Fabrication and Characterization of Hybrid Polymer Matrix Composite Reinforced with Nettle, Sisal and Glass Fiber

By

Buzuwork Abebe Negash

A Thesis Submitted to

Department of Mechanical Design and Manufacturing Engineering

School of Mechanical Chemical and Materials Engineering

Office of Graduate Studies

Adama Science and Technology University

January, 2021

Adama, Ethiopia

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "Fabrication and Characterization of Hybrid Polymer Matrix Composite Reinforced with Nettle, Sisal and Glass Fiber "in partial fulfillment of the requirements for the award of the degree of master science in manufacturing engineering is an authentic record of my own work carried out from October 2019 to February 2021 under the supervision of Dr. Moera Gutu Jiru department of mechanical design and manufacturing engineering ,Adama Science And Technology University ,Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma all relevant resource of information used in this thesis have been duly acknowledged.

Name	Signature	Date
Buzuwork Abebe Negash	____________	____________
(Candidate)		

This is certified that the above statement made by candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name	Signature	Date
Dr. Moera Gutu	__________________	______________
(Adviser)		
Dr. Somasandera	_____________________	_______________
(Co-adviser)		

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Buzuwork Abebe Negash have read and evaluated his thesis entitled "Fabrication and Characterization of Hybrid Polymer Matrix Composite Reinforced with Nettle, Sisal and Glass Fiber" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements of the Degree of Master of Science in Mechanical Design and Manufacturing Engineering**.**

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Advisor	signature	date
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Co-advisor	signature	date
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Chairperson	signature	date
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Internal examiner	signature	date
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External examiner	signature	date

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I would also like to thank all my friends for their thoughtful and open cooperation, inspiration, and support during my thesis work.

Finally, I would like express my deep gratitude to my family for their unfailing support and continuous encouragement throughout the years of my studies and working this thesis.

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LIST OF ACRONYMS

ASTM	America Society for Testing and Material
CSM	Chopped Strand Mat
ECAE	Ethiopian Conformity Assessment Enterprise
GF	Glass Fiber
GP	General Purpose
NF	Nettle Fiber
NFPC	Natural Fiber Polymer Composite
PVA	Polyvinyl Alcohol
SEM	Scanning Electron Microscope
SF	Sisal Fiber
SPF	Sugar Palm Fiber
UTM	Universal Test Machine
UTS	Ultimate Tensile Strength
VHN	Vickers Hardness Number
MMC	Metal Matrix Composite

NOMUNCLATURE

S1, S2, S3, S4, S5, 56	Specimen (one, two, three, four, five, six)
S1’	Specimen one longitudinal load along nettle fiber
S2’	Specimen two longitudinal load along nettle fiber
S5’	Specimen five longitudinal load along nettle fiber
1, 2, 3, 4, 5, 6	Sample (1, 2, 3, 4, 5, 6)
MPa	mega Pascal
mm	millimeter
wt%	weight
m_c	mass of composite
m_r	mass of resin
V_r	volume of resin
V_f	volume of fiber
M_s	mass of sisal
M_n	mass of nettle
Mf	mass of fiber
ρ_c	density
Hv	Vickers hardness

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ABSTRACT

- *In modern industries, the majority of the conventional materials have been replaced by Natural fiber composites due to their high strength to weight ratio, biodegradable, eco-friendly environment, etc. Moreover, natural fibers are abundantly available and can be extracted easily from their trees. Based on various literature surveys, natural fibers are the best alternative for the Engineering and Manufacturing industries. The main goal of this thesis is to fabricate and characterize different mechanical properties of hybrid polymer matrix composite reinforced with nettle, sisal, and glass fiber. It is observed that nettle fiber, which can be extracted from its bast is abundantly available in Ethiopia and is not yet used widely as composite materials. This work started with plant harvesting (collecting) and fiber extraction then the composites were prepared with different fiber orientations. Different composition wt% of nettle and sisal fiber was used with* $0^0/90^0$ *and* 45^0 *orientation. Both fibers were extracted manually and treated with NaOH. 20NF:10SF, 15NF:15SF, and 10NF:20SF wt% composition with* $0^0/90^0$ *and* 45^0 *orientation was used by keeping wt% glass constant, which was 10%. The composites were manufactured by hand lay-up technique. Mechanical tests were performed to characterize the composites. The obtained tensile strength, impact strength, and hardness for sample 1 were 99MPa, 8.7J, 21.06 Hv, respectively with a low % of water absorption. But it has been a big drawback. The drawback was that it shows good mechanical property only if the applied load was carried out through the longitudinal direction of sisal fiber. Sample 5 solved those drawbacks. Tensile and impact strength of sample 5, specimen S5 and S5' were 97MPa, 8.4J, and 91MPa, 6.9 J respectively. Therefore, hybrid composite with good mechanical property can be manufactured from locally available nettle fiber*

Key words: *Nettle, composite, hybrid, biodegradable, eco-friendly, polymer*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

There is a steady increase both in the number of applications being found for fiber-reinforced plastics and, concurrently, in the variety of fiber/resin systems that are available to designers or engineers. Some of these systems are useful, however, only in highly specialized situations where limitations such as variable in cost and fracture behavior are considered secondary to such qualities as low density, high rigidity and high strength. By mixing two or more types of fiber in a resin to form a hybrid composite it may be possible to create a material possessing the combined advantages of the individual components and simultaneously mitigating their less desirable qualities.

In the other way, the sustainable world's economic growth and people's life improvement greatly depend on the use of alternative product in various fields. In an advanced society like ours we all depend on composite materials in some aspect of our lives. Composite materials are heterogeneous mixtures of two or more homogeneous phases, which have been bonded together. In composites, properties or set of properties can be attained which could not have been obtained separately.

Many naturally occurring materials can be regarded as composite e.g. bones, woods and others. Man-made composites are used for thousands of years, e.g. straw and natural fibers in bricks, laminated woods, etc. In the last century, the use of composites has been extended after the appearance of pneumatic tyers for vehicles and reinforced concrete. The next step was the development of glass fiber reinforced plastics during the Second World War. In the 1970s and 1980s, new types of composites have been developed to meet the strict requirements of aircraft and space industries **Prabhuram et al. (2010**)

Natural fibers show many advantageous properties; they are low density natural yielding relatively light weight composites with high specific properties. Natural fiber composites are very cost-effective materials especially in building and construction purpose packaging, automobile and railway coach interiors, house hold and storage devices. These can be potential candidates for the replacement of high cost fibers that have the advantages of low density, low cost and biodegradability. However, the main disadvantages of natural fibers and matrix are the relative to high moisture absorption. Therefore chemical treatments are considered in modifying the fiber surface properties **Verma et al. (2013)** Sodium hydroxide (NAOH) treatment on the fiber would remove the impurities like pectin, facts and lignin in the fiber, resulting in improvement in the bond between fiber and matrix also increases mechanical (tensile, flexural and compression) properties of fabricated component**.**

The hybrid composites were studied extensively by researchers and they concluded that hybrid composites can offer better resistance to water absorption, cost reduction, weight savings and increase the modulus of materials. **Girisha et al. (2012)** fabricated composite specimen of different weight % of alkaline treated sisal fibers and performed mechanical characterization. Results indicate the tensile strength increases with increasing fiber percentage up to a certain limit.

Dixit et al. (2012) studied the effect of hybridization on mechanical Properties of coir. Composite fabrication was done using compression moulding technique. The results demonstrated that hybridization plays an important role for improving the mechanical properties of composites. The tensile and flexural properties of hybrid composites are improved as compare to unhybrid composites.

Ramesh et al. (2013) evaluated the tensile and flexural properties of hybrid of glass/sisal fiber and glass/jute fiber reinforced epoxy composites. Glass/sisal fiber reinforced epoxy composite exhibits more tensile strength and glass/jute fiber reinforced epoxy composite exists more flexural strength.

Samuel et al. (2012) evaluated the mechanical properties of ukam banana, sisal, hemp, coconut and e-glass fiber reinforced to access the possibility of using it as a new material in engineering application. Samples were fabricated by the hand layup process. The literature survey indicates that the overall mechanical properties of natural fiber reinforced hybrid composites are completely depend on the amount and type of fibers used.

Hybridization processes cross over many research areas, such as mechanics, chemistry, engineering, physics, science and technology, polymer science, electrochemistry, metallurgy and metallurgy engineering and energy fuels. Irrespective of the research area, the main objective was to come up with the combination of three or more materials that have better performance/properties when compared to each material for an intended application. Fig. 1.1 a presents the top ten countries that are relatively more active in hybrid composites, with China being the most active, followed by India and USA **Mochane et al. (2019)**

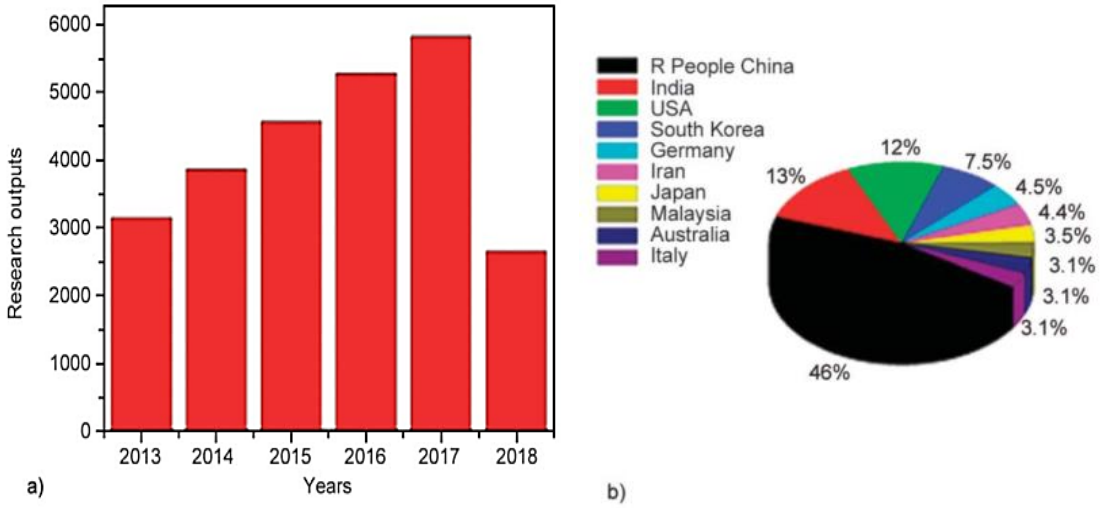


Figure 1. 1 (a) Number of outputs per year and (b) contribution of the countries in hybridized composites**.** Data analysis completed using Web of Science search system on 7 July 2018

Table 1. 1 Lists of some fibers, origin and physical properties **Mochane et al. (2019)**

Source	Annual production (million)	Origin	Price per Kg(USD)	Density (g/cm^3)	Tensile strength (MPa)	Elongation %	Moisture content%
Bagasse	Abundant	grass	0.2	0.89	350	5.5	-
Bamboo	100	grass	2.2-3.25	0.6-1.25	290	-	9
Banana	2.5	leaf	0.1-0.75	1.35	529-914	2.6-5.9	10-11
cotton	0.0185	seed	1.5-2.2	1.51	400	3-10	33-34

jute	0.25	plants	0.926	1.3-1.48	393-800	1.16-1.8	12
nettle	-	Bast	-	1.51	650	1.7	11-17
sisal	0.3	Plant leaf	0.65	1.3-1.4	390-450	2.3-2.5	11

The table above summarizes some types of natural fibers, their origin and physical properties separately. But when the fibers are hybridized they can obtain more and better physical and mechanical properties.

