0.08	0.76
6	0.11	1.02
7	0.15	1.28
8	0.18	1.54
9	0.23	1.81
10	0.28	2.06
11	0.34	2.32
12	0.45	2.83
13	0.45	3.12
14	0.58	3.38
15	0.65	3.65
16	0.74	3.90
17	0.82	4.16
18	0.85	4.45
19	0.56	4.74
20	0.35	5.02
21	0.26	5.31
22	0.21	5.60
23	0.18	5.87
24	0.15	6.15
25	0.12	6.43
26	0.05	6.96
27	0.05	7.27
28	0.02	7.55
29	0.01	7.69
30	0.03	8.57
31	0.03	12.07
32	0.03	15.62
33	0.03	19.22
34	0.03	26.42

Output force-elongation-table

Material: cws20
Free Text:
Initial measurement length: 165mm
Specimen diameter: 20mm
Date: 18.08.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.15
2	0.02	0.45
3	0.03	0.75
4	0.04	1.05
5	0.04	1.37
6	0.04	1.68
7	0.04	1.99
8	0.05	2.30
9	0.05	2.62
10	0.05	2.92
11	0.05	3.24
12	0.06	3.56
13	0.06	3.86
14	0.07	4.46
15	0.07	4.80
16	0.09	5.11
17	0.10	5.43
18	0.12	5.74
19	0.12	6.06
20	0.12	6.36
21	0.15	6.67
22	0.21	6.99
23	0.30	7.28
24	0.38	7.60
25	0.43	7.91
26	0.50	8.21
27	0.45	8.53
28	0.58	9.10
29	0.58	9.44
30	0.86	9.74
31	1.01	10.05
32	0.75	10.44
33	0.08	10.69

Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	______________
Kind of specimen	Bending specimen 20 DIN 50110
Temperature:	20°C
max.test force:	30 N
flectional strength	62.50 N/mm²
Ductile yield	______________
Description of the fracture area:	______________
Distance between supports:	250 mm
Date:	18.08.2021
Name of tester:	______________
Signature:	______________

Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	cs
Dimensions of specimen:	Tension specimen B20 x 165 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	______________
Yield stress Rp:	______________
Tensile Strength Rm:	27.33 N/mm²
Elongation at fracture A:	______________
Contraction at fracture Z:	______________
Date:	18.08.2021
Name of tester:	______________
Signature:	______________

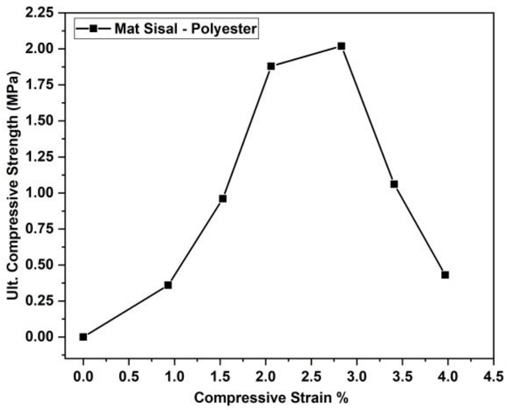
Test report

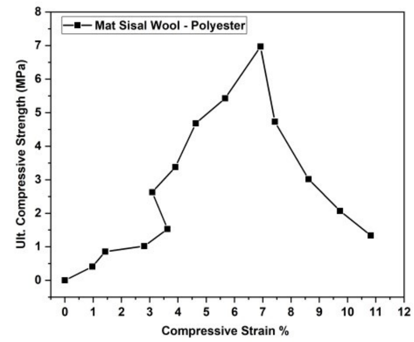
Kind of test:	Tensile test DIN 50106
Material of specimen:	St37
Dimensions of specimen:	Tension specimen B6 x 30 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	20.16 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	18.08.2021
Name of tester:	
Signature:	

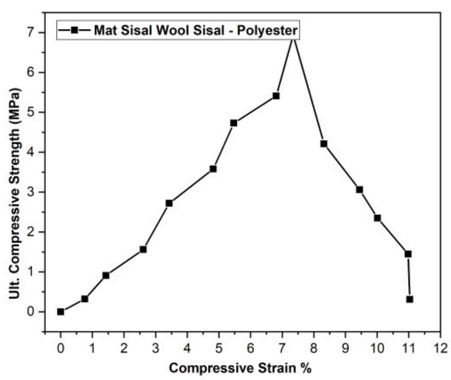
Test report

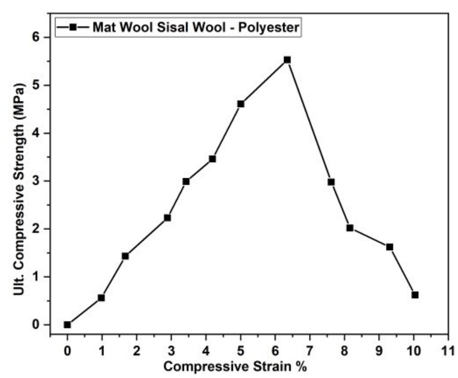
Kind of test:	Tensile test DIN 50106
Material of specimen:	sws
Dimensions of specimen:	Tension specimen B20 x 165 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	13.77 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	18.08.2021
Name of tester:	
Signature:	

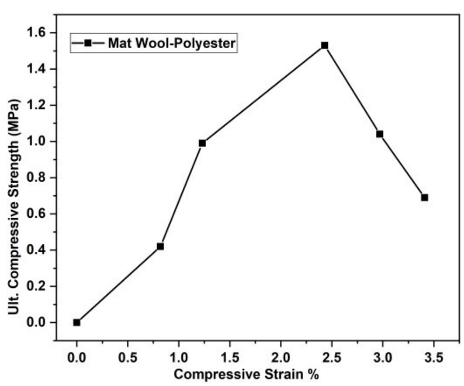
Figures stress vs. strain curves for each composite laminates of compression tests.

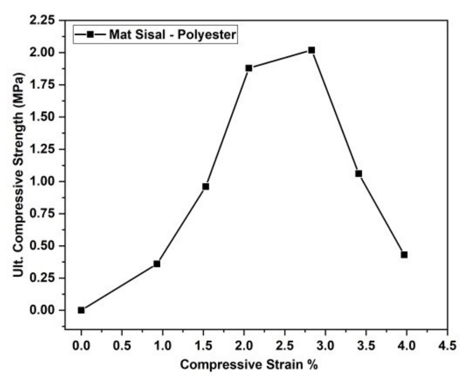


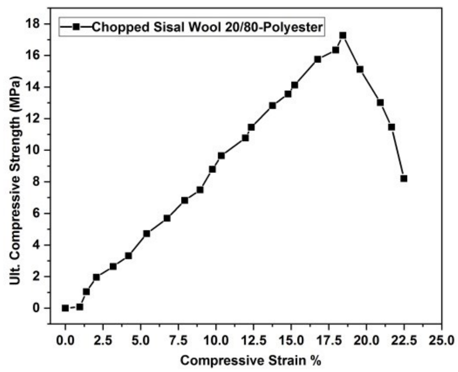











Chopped Sisal Wool 20/80-Polyester
Ult. Compressive Strength (MPa)
Compressive Strain %
0
2
4
6
8
10
12
14
16
18
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0