The present work is based on the development of hybrid nettle-sisal fiber reinforced epoxy composites and the determination of mechanical properties at varying weight percentage of fiber, further, a comparative study of the various properties of the prepared composites will be present**.**

1.2 Statements of the problems

Fabrication of composite material has many advantages to meeting human demand in different equipment, machine parts and household products. This should be economically manufactured from materials that can be easily available in our country. Importing different machines, tools and equipment need lots of investment cost and long delivery time. While manufacturing in the country will solve such problems. On the other hand, ensuring sustainable development of our economy should focus on indigenous resources. The current research is focused to fulfill this gap and solve the problem of wasting natural fiber of sisal and nettles by converting to useful products.

In developing country including our country Ethiopia, there are many fiber content plants which are manufactured into useful products. Since our country is agricultural dependent country sisal and nettles are easily found. Starting from the recent time the source of fibers in our country is related to false bananas and sisal. But in this research nettle plant fiber which is found in our country but not well known is conducted with sisal fiber. This thesis work will intricate a great opportunity for our country to produce different types of products and to increase the sustainability of their manufacturing process from a hybrid of nettle and sisal fiber with glass fibers as a reinforcement for more strength, long service lifetime products.

1.3 Objective

1.3.1 General Objectives

The general objective of this thesis work is to fabricate hybrid composite from locally available nettle and sisal plant fiber with glass fiber reinforced polymers and investigation of problems related to fabrication and testing of a new product.

1.3.2 Specific Objectives

To achieve the aim of this thesis work, few specific objectives are designed as follows:

1. Fabrication of new hybrid composite using different combination ratios (weight by mass) and orientation angles of nettle, sisal and glass fiber through hand lay-up method.
2. Characterization of mechanical properties of the hybridized composite with the available testing machine.
3. Investigates microstructural and morphological structures of the product
4. Testing the machinability of the fabricated composite through-hole after drilling

1.4 Significance of the Study (Benefits)

Natural fibers are emerging as low cost, lightweight and environmentally superior alternatives to glass fibers in many composites. Fabricating locally reinforced composites from hybrid of nettle and sisal fiber will increase the use and replacement of the manufacturing process.

It provides many advantages in house hold equipment, construction materials, in various industries such as the transportation industry, aeronautics, naval, automotive industries and components for the electronic industry. Both nettle and sisal fibers are biodegradable, easily available, and low cost and provide an opportunity for the utilization of the agricultural product. They also help to develop rural industries. They are non-abrasive, deforestation can be reduced to some extent and hence tool wear cost can be reduced.

In general, there are some advantages

- Low density and high specific strength and stiffness

- Nettle and sisal fibers can be produced at a lower cost than synthetic fiber
- Both fibers are a renewable resource, for which production requires little energy, involves CO_2 absorption, at the same time as returning oxygen to the environment
- Low exposure manufacturing Processes

The directed beneficiaries are farmers, engineers, the transportation industry, researchers in this field society and country as a whole.

1.5 Scope of the Study

This thesis work was delimited to the preparation of composite samples with varying proportions of nettle fiber, sisal fiber, and fiberglass through different angular orientations. Testing of the sample with the available testing facilities, heat treatment of the sample if possible, and investigates microstructural and morphology.be reduced to some extent and hence tool wear cost can be reduced.

1.6 Limitations of the Study

Carrying out this thesis work come up with many challenges. There is no available equipment used for processing composite materials, testing, and production in our country Ethiopia. To list some of them:

- The hand layup method (which was very strong) was used in this work because there is no other available method.
- A suitable machine to prepare standard test specimen is also no available, especially for composite materials.
- It was boring to gate different mechanical property tests of the fabricated composite.
- There was a calibration problem on most of the test machines.
- Most of the machines available are very old and not calibrated plus they are not computerized.

1.7 Research Motivation

It is known that our country is an agricultural-based country. It has enough rainy season and fertile soil. Having this natural appearance gives it different plant species. The nettle plant is among one of them. It has a nice fiber which is extracted from its bast. But in our country, it simply grown during the rainy season and then dried around three or four months after its germination. No one can carry about it and simply it becomes degradable. To solve this problem it is necessary to use its fiber as a composite material with other reinforcement.

1.8 Structure of the Thesis

In this section, an overview of the thesis work is explained. Five chapters are done in the thesis work. In which Chapter one is introduces to composite materials. Chapter Two is literature reviews of related works in different sections. This is to provide information on different issues. In Chapter Three, Material and Methods are discussed. As well, testing procedures are illustrated. Chapter Four presents the result and discussion of the fabricated composites under study. The last Chapter provides summary, conclusion of the work and recommendations for future research.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

The main objectives of the literature are to give the special meaning of earlier work, the current study and to provide an overview of work done to date towards the mechanical description of ordinary fiber composites and their properties.

2.2 Previous Works on Natural Fiber Hybrid Polymer Composites

Since the 1990s, natural fiber composites are evolving as realistic alternatives to glass fiber reinforced composites in many applications. Research has began to focus attention on natural fiber composites (i.e. coir, jute, sisal, banana, hemp and bagasse fibers) which are composed of natural or synthetic resins, reinforced with natural fibers.

Girisha et al. (2012) Fabricated composite specimen of different weight % of alkaline treated sisal fibers and performed mechanical properties. Results indicate the tensile strength increases with increasing fiber fraction up to a certain limit. Natural fibers can be merged with other natural fibers and can also be incorporated into a polymer matrix to form a hybrid composite. This can balance the costs of the natural fibers, improve the performance and properties of the resultant material.

Edhirej et al. (2017) Reported that the optimum tensile strength of a natural-natural fiber reinforced hybrid can be obtained when high strain is achieved. Researchers are currently focusing on natural-natural fibers reinforced hybrid composites as suitable alternatives to synthetic fibers, such as carbon and glass fibers. Many researchers have investigated the mechanical properties of natural-natural fibers reinforced hybrid composites **Olusegun et al. (2012)** amongst these researchers,

A very recent study on the mechanical properties (tensile, compressive, hardness and impact strength) of woven banana fiber and groundnut shell ash reinforced epoxy hybrid composite was reported in **Velmurugan et al. (2014).** It was found that hybrid composite composed of 82% epoxy, 1.5% banana fiber and 3% groundnut shell ash had good mechanical properties than other composites, except impact strength. It had a tensile strength of 12.02 MPa, a hardness of 37.3, impact strength of 0.340 J/mm2 and compressive strength of 24.4 MPa, whereas composite composed of 85% epoxy and 15% banana had a tensile strength of 10.21 MPa, hardness of 35.6, the impact strength of 0.252 J/mm2 and compressive strength of 20.7 MPa. A maximum impact strength (0.65 J/mm2) was obtained for a hybrid composite composed of 77.5% epoxy, 15% banana and 7.5% groundnut shell ash.

Ramesh.et al. (2013) evaluated the tensile and flexural properties of a hybrid of glass/sisal fiber and glass/jute fiber reinforced epoxy composites. Glass/sisal fiber reinforced epoxy composite exhibits more tensile strength and glass/jute fiber reinforced epoxy composite exists more flexural strength.

Samuel et al. (2012) evaluated the mechanical properties of ukam banana, sisal, hemp, coconut and e-glass fiber reinforced to access the possibility of using it as a new material in engineering application. Samples were fabricated by the hand layup process (30:70 fibre and matrix ratio by weight) and the properties were evaluated using the INSTRON material testing system. Results indicated that natural fibres are of interest for low-cost engineering applications and can compete with artificial glass fibres (E-glass fibre) when a high stiffness per unit weight is desirable.

Edhirej et al. (2017) developed hybrid composites by using starch as a matrix and reinforced with seaweed and sugar palm fibers (SPF), cassava and SPF, respectively. In the case of **Jumaidin et al. (2017)** work, the results demonstrated that hybrid showed higher tensile and flexural strength in comparison to the individual composites.

Borukati et al. (2018) Studied mechanical characterization of new polymer composites consisting of glass fiber reinforcement, epoxy resin, and sisal fiber. The developed composites are characterized for their mechanical properties and Experimental investigation like the tensile test, compression test, hardness test and impact test was conducted to find the significant influence of sisal fiber on mechanical characteristics of Glass Fiber Reinforced Polymer composites. From experiment conclude that the Hardness, tensile, compression, impact characteristics of E-Glass fiber-reinforced sisal composite material gives better results compare to ordinary E-Glass fiber composite material hardness, tension and compression values are better than normal E Glass fiber matrix material by adding natural fiber (Sisal fiber).

Velmurugan et al. (2014) This study Evaluated mechanical properties such as tensile strength, flexural strength and impact strength for different fiber length and fiber volume fraction Specimen1 [3mm] Sisal (25%) - coir (15%), Specimen 2 [3mm] Sisal (20%) - coir (20%), Specimen 3[5mm] Sisal (20%) - coir (20%). Sisal and coir fibers used as reinforcement materials with a matrix of Epoxy resin to the manufacturing of composite plate by hand lay-up process and cut into that as per ASTM for testing the materials. The results obtained from this study conclude that 20% sisal and 20% coir having 3mm fiber length is suitable for lightweight and low load applications.

Sahu et al. (2015) Investigated hybrid composites were prepared using sisal/pineapple fibers of 100/0, 70/30, 50/50, 30/70, and 0/100 Weight fraction ratios, while the overall fiber weight fraction was fixed as 20gram. Samples are prepared using Hand layup method, specimens are prepared, fibers are arranged in a unidirectional manner and tests are carried out, which shows tensile and bending strengths. The investigation concludes that from thetest result the composite made by 50/50 fibers weight fraction of sisal & pineapple fiber has been shown best impact strength 47.2 N⁄mm2 as compare to other constitutes of sisal & pine fibers. This constitutes have good tensile & bending strength & their density is also less than sisal fibers.

Manjunath, (2018) the mechanical behavior of natural fiber reinforced hybrid epoxy composites. The glass fiber, cotton and silk were used to fabricate hybrid natural composites by varying the fiber percentage from 2-6%. The maximum compressive strength of 0.402 kN/mm² was found for the fiber loading (mass fraction) of 6% for both glass fiber, Cotton and silk fiber hybrid epoxy composite., Cotton and silk fiber hybrid epoxy composite. The maximum bending strength of 1.0395 kN/mm² was found for the fiber loading (mass fraction) of 6% for both glass fiber, cotton and silk fiber hybrid epoxy composite.

Gupta et al. (2016) the hybrid composite sisal/hemp reinforced with epoxy matrix has been developed by compression molding technique according to ASTM standards. Sodium hydroxide (NAOH) was used as an alkali for treating the fibers. The amount of reinforcement was varied from 10% to 50% in steps of 10%. Prepared specimens were examined for mechanical properties such as tensile strength, flexural strength, and hardness. Hybrid composite with 40wt% sisal/hemp fiber were found to possess higher strength (tensile strength = 53.13Mpa and flexural strength = 82.07Mpa) among the fabricated hybrid composite specimens. Hardness value increases with increasing the fiber volume. Morphological examinations are carried out to analyze the interfacial characteristics, internal structure and fractured surfaces by using scanning electron microscope.

Shashank et al. (2016) Composites of different combinations with varied fiber content were prepared using hand lay-up technique using L-12 epoxy resin and K-6 hardener as reinforcing materials. Banana fiber with 15, 20, 25 and 30% were hybridized with 20, 15, 10 and 5% of glass fiber to form composites and compared with non-hybrid 35% glass and banana fiber composites. The fracture toughness (KIC) was investigated according to ASTM D5045 by single edge notch bending (SENB) technique, with SEM image confirmation. The non-hybridized 35% banana fiber showed the highest KIC value and 35% glass fiber showed the least. Whereas, the hybrid composite with fiber volume of 20% banana and 15% glass showed a higher KIC value when compared with other hybrid fractions. The results thus obtained signified the fracture toughness got improved in banana-glass hybrid composite with increased glass fiber content from 5%-15%, thus acting as a positive reinforcement in providing extra strength and smooth surface finish to the composite and at the same time, the banana fiber imparted elasticity to the composite.

Sanjay et al. (2012) Sisal fiber has been hybridized with glass fiber reinforced polyester using hand lay-up process to improve the mechanical properties. Test specimens were prepared using glass fiber(GF)/sisal fiber of 30/70, 50/50 and 70/30 weight fraction ratios as per ASTM standards and mechanical properties like tensile, impact and flexural strength of sisal /glass fiber reinforced polyester are evaluated and compared. The results show that tensile strength of 30%GF-70%sisal composition and flexural strength of 70%GF-30%sisal composition and impact Strength of 50%GF-50%sisal composition is found to be better than the remaining two compositions.

Dixit and Verma (2012) study the effect of hybridization on mechanical properties on coir and sisal reinforced polyester composite (CSRP), coir and jute reinforced polyester composite (CJRP), jute and sisal reinforced polyester composite (JSRP) were evaluated experimentally. The results demonstrate that hybridization plays an important role in improving the mechanical properties of composites. The tensile and flexural properties of hybrid composites are markedly improved as compare to unhybrid composites. Hybrid composites offer better resistance to water absorption. This work demonstrates the potential of the hybrid natural fiber composite materials for use in several of consumable goods.

Madhukiran et al. (2017) three types (sisal-coir) of hybrid laminate and two pure laminate composites are fabricated using manual layup technique. Epoxy (Ly556 and HY951) resin is used as matrix material in the present work. The experimental result shows that the sisal-coir fiber hybrid composites exhibited superior properties when compared to pure composites.

Acharya. (2014) investigated the mechanical properties of jute and glass fiber reinforced epoxy resin hybrid composites and noticed considerable improvement by the incorporation of glass fiber. According to **Girisha et al. (2012),** the strength of hybrid composite increases with increasing the volume % of fibers in composite and hybridization has also increased the mechanical properties. The strength of hybrid composites depends on the properties of fiber, the aspect ratio of fiber in composites, the orientation of fiber, an intermingling of fiber and fiber matrix interface**.**

Pankaj et al. (2018) fabricate hybrid composite of nettle and glass fiber and study their tensile and flexural strength. Results indicated that nettle fibers when hybridized with glass fibers increases tensile strength and flexural strength. Flexural strength of nettle and glass fiber hybrid composite is the largest among all specimens.

Mahendrakumar et al. (2015) work deals with the use of Himalayan Nettle (a natural plant fiber) as reinforcement in polyester resin matrix and characterization of an as-formed nettle-polyester composite. Tensile test on single nettle fibers revealed that Young’s modulus and tensile strength decrease with an increase in fiber diameter, and chemical composition test results show that the fiber has a higher content of cellulose, hemi-cellulose and lignin that result in better mechanical, biodegrading and thermal stability properties of the composite respectively.

Suryawan et al (2017) potency of stinging nettle to be used as reinforcement of composite materials is so great, it can be seen from the result of the study that was conducted by the researcher. The fibers were taken from the stems of the nettle. Some treatments with chemicals on nettle fiber are needed to be done, for example on flax, hemp and ramie, and to reinforce the fiber and the bound between fiber and matric.

Kumar et al (2019) fabricate Himalayan bast fibers (Nettle fiber (NF)/bauhinia vahlii fiber (BF)) based mono/hybrid epoxy composites at varying weight percentage of 2~6 wt% and evaluate the physical (void fraction and water absorption), mechanical (tensile strength, flexural strength, hardness) and sliding wear properties of as-fabricated composites. The 6 wt% NBF reinforced composites exhibited higher mechanical properties as compared to NF and BF composites with a tensile strength of 34.04 MPa, the flexural strength of 42.45 MPa, and hardness of 37.01 Hv respectively.

Fischer et al (2012) Studies results show good potential for nettle as reinforcement for PLA. The crucial point for future development will be to improve the fibre–matrix interaction to increase especially the tensile strength of the composites by closing the large gap between fibre and matrix strength.

Bodros and Baley (2008) Studies mechanical performances of stinging nettle fibres are measured and compared to flax and other lignocellulosic fibers. The stress/strain curve of stinging nettle fibers (UrticaDioica) shows they have a linear behavior which can be explained by the orientation of the cellulose microfibrils. The average tensile properties are a Young's modulus equal to 87 GPa, a tensile strength equal to 1594 MPa and, a strain at failure equal to 2.11 %. Their study proves nettle fibers have very interesting tensile properties and could also be suitable as reinforcing components in composite materials

Swolfs et al. (2014) Fibre hybridization is a promising strategy to toughen composite materials. By combining two or more fibre types, these hybrid composites offer a better balance in mechanical properties than non-hybrid composites.

Prabhuram et al. (2010) Hybridization is a process of incorporating synthetic fibers with that of natural and metallic fibers in order to yield better strength, stiffness, high strength to weight ratio and other mechanical properties. Reinforcement of composite materials can be done to increase the load-carrying capacity.

Megha et al. (2019) Banana and Jute Fiber-reinforced Polyester Composites were fabricated using banana fibers of length 10 mm and jute fibers of length 10 mm as reinforcements and polyester resin as matrix respectively. The thickness of composite panels varied from 3 mm to 5 mm and fiber volume fractions was adopted as 5 %, 10 %, 15 %, 20 % and 25 % respectively. It is observed that Jute Fiber reinforced Polyester Composites exhibit higher values of tensile and flexural strength compared to Banana

Fiber reinforced Polyester Composites. However, both Banana and Jute Fiber reinforced Polyester Composites revealed optimum tensile and flexural strength at a fiber volume fraction of 25 % and 20 % respectively.

Dashtizadeh et al. (2017) Hybrid composites are made up by two or more fibers in one matrix or two polymer blends and with one natural fiber reinforcement. By hybridizing one natural fiber with another natural fiber/synthetic fiber in one matrix, the resulting composite is a unique product (hybrid composites) that displays better mechanical and thermal properties in comparison with individual fiber-reinforced polymer composites.

Fiber-reinforced composites are rapidly gaining market share in structural applications, but further growth is limited by their lack of toughness. Fiber hybridization is a promising strategy to toughen composite materials. By combining two or more fiber types, these hybrid composites offer a better balance in mechanical properties than non-hybrid composites. **Swolfs et al. (2014)** stated that predicting hybrid composite mechanical properties is challenging due to the synergistic effects between both fibers**.**

Summary of the literature review: - Generally to summarize, several experimental investigations were done to characterize the mechanical properties of the different hybrid natural fiber reinforced composite materials. Through an exhaustive literature review it has been observed that although the literature is rich in the study of mechanical behavior of sisal and glass fiber hybrid with other synthetic.

2.3 Research Gap

From the literature, different researchers were evaluated and characterized about hybrid natural fiber and synthetic material composites. Number of papers have been published on glass/bamboo fiber, glass/sisal fiber, glass/banana etc. hybrid composites. Few of them fabricate and characterize nettle plat fiber as a composite material. There is a gap between hybrid nettle fibers with other fibers to fabricate and characterize mechanical property of the composites. On the other way, our country Ethiopia used nettle fiber as a textile raw material yet. But this work wants to fabricate composites from this typical local plant fibers.

2.3 Overviews of Composite

Over the previous thirty years composite materials, plastics and ceramics have been the main developing materials. The amount and number of fabrication of composite materials have grown progressively, piercing and leading new markets persistently. Current composite materials constitute an important amount of the engineered materials market ranging from everyday goods of sophisticated place applications. While composite has already established their value as mass-saving materials, the present challenge are to make them price effective. The efforts to produce economically good-looking composite components have resulted in several inventive manufacturing techniques currently being used in the composite industry.

When compared composites with metals, the composite materials have the following advantages:

- ✓ Good fatigue resistance
- ✓ Light weight
- ✓ Simple moldable to complex forms
- ✓ High specific stiffness and strength
- ✓ Good dumping
- ✓ Easy bonding
- ✓ Small radar visibility
- ✓ As insulator and thermal expansion
- ✓ Part joined due to lower overall system costs
- ✓ Internal energy luggage compartment and release

But composites have also some disadvantages

- ✓ Low ductility
- ✓ Temperature limits
- ✓ Extended development time
- ✓ Solvent or moisture attack
- ✓ Complexity manufacturing
- ✓ Hidden damage and damage weakness

2.4 Classification of Composite

2.4.1. Based on the type of strengthening used, composites are classified as follow

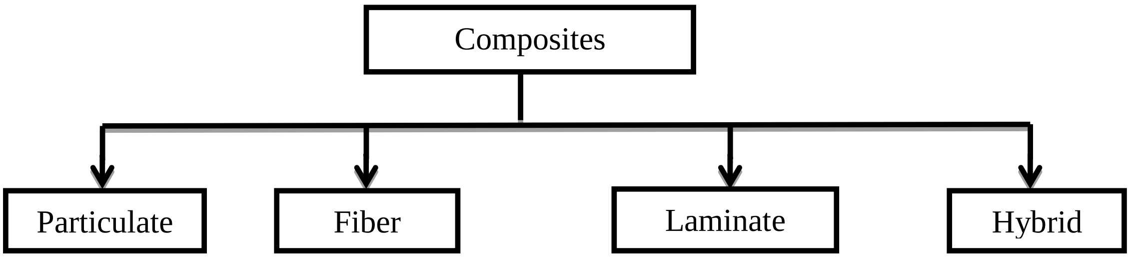


Figure 2. 1 Composite materials classifications

Structurally composites into particle reinforced, sheet molded and fiber reinforced.

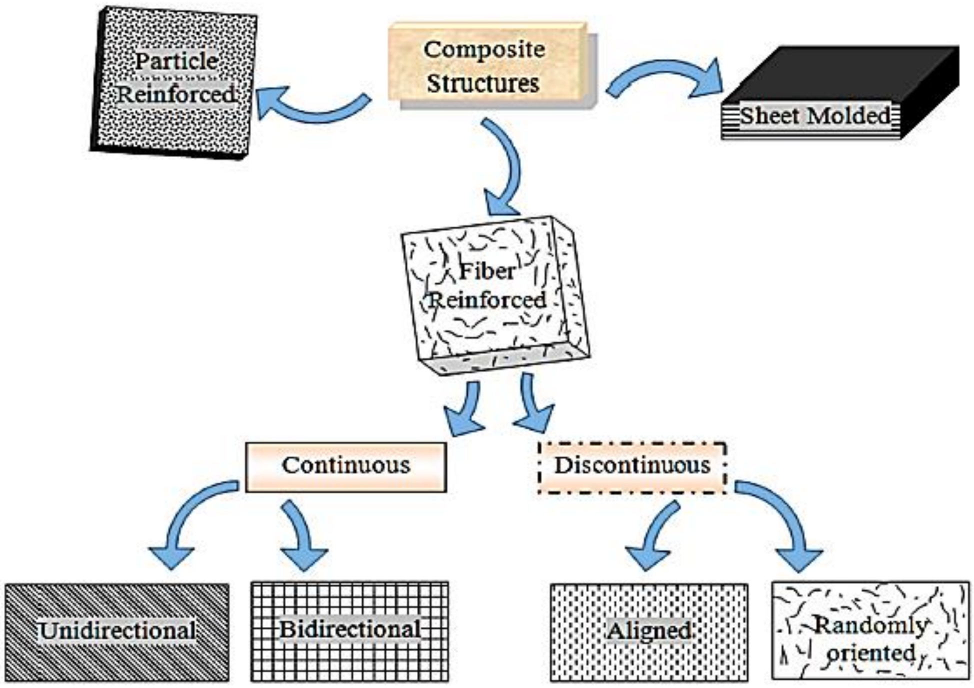


Figure 2. 2 Classification of composites based on the structure (**Dipen Kumar, 2019**)

Particle Reinforced Composite: A composite which strengthens is a particle of all the dimensions more or less equal is called particulate reinforced composites. Particulate fillers are working to improve high-temperature performance, reduce friction, increase to wear resistance and to reduce shrinkage. The particle will also donate the load with the matrix, but a smaller extent than a fiber. A particulate reinforcement will therefore get better stiffness but will not normally strengthen.

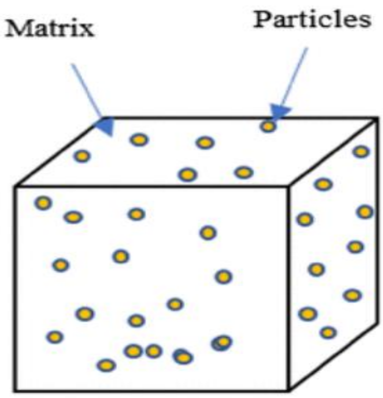


Figure 2. 3 Particle reinforced composite

Fiber-reinforced Composite: Fiber reinforced composites enclose reinforcements having lengths higher than cross-sectional dimension. Fibrous reinforcement represents physical rather than a chemical means of changing a material to leave well with various engineering applications. These can be usually classified as follow:

Composites consist of fibers in the matrix structure and can be classified according to fiber length. Composites with long fiber reinforcements are termed continuous fiber reinforcement composites, while composites with short fiber reinforcements are termed discontinuous fiber-reinforcement composites.

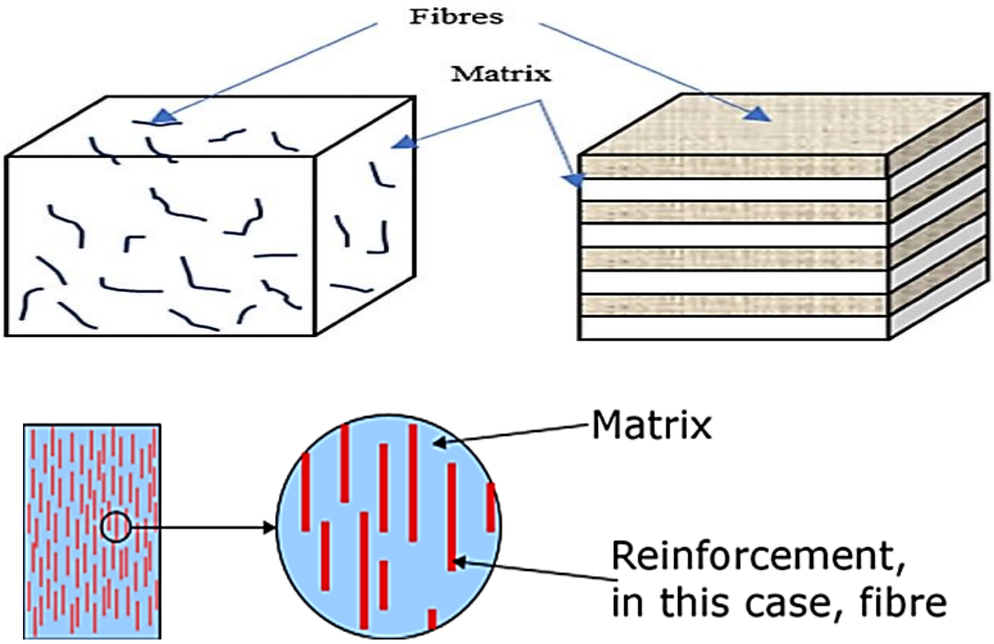


Figure 2. 4 Fiber reinforced composite

Hybrid fiber-reinforced composites are those where two or more types of fibers are reinforced in a single matrix structure. Fibers can be placed unidirectionally or bidirectionally in the matrix structure of continuous fiber composites, and they take loads from the matrix to the fiber in a very easy and effective way. Discontinuous fibers must have sufficient length for effective load transfer and to restrain the growth of cracks from avoiding material failure in the case of brittle matrices. The arrangement and orientation of fibers define the properties and structural behavior of composite material. Improvement in properties such as impact toughness and fatigue strength can be seen with the use of chemically treated natural fibers.

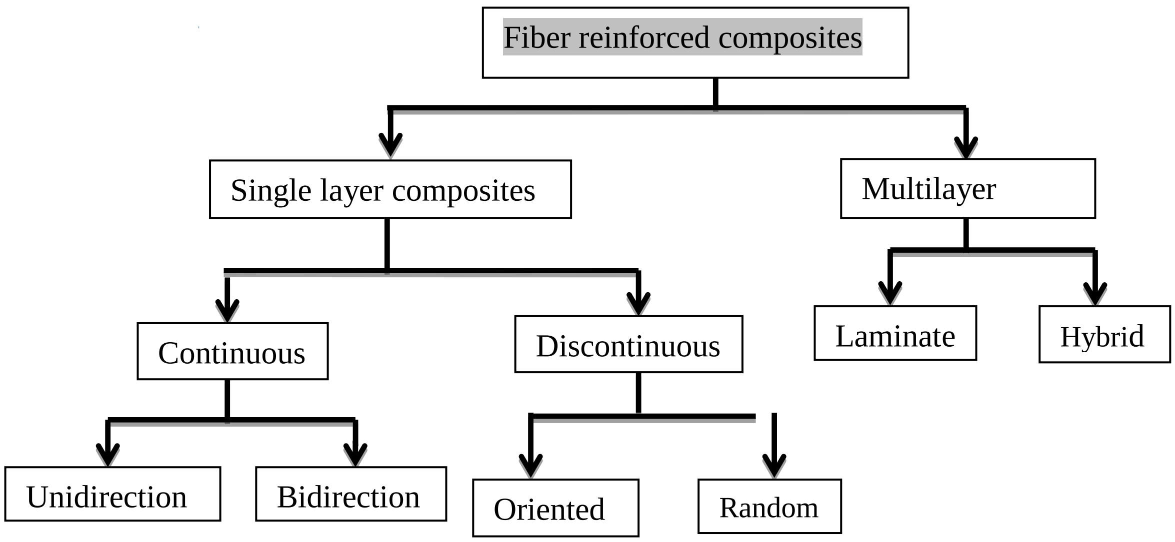


Figure 2. 5 Fiber-reinforced composite materials sub-classifications

Composite Laminate: Laminates are sheet constructions which are made by stacking layers (also called plies or lamina) in a specified sequence. The layers are often in the form of prepare‟ (fibers pre filled with partly cured resin) which are consolidated in an autoclave.

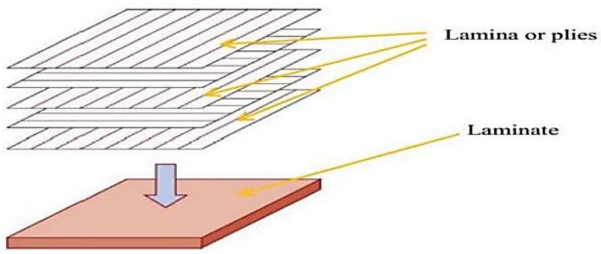


Figure 2. 6 Laminate composite

A laminate may have more than 4 layers and the fiber orientation changes from layer to layer regularly through the thickness of the laminate. The figure shown describes how the laminate is formed from the ply or lamina **(Kaw, 2006).**

Hybrid Composites: One way of purposefully regulating the properties and performance of composite materials is to use hybrid fibrous fillers (natural or synthetic fiber) into a single matrix. It will give these composite materials explicit properties, and allow for the expansion of the area of their application. Its functionality depends on the balance between the properties of each component. The properties of a hybrid composite depend directly on the fiber content, length of fibers, arrangement and orientation of both the fibers and also fiber-matrix bonding. Fibers are a significant class of reinforcement materials. The main usage of fibers in composite materials is to improve the mechanical and physical properties of the matrix resin due to their high strength weight ratio. Fiber materials are characterized by high tensile and compression strength, and high elastic modulus. They will impart their properties to the composites. Fibers would carry the most subjected loads, and thus will improve the stiffness of the composites.

2.4.2 Based on the Matrix Material

Another way of classifying composite materials is concentrating on the type of matrix constituent of the composite. Based on this measurement, composite materials can be organized as shown figure.

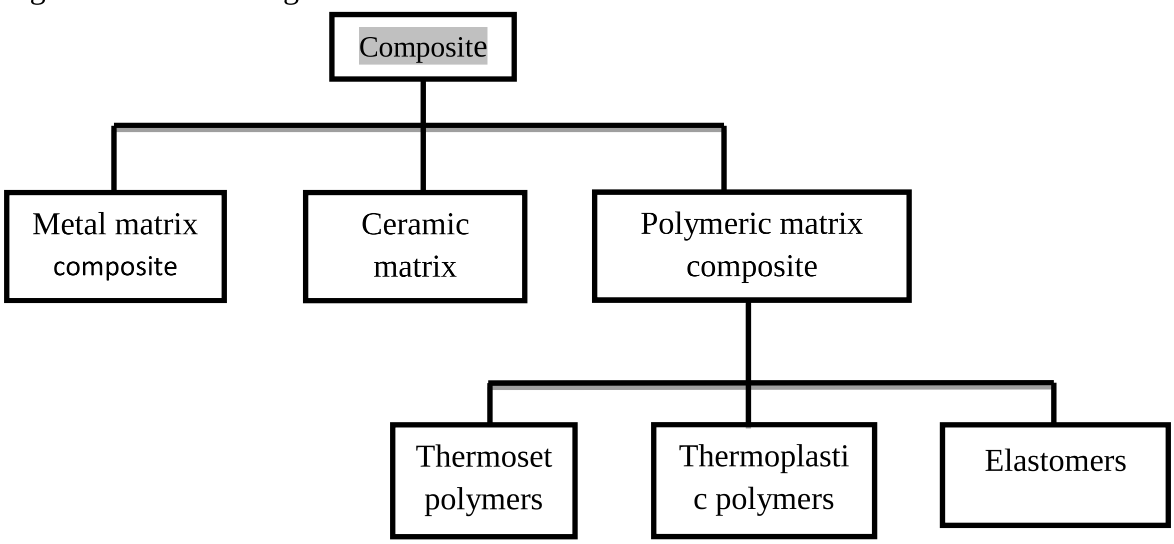


Figure 2. 7 Classification of composite based on the matrix material

Metal-matrix composites typically use silicon carbide fibers embedded in a matrix made from an alloy of aluminum and magnesium, but other matrix materials such as titanium, copper, and iron are increasingly being used. Typical applications of MMCs include bicycles, golf clubs, and missile guidance systems; an MMC made from silicon carbide fibers in a titanium matrix is currently being developed for use as the skin (fuselage material) of the US National Aerospace Plane.

Ceramic-matrix composites are the third major type and examples include silicon carbide fibers fixed in a matrix made from borosilicate glass. The ceramic matrix makes them particularly suitable for use in lightweight, high-temperature components, such as parts for airplane jet engines. The principal advantages of ceramic materials over other materials are their resilience to oxidation and deterioration at elevated temperatures, their high melting points, and high compressive strengths. Unfortunately, ceramics suffer from susceptibility to brittle fracture and therefore have relatively low values of fracture toughness. One method of increasing the fracture toughness of a ceramic is to reinforce it with fibers, whiskers, or particles. Crack propagation is severely hindered by the presence of the reinforcing phase.

Polymer matrix composites commonly used matrix materials are polymeric. The reason for this is twofold. In general, the mechanical properties of polymers are insufficient for structural purposes. In particular, their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly, the processing of PMC need not involve high pressure and doesn’t require high temperature. Also, the equipment required for manufacturing PMC is simpler. For this reason, PMC developed quickly and soon became common for structural applications of which glass fiber reinforced plastic (GRP) is the best-known example, use ceramic fibers in a plastic matrix.

Because of the above reason this work interesting on the polymer matrix composite materials only. They are collected of long chain-like molecules comprising of many simple repeating units. The most commonly adopted polymer composites in more industries are thermosetting and thermoplastic polymer matrix composites. These fiber-reinforced polymer composites can be found in products that people interact with everyday activities.

Thermoset polymers are polymers that are cured into a solid form and cannot be returned to their unusual uncured form. Composites made with thermoset matrices are strong and have very good fatigue strength. They are extremely brittle and have a low impact - toughness making. They are commonly used for high-heat applications because the thermoplastics. Thermoset composites are generally cheaper and easier to produce because the liquid resin is very easy to work with. Thermoset composites are difficult to recycle because the thermoset cannot be remolded or reshaped; only the reinforcing fiber used can be reclaimed **(Cheung, 2009).**

Thermoplastic polymers are polymers that can be molded, melted, and remolded without altering their physical properties. Thermoplastic matrix composites are tougher and less brittle than thermoset, with very good impact resistance and damage tolerance. Thermoplastic composites are less dense than thermosets making them a viable alternative for weight-critical applications. The thermoplastic composites manufacturing process is more energy-intensive due to the high temperatures and pressures needed to melt the plastic and impregnate fibers with the matrix. The energy required makes thermoplastic composites more costly than thermosets **(Patil, 2012).**

Functions of a Matrix: In a composite material, the matrix material helps for the following functions:

- ✓ Holds the fibers together.
- ✓ Protects the fibers from environment.
- ✓ Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.
- ✓ Enhances transverse properties of a laminate.
- ✓ Improves impact and fracture resistance of a component.
- ✓ Helps to avoid the propagation of crack growth through the fibers by providing an alternate failure path along the interface between the fibers and the matrix.
- ✓ Helps to carry interlaminar shear.

2.6 Fiber

Fiber is any single unit of matter characterized by elasticity fineness and high aspect ratio. It is a slender filament that is longer than 100mm or an aspect ratio greater than 10.

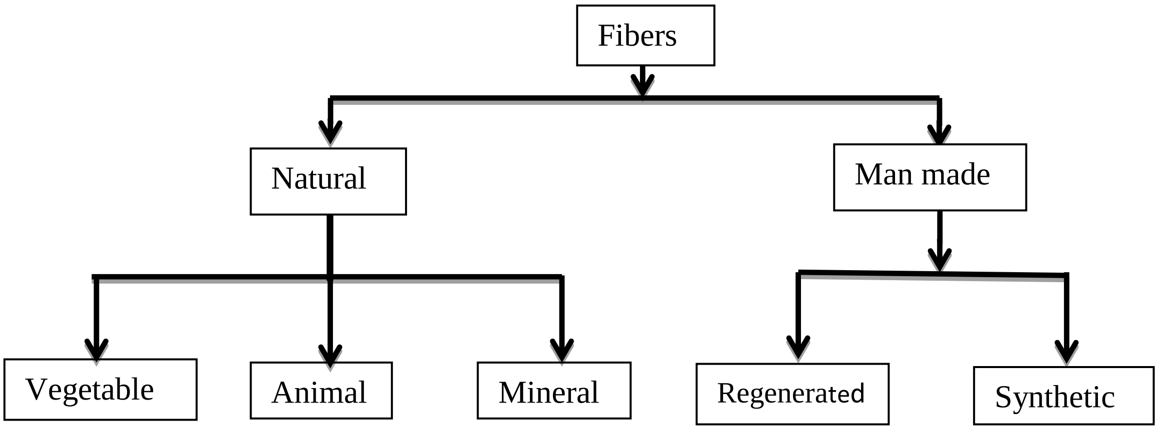


Figure 2. 8 Fiber classification

Fibers have a fine hair like structure and they are of animal, vegetable, mineral or synthetic origin. Fibers are generally classified into two types, natural and synthetic.

2.7 Natural Fibers

The major advantage of fiber-reinforced composites is to offer high strength and modulus those are either comparable to or better than many traditional polymer materials.

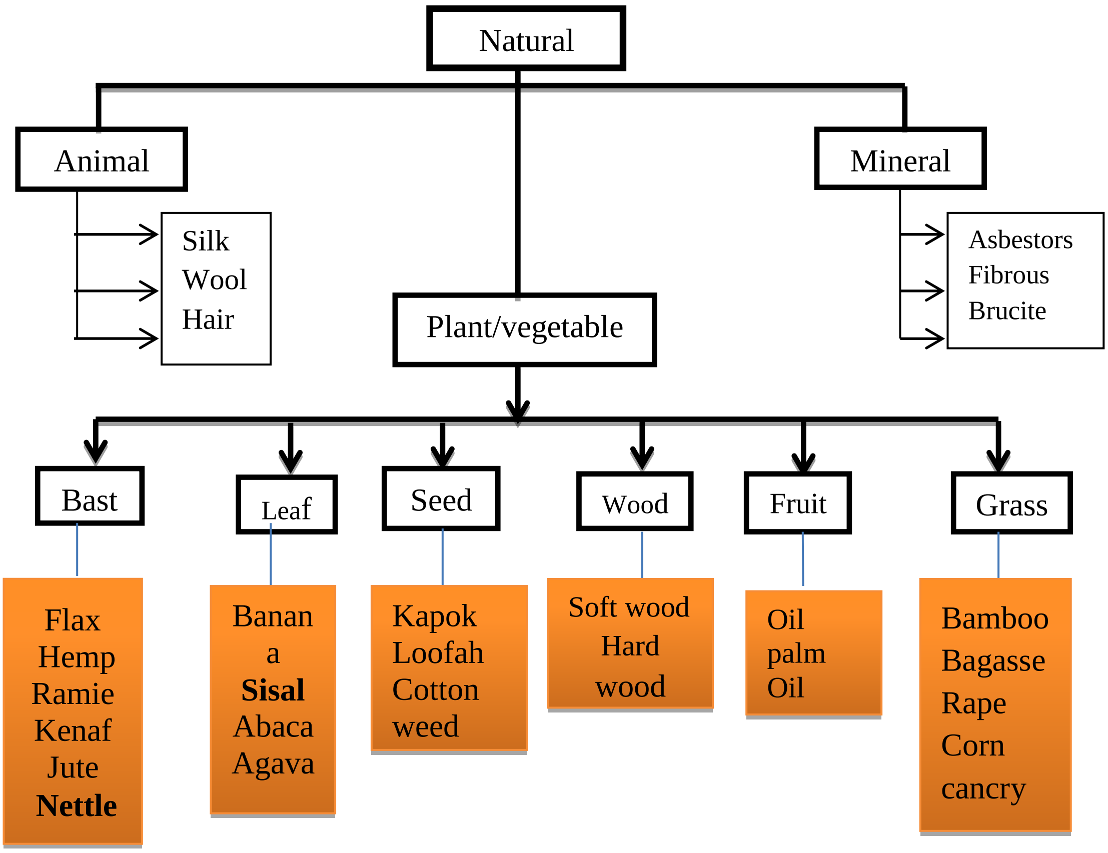


Figure 2. 9 Further classification of fiber material (**Elanchezhian, 2018**)

Because of their low specific gravity, high strength-weight ratio, and modulus – weight ratios, these composite materials are markedly superior to those of polymer materials. Besides, fatigue strength - weight ratio as well as fatigue damage tolerance of many composite laminates is excellent **Ren et al. (2018)**.

Fibers have two main group synthetic fiber and natural fiber. Under synthetic fiber, fiberglass is light in weight, extremely strong, and robust. Its bulk strength, stiffness and weight properties are also very favorable when compared to metal. Natural fibers are classified into six different types. The first is a bast fiber, the second is leaf fibers (abaca, sisal, and pineapple), the third is seed fiber (coir, cotton, and kapok), the fourth is core fiber (kenaf, hemp, and jute), the fifth is grass (bagasse, bamboo and corn) and the sixth is fruit fiber (wheat, corn, and rice). Bagasse fiber can be obtained by crushing sugarcane stalks. It is used as a natural fiber to develop composite materials **Elanchezhian et al. (2018).**

2.8 Nettle Plant and its Fibers

Nettle, or stinging nettle, is a returning plant growing in temperate and tropical wasteland areas around the world. It grows 2 to 4 meters high and produces sharp leaves and white to yellowish flowers and it belongs to the family of Urticaceaea. The genus name Urtica comes from the Latin verb urere, meaning 'to burn,' because of these stinging hairs. The species name dioica means 'two houses' because the plant usually contains either male or female flowers. Nettle has a well-known reputation for giving a savage sting when the skin touches the hairs and bristles on the leaves and stems.

Figure 2. 10 Nettle plant

2.8.1 Origin and Distribution

Dioica is originally from the colder regions of northern Europe and Asia, today this herbaceous shrub grows all over the world. Stinging nettle grows well in nitrogen-rich soil, blooms between June and September of every year, and reaches nearly 3 feet high. The stem is straight and green; the leaves are opposite, cordate at the base, oblong or ovate, finely toothed, dark green above and paler beneath. The flowers are in Reddish-brown to greenish-white color.

In Europe, nettles have a strong association with human habitation and buildings. The presence of nettles may indicate the site of a long-abandoned building, and can also indicate soil fertility. Human and animal waste may be responsible for elevated levels of phosphate and nitrogen in the soil, providing an ideal environment for nettles.

Urticadioica is considered to be native to Europe, much of temperate Asia and western North Africa. It is abundant in northern Europe and much of Asia, usually found in the countryside. It is less widespread in southern Europe and North Africa, where it is restricted by its need for moist soil, but is still common. It has been introduced to many other parts of the world. In North America, it is widely distributed in Canada and the United States, where it is found in every province and state except for Hawaii, and also can be found in northernmost Mexico. It grows in abundance in the Pacific Northwest, especially in places where annual rainfall is high. The European subspecies has been introduced into Australia, North America and South America.

2.8.2 Nettle plants in Ethiopia

Ethiopian originated stinging nettle fiber/local name Samma fiber is a plant from Urtica Dioica family which is used as the source of fiber for domestic use (rope, whip) in rural parts of our country having comparable mechanical property with sisal, banana, jute and other leaf-based fibers. So far this fiber was not commonly well known as reinforcement in the preparation of composite. In the case of domestic application nettle/samma fiber have a comparable property with jute. It is classified under the category of fibers extracted from the bast of the plant like hemp, jute, flax, etc. Stinging nettle is classified into shrub category with 30–45 species. It prefers fertile soil to grow 40 up to 120 cm in height. Stinging nettle as natural biomass, the applications that have been developed are in livestock, medicine, cosmetics and fibers.

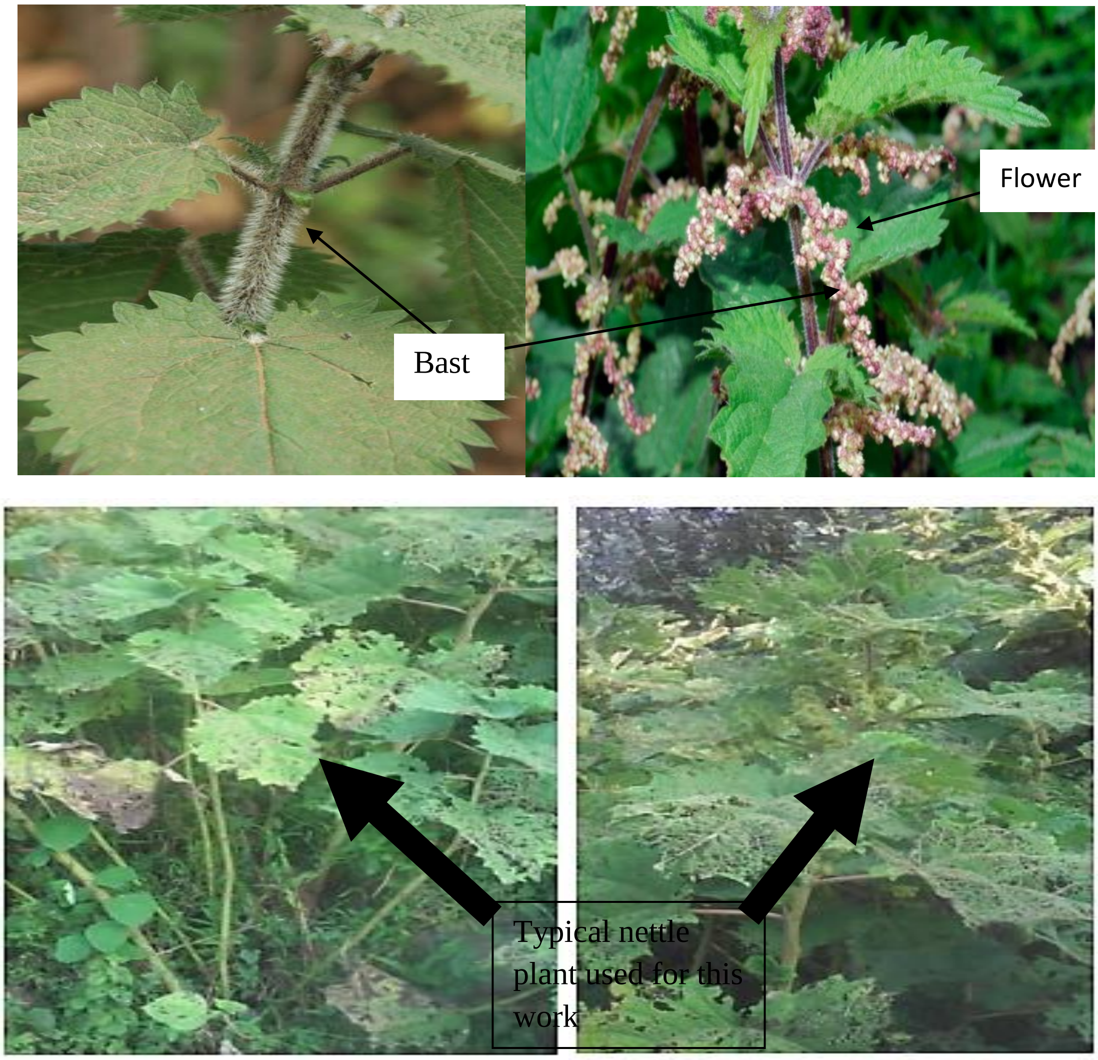


Figure 2. 11 Ethiopian origin nettle plants

2.8.3 Mechanical and physical properties of nettle fiber

Nettle fibers have high mechanical and physical properties. The Young's modulus and strain to failure obtained for nettle fibers correspond well to those reported for ramie fibers (which are part of the same family). The ultimate stress is greater for nettle fibers in comparison to ramie and equivalent to that of flax.

Table 2.1 Mechanical properties of nettle compared with other natural/synthetic fibers

Suryawan et al. (2017)

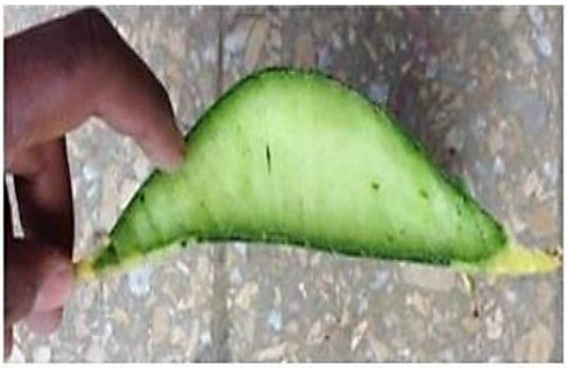
Fiber	Young's modulus (GPa)	Strain to failure (MPa)	Ultimate Stress (%)	Density (g/cm3)	Average diameter (µm)
Stinging nettle	87	2.1	1594	Na	20
Flax	58	3.3	1339	1.53	23
Hemp	35	1.6	389-900	1.07	31.2
Ramie	20-128	1.2-3.8	400-100	1.56	50
Sisal	9-21	3-7	350-700	1.45	100-300
Glass	72	3	2200	2.54	5-25

2.9 Sisal Plant

Agave sisalana (Agavaceae) is a Scientific name: Common names: sisal (English); gaming boom (Afrikaans) Sisal is Agave species of inhabitant to southern Mexico and broadly refined and familiarized in many countries. Sisal fiber is a hard fiber extracted from the leaves of the sisal plant (Agave sisal Ana). Though native to tropical and subtropical North and South America, the sisal plant is now widely grown in tropical countries of Africa, the West Indies, and the Far East. Sisal fibers are extracted from the leaves. Sisal fiber is one of the most widely used natural fibers and is very easily cultivated. It has short renewal times and grows wild in the edges of fields. Tanzania and Brazil are the two main producing countries. A sisal plant produces about 200-250 leaves and each leaf contains 1000- 1200 fiber bundles which are composed of 4% fiber, 0.75% cuticle, 8% dry matter and 87.25% water. So normally a leaf weighing about 600 g will yield about 3% by weight of fiber with each leaf containing about 1000 fibers. Fig. 2.12 shows a typical sisal plant.

Figure 2. 12 Sisal plant

The sisal leaf contains three types of fibers, mechanical, ribbon and xylem. The mechanical fibers are mostly extracted from the periphery of the leaf. They have a roughly thickened-horse shoe shape and seldom divide during the extraction processes. They are the most commercially useful of the sisal fiber. Ribbon fibers occur in association with the conducting tissues in the median line of the leaf. Fig. below shows a cross-section of sisal leaf and indicates where mechanical and ribbon fibers are obtained. The related conducting tissue structure of the ribbon fiber gives them considerable mechanical strength. They are the longest fibers and compared with mechanical fibers they can be easily split longitudinally during processing. Xylem fibers have an irregular shape and occur opposite the ribbon fibers through the connection of vascular bundles as shown in Fig. 2.13 They are composed of thin-walled cells and are therefore easily broken up and lost during the extraction process.



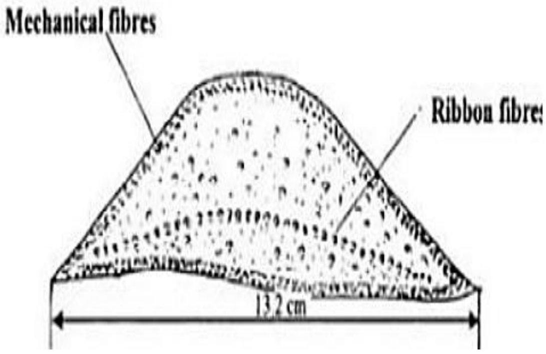


Figure 2. 13 Sisal leaf Photograph of a sisal plant

2.9.1 Sisal Plants in Ethiopia

Sisal is a plant within the same position as aloe vera. It resembles a vast aloe vera plant, with very coarse leaves that are pointy on the ends, and it can grow to be six feet tall. It produces a rigid fiber that is used for fiber in a mixture of products, such as floor mats, twine, carpet, rope, and bags. It grows in Ethiopia, especially Southern Nation of Ethiopia Gamogofa zone Arbaminch area and Amhara regional state around Shewarobit area and it could be harvested and together by local people. Here is a require for these products of Ethiopia, and there is a market for sisal in Addis Ababa, so it would go after that other belonging to people could advantage from the harvesting of the plant, as well. This would be a great opportunity to generate a more industrious people with hope for the future (Sisal Initiative – Ethiopia).

2.9.2 Sisal Fiber

Sisal fiber is a kind of natural fiber, which retains high specific strength and modulus, low Price, recyclability, easy availability. Sisal fiber is a potential reinforcement for polymer composites. Beyond its traditional applications (ropes, carpets, mats, etc.), sisal fiber has potential applications in the aircraft and automobile sectors. The physical and mechanical behaviors of sisal fiber depend on their source, age, and location, but also their fiber diameter, experimental temperature, gauge length, and strain rate. Sisal fiber is used as reinforcement to make a composite. Reinforced polymer composites have aroused great interest of materials scientists and engineers all over the world (**Jackson & Samanta, 2014**).

2.9.3 Mechanical and physical properties of sisal fiber

The chemical composition of sisal fiber depends on the location, age factor, and so on. Like other natural fibers, sisal fiber contains cellulose, lignin, hemicellulose, and moisture.

Many researchers reported that sisal fiber-based polymer composites can be used effectively in automobiles, such as their internal engine covers, door panels, hat racks, package trays, sun visors, seatbacks, and exterior or under-floor paneling. They have been used in interior paneling in the aerospace and aircraft industries. Table 2.1 compares the physical and mechanical properties of sisal fiber with those of other natural and synthetic fibers. The table shows that sisal fiber has comparable specific strength and modulus concerning glass fiber.

Table 2.2 Mechanical properties of sisal compared with other natural/synthetic fibers **(Singh, 2014)**

Fibers	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)
Sisal	1.33-1.5	400-700	9.0-38.0
Kenaf	1.2-1.24	297-930	53
Bamboo	0.6-1.1	140-800	11-32
Jute	1.3-1.46	393-800	10-30
E-glass	2.55	3400	71
Carbon	1.4	4000	230-240

2.10 Natural Fibers and Its Extraction

Natural fibers, often referred to as thin fibers, are extracted from plants and are classified into three categories, depending on the part of the plant they are extracted from. Those are:-

a. **Fruit fibers**:-are extracted from the fruits of the plant, they are light and hairy and allow the wind to carry the seeds.
b. **Bast fibers:-**are found in the stem of the plant providing the plant its strength. Usually, they run across the entire length of the stem and are therefore very long.
c. **Leaf fibers:-**fibers extracted from the leaves are rough and sturdy and form part of the plant's transportation system, they are called leaf fibers

Mukhopadhyay et al. (2009) Described fiber extraction methods like: Steam explosion and thermomechanical processes fall in the first category while plasma, dielectric barrier techniques and corona fall in the second. Several physical and chemical methods have been used to modify the fiber surface to make them more suitable for such applications. The thermoplastic polymers used as matrices are also inert. Due to the presence of hydroxyl and other polar groups in their constituents, natural fibers exhibit high moisture absorption. Increased moisture decreases the mechanical properties and provides the necessary condition for biodegradation and dimensional instability.

Physical treatments are done on natural fibers for two reasons:

- Separation of the fiber bundles into individual strands

  The first step of using the natural fibers for composites is the separation into individual filaments. Processes so far used to remove lignin are chemical treatment or chemo mechanical treatment. Water-retting, which was formerly the method of choice because of high-quality fiber, produces environmentally unacceptable fermentation waste.

- Modification of the fibers for composite applications

  The surface of the fibers can be modified by physical or chemical means. The way is to roughen the surface to enhance the contact area and facilitate mechanical interlocking.

The purpose of a composite matrix is to bind the reinforcement together and to transfer load between fibers. This binding is made due to the cohesive and adhesive characteristics of the matrix material (**Konnur, 2014**).

2.11 Alkaline Treatment of Natural Fibers

Kabir et al. (2014) studied the mechanical property of chemically-treated hemp fiber-reinforced composites. They found that due to the rapid climate changes in environment, the physical and geometrical characteristics of natural fiber and synthetic fiber components are affected. For the better surface finish of the hemp fiber composites the Chemical treatment process like alkali, acetyl and silane treatments are carried out.

Gope (2013) chemical treatments are considered in modifying the fiber surface properties. Sodium hydroxide (NAOH) treatment on the fiber would remove the impurities like pectin, facts and lignin in the fiber, resulting in improvement in the adhesion between fiber and matrix also increases mechanical (tensile, flexural and compression) properties of fabricated component.

Perumal et al. (2018). This review explained improvement in properties of natural fiber reinforced polymer composites along with its applications; the chemically treated natural fiber shows better improvement in properties than untreated fibers. The chemically treated natural fiber has improved interfacial adhesion between fiber surface and polymer matrix. Natural fiber reinforcements have shown better results in impact toughness and fatigue strength.

Mohammed et al. (2015).Evaluated the characteristics and properties of natural fiber reinforced polymer composites: mechanical, thermal, energy absorption, moisture absorption, biodegradability, flame retardancy, tribology properties. Viscoelastic behavior and relaxation behavior of NFPCs are researched. The effects of chemical treatment of the natural fiber properties were also addressed. The physical and mechanical properties of these NFPCs can be further enhanced through the chemical treatment, while moisture absorption of the NFPCs can be reduced through surface modification of fibers such as alkalization and addition of coupling agents.

Lope et al. (2007). Studied chemical treatment of fiber aimed at improving the adhesion between the fiber surface and the polymer matrix may not only modify the fiber surface but also increase fiber strength. Water absorption of composites is reduced and their mechanical properties are improved.

Martins (2017). Studied the important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. The treatment changes the orientation of the highly packed crystalline cellulose order, forming an amorphous region. It has been reported that alkaline treatment has two effects on the fiber:

- ✓ It increases surface roughness resulting in better mechanical interlocking.
- ✓ It increases the amount of cellulose exposed on the fiber surface

In general chemical treatments reduce some portion of hemicelluloses, lignin, pectin, wax and oil covering materials. Thus fiber surface became more uniform due to removal of micro voids. Stress transfer capacity between alternate cell improved and increase effective fiber surface area for good adhesion with matrix. It decrease hydrophilic nature of fiber by raising its cellulose content and stabilized the material.

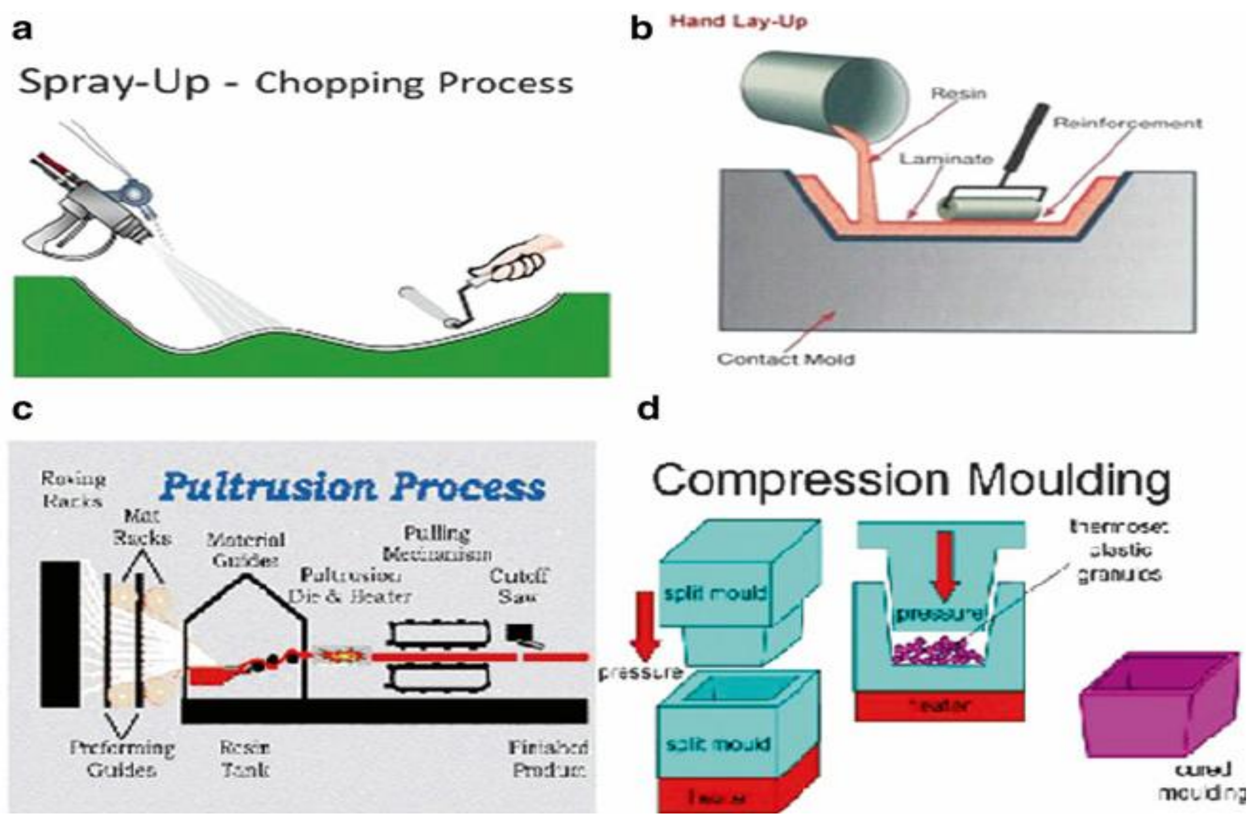
2.12 Natural Fiber Composites preparation

Fiber-reinforced composite has been fabricated by several methods depending upon the shape of component to be manufactured. All those methods fall under a principle called polymerization. Polymerization is the process of joining a large number of synthetic molecules together to form a rigid structure. The following are some important manufacturing process:

Spray layup: is also one of the hand mounding techniques which are actually an extension of hand layup method. In this method, a spray gun is used to spray pressurized resin and reinforcement that is within the shape of chopped fibers. Matrix material and reinforcement can be sprayed concurrently or simultaneously one after one. A roller is rolled with a little strain over the sprayed surface to remove the air trapped into the layups.

Compression molding: is usually used for thermoplastic matrices with unfastened chopped fiber Or mats of short or long fiber either randomly oriented or aligned, however can also be used with thermoset matrices. Filament winding: is the manufacturing process that mainly produces the open or closed end structures. The system entails winding filaments underneath tension over a rotating mandrel.

Injection Molding: Material granules for the element is fed through a hopper into a heated barrel, melted using heater bands and the frictional movement of a reciprocating screw barrel. The plastic is then injected through a nozzle right into a mold hollow space in which it cools and hardens to the configuration of the cavity**.**



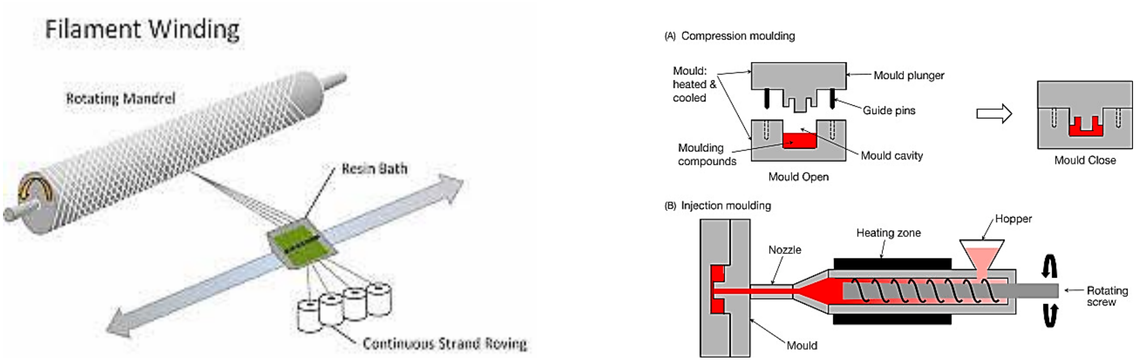


Figure 2. 14 Flament windingcompression and injection molding

Hand layup: It is a moldings approach wherein fiber reinforcements are positioned by way of hand then polymer resin is poured at the fiber reinforcement. The second layer of the fiber reinforcements is located on the polymer resin surface and a roller is moved with a little strain on reinforced fiber to avoid the trapped air between the layers as indicated in Figure. Materials used in this process are Matrix (Epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester, polyurethane resin) and Reinforcement (Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax etc.)). All these fibers are in the form of unidirectional mat, bidirectional (woven) mat, stitched into a fabric form, mat of randomly oriented fibers.

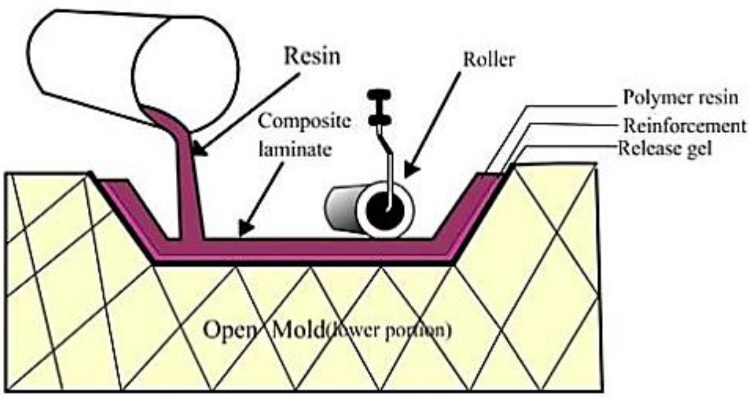


Figure 2. 15 Hand layup process components

2.13 Properties of natural fibers and synthetic fibers

Table 2.3 shows the comparison between natural and synthetic fibers. It represents the natural fibers that have moderate mechanical properties when compared to synthetic fibers like glass, carbon, Kevlar etc., but the major disadvantage of natural fibers is high moisture sensitivity **(Kumaresan. 2015)**

Table 2.3 Properties of natural fiber and synthetic fiber.

Aspects Property	Natural fiber	Synthetic fiber
Mechanical property	Moderate	High
Moisture sensitivity	High	Low
Technical Thermal sensitivity	High	Low
Resource	Infinite	Limited
Environmental Production	Low	High
Recyclability	Good	Moderate

The mechanical properties are dependent on temperature because the resins, as well as hardener and catalyst are also affected by temperature. At higher temperature, there will be fast reactions and affect the mechanical properties. A fast reaction of polymerization results in the brittle formation of resin when applied to fibers, therefore there is no proper bonding and poor interfacial adhesion between resin and fiber occurs. Higher curing time will also affect the results because oxygen is entrapped and bubble formation takes place. As the curing temperature reduces, the mechanical properties will be better due to the proper adhesion of fiber and matrix laminates. Therefore when the tensile force is applied to the composites it resists the applied force to delaminate the fibers from the matrix due to better adhesion between fiber and matrix (**Mamat, 2012).**

The use of natural fibers can reduce harmful impurities, and their eventual breakdown is environmentally benign. Natural fibers emit less CO_2 when they break down than is absorbed during plant growth. Fiber-producing crops are easy to grow **(Cioara, 2016).**The Table below shows the comparable property of nettle fiber and sisal fiber with other natural fibers **(Sanjay, 2016).**

Table 2.4 Comparison of mechanical properties of sisal and nettle fiber

Fiber	Young modulus [GPa]	Strain to failure [%]	Ultimate stress[MPa]	Density [g/cm^3]	Average diameter
Sisal	9-21	3-7	350-700	1.45	100-300
Lignin	58	3.3	1339	1.53	23.0
Hemp	35	1.6	389-900	1.07	31.2
Ramie	20-128	1.2-3.8	400-1000	1.56	50.0
Glass	72	3	2200	2.54	5-25
Nettle	87	2.11	1594	0.72	20.0

Applications of the composite

Natural fiber composites can be very cost-effective material for the following applications: Building and construction industry: sheets for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc.

- ✓ Storage devices: post-boxes, grain storage silos, etc.
- ✓ Furniture: chair, table, shower, bath units, etc.
- ✓ Electric devices: electrical appliances, pipes, etc.
- ✓ Everyday applications: lampshades, suitcases, helmets, etc.
- ✓ Transportation: automobile and railway coach interior, boat, etc.

CHAPTER THREE

3. MATERIAL AND METHODS

This chapter deal with the materials and methods used for making the composite as well as the chemical treatments and the machines and test methods used to characterize the fabricated hybrid composite.

3.1 Matrix

The matrix is a homogeneous and monolithic material in which a fiber system of a composite is embedded. It is completely continuous. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, color, durability and functionality.

Resins are of at most importance matrix material within the composites markets as they bind the fibers together and help create the material's strength and stiffness characteristics. There are two types of resin systems: thermoset and thermoplastic. In a thermoset, the resin molecules are locked together irreversibly after a thermal cure; it is a one-way cure that cannot be undone. In a thermoplastic resin, the chemical link which is bonding the molecules together can be broken again and again by increasing the temperature steadily which causes the matrix to go from solid to liquid. In the same way, when cooled down the thermoplastic matrix solidifies. Thermoset resins that are playing a key role in the composite industry include Polyester, Vinyl Ester, Epoxy, and Phenolic Resin, etc. Among the above different thermoset, resin polyester is used for this research work.

3.1.1 Polyester

Polyester resins are one of the most common resins used in the composite industry. The success of Polyester is mainly based on the low cost that makes it more attractive than some higher-performing resins like epoxies. Polyester resins require a catalyzer, which functions as an initiator of the chemical reaction, to solidify. The quantity of catalyzer effects on the speed of the reaction and is responsible for the solidification. During the cure the polyester resins shrink significantly. The resin used for this study is polyester resin with brand name of general-purpose polyester resin.

Advantages of polyester resin over other resins

- Polyester resins are relatively cheap in comparison to other types of resin
- It can accept a broad variety of fillers which makes them applicable to a wide range of projects.
- Polyester is not impacted by UV radiation like other resins which are essentials for applications exposed to the sun, for instance, surfboards

3.1.2 Hardener (catalyst)

Epoxy resin is cured by adding a catalyst, which causes a chemical reaction without changing resin, is cured by adding a catalyst, which causes a chemical reaction without changing its composition. The catalyst initiates the chemical reaction of the epoxy resin and monomer ingredient from liquid to a solid-state. The liquid epoxy resin is a hardener HY-951 purchased from the local market.

3.1.3 Wax

After applying polyvinyl alcohol (PVA) to the mold; Meguiar's Maximum Mold Release Wax (M-08 v2.0) shown in Fig was used for ease release of mold from the composite material. Applying a thin coat of wax and wipe off or polish the haze/obscure/ part using cloth towel is recommended for better performance of the material.

Figure 3. 1 Wax release

3.1.4 Functions of a Matrix

In a composite material, the matrix material serves the following functions:

- Holds the fibers together.
- Protects the fibers from environment.
- Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.
- Improves impact and fracture resistance of a component.
- Helps to avoid propagation of crack growth through the fibers by providing an alternate failure path along with the interface between the fibers and the matrix.
- Carry interlaminar shear.

3.2 Reinforcement

A strong, inert woven and nonwoven fibrous material is incorporated into the matrix to improve its metal glass and physical properties. Typical reinforcements are asbestos, boron, carbon, metal glass and ceramic fibers, flock, graphite, jute, sisal and whiskers, as well as chopped paper, macerated fabrics, and synthetic fibers. The primary difference between reinforcement and filler is the reinforcement markedly improves tensile and flexural strength, whereas filler usually does not. Also to be effective, reinforcement must form a strong adhesive bond with the resin.

3.2.1 Sisal fiber

A suitable quantity of sisal plant leaves will collect from different aria of our country, Ethiopia. The fibers are extracted through hand extraction with a knife. The length of sisal fiber is between 1.0 and 1.5 m and the diameter is about diameter 50–200µm **(Satena, 2005).**

3.2.2 Nettle fiber

Like sisal fiber, suitable quantity of nettle plant leaves will collect from different aria of our country, Ethiopia. The fiber is extracted by using the method of extraction mention above. It will exhibits the following physical properties as a length of 5-75 cm, fineness 1.0-1.2 tex, diameter under X400 microscopic view 5- 6microns

3.2.3 Glass Fiber

Glass fiber is a material that contains extremely fine fibers of glass. It has less weight, awfully strong, and vigorous. The glass fibers are prepared when thin strands of silica glass are extruded into many fibers with small diameters. Its majority strength and weight properties are also very satisfactory when compared to the metals, and it can be certainly made using molding processes. This is used as the reinforcing agent for mixtures to form a very tough and light fiber-reinforced polymer (FRP) composite material. Depending on the final use of the products, several types of glass fibers are produced. Out of these glass fibers, more than 90% are E-glass fibers, which are inexpensive and used for much general application.

3.3 Sodium Hydroxide (NaOH)

Sodium hydroxide, also known as lye or caustic soda, has the molecular formula NaOH and is a highly caustic metallic base and alkali salt. In this work NaOH will be used in pellets form, purchased from local suppliers with the brand name and code of RANKEM, S0290 respectively to perform chemical treatment of sisal and nettle fiber. Caustic soda forms a strong alkaline solution when dissolved in a solvent such as water. It is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents **(Greenwood, 1997).** Table 3.1 shows that list and amount of material required for the fabrication of the composite. The selection of the materials was based on amount of sample prepared with relative to the percent composition ratio.

Table 3.1 List and amount of material required

Item	Unit	Quantity
Nettle fiber	Kg	5 kg
Sisal fiber	Kg	5 kg
Fiber glass (E- glass)	Kg	1.5kg
Sodium hydroxide (NaOH)	Liter	1 lit
Hardener	Liter	2 lit
Glove	Packet	1 Pac
General purpose resin	Liter	10 lit
Sand paper	Pics	15 pic

Paint	Can	1.5 can
Distilled water	Lit.	30 Lit.
Wax	Kg	1 kg

Table 3.2 Equipment used

Items	Quantity/ unit
Molds	3
Normal brush	3
Roller brush	2
Mixing container	2lit.
Steel rule	2m
Scissor	1
Weighting machine	2
Grinding machine	1
Drilling machine	1
SEM	1
Optical microscope	1

3.4 Fiber extraction

3.4.1 Extraction of nettle fiber

Ethiopian Origin Stinging Nettle/samma was collected after drying on the field after germination which takes around 5 to 6 months. Its height measures from 2-3m depending on the soil fertility. Plant harvesting process can be accomplished using different local equipment, in this work traditional farm machinery like Machid, small axe etc. were used. **Figure 3.2** shows the collected Ethiopian origin stinging nettle.

Figure 3. 2 Ethiopian origin stinging nettle plant

The nettle plant fiber was extracted after complete growth of the plant which takes about five to six months. After collection to extract the fiber, here are two approaches to extract the fiber from its bast.

- The first method is first crush the stem and then collect the bast from the week's internal structure of the hallow plant. This method was used in this work.
- The second one is soaking the nettle stem with its bast in to the water at least for some limited times as the bast becomes easy to remove, then separate the bast of Ethiopian origin stinging nettle from the stem, and process it for better fiber quality. This process makes the fiber extraction easy and protects the fiber from a breakdown but some of the fiber destroyed.

Figure 3. 3 Processing and collected nettle fiber product after processing

As observed from Figure 3.3 the nettle fiber was still needed another method to purify. Therefor it was soaked in water for a day, which helps to remove the external epidermis of the bast to have better mechanical properties in composite production indicated in Fig. 3.4.

Figure 3. 4 Soaking nettle fiber into the water for further purifications

3.4.2 Extraction of sisal fiber

Sisal fiber can be extracted from its leaves by the following methods.

Retting: Water retting is a traditional biodegradation process involving microbial decomposition (breaking of the chemical bonds) of sisal leaves, which separates the fiber from the pith. The fibers are washed and processed further. This process takes 15–21 days for a single cycle of extraction and degrades the quality of fiber. Retting is a very slow, water-intensive process, unhygienic, and not eco-friendly. Fiber extracted by this method is poor in quality.

Boiling: In this method leaves of the sisal plant are boiled, next beating is done then after washing and sun drying it may give the usable clean fiber. This method is not suitable for large-scale extraction **(Lewin. 2007).**

Mechanical Method: Mechanical extraction involves inserting leaves into the Raspador machine and pulling the raw material out. A harmless mechanical extraction method, this process does not worsen the fiber quality and is suitable for small-scale operations. The Raspador, run by an electric motor, is efficient, flexible, safe for labor, and cost effective; it takes minimum time and is an eco-friendly process. Also, residues are available after extraction of fiber of which about 96% is useful for other applications, such as biogas generation, composting, and isolation of a steroid, hecogenin.

Decortication: 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. Initially` the leaves trimmed in longitudinal direction into strips for ease of fiber extraction The peel is clamped between the wood plank and knife and hand-pulled through in longitudinal direction gently, removing the resinous material as shown in Fig. 3.5 (c) and (d) then the extracted fiber washed with pure water to loosen, and separate the fiber until individual fibers are obtained.

(a) (b)

(c) (d)

Figure 3. 5 Sisal fiber extraction process

3.4.3 Chemical treatment of fiber

The characterization of the interface between fiber and matrix is largely important during the development of composites. To improve the interface for producing composites with better mechanical properties chemical treatment has to be done. Because of this improvement, treatments of fibers are used plus helps to improve the surface of reinforcement (**Mohit Sooda, 2018)**

In the other way natural fibers should pass through upper surface pretreatment to improve the adhesion property between the fiber and matrix by modification of the fiber and polymer matrix using physical and chemical methods, in this work alkaline treatment /NaOH/ was used to treat the fiber.

3.5 Overall importance of chemical treatment of nettle and sisal fibers

- ✓ To improve an adhesive properties for fiber–matrix interface
- ✓ To improve fiber's shear strength
- ✓ To improve fiber's rigidity and stiffness
- ✓ To improve moisture absorption problems
- ✓ To reduce fiber's weight etc.

However, as concentration of NaOH increased the result obtained deteriorated the mechanical properties of the fibers. Because of that, after several trials, medium concentration of NaOH (i.e. 5%) is used for this work. In general, this study consumed totally 330ml of molten NaOH for all fibers used in this product. Eq.3.1 and 3.2 show the chemical reaction between nettle/sisal fiber and aqueous sodium hydroxide solution.

Nettle fiber -OH +NaOH → FIBER-O-Na+ H2O …………………………….. (3.1)

Sisal fiber-OH +NaOH → FIBER-O-Na+ H2O…………..…………………… (3.2)

3.6 Alkaline/ Mercerization / treatments of nettle fibers

The time requirement to soak nettle fiber in NaOH depends on the concentration of base with a concentration ranges from 2% up to 10% in distilled water. So time varies from 2 to 8 hrs. By observing the physical change takes place in the solution. As undesirable components of the fiber are removed, it is washed with distilled and fresh water again and again until the base/NaOH component is removed. Finally, the PH value of the water used to wash can be tested. Distilled water is taken from Adama Science and Technology University, a material science lab with a distiller machine have a capacity of 15ltrs per hrs. Shown in Figure 3.6 and from Adama Wudeneh bajaj spare part and oil seller shop.

Figure 3. 6 Water distiller machine setup of the material science department and Adama Wudeneh bajaj spare part and oil seller shop distilled water.

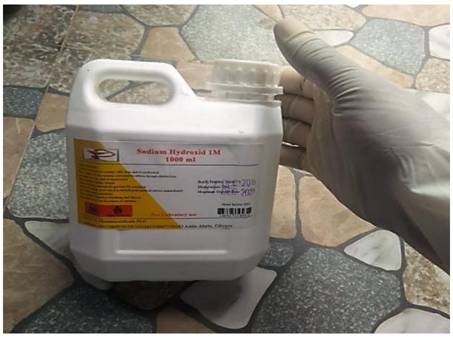


Figure 3. 7 NaOH in liquid form

Figure 3. 8 Soaking nettle fiber in NaOH solution and drying it in the sun

3.7 Alkaline/ Mercerization / treatments of sisal fibers

After extraction of sisal fiber in order to increase interfacial surface adhesion fiber are chemically treated the same as to nettle fiber using NaOH solution. The solution was prepared with 5% NaOH concentration. Next soaked the fibers in NaOH solution for 24 hours. After treatment, the fiber was washed many times with distilled and tap water. Finally, these fibers dried in sunlight for two days or more. After the fiber dried, bidirectional nettle and sisal fiber is woven with the proposed composition and orientation is prepared.

Figure 3. 9 Soaking sisal fiber in NaOH solution and drying in the sun

3.8 Composite sample preparation

To prepare the composite from Ethiopian origin stinging nettle (samma) local plant and sisal fiber is used as a reinforcement component with E-glass fiber and the matrix is general-purpose resin. By hybridizing those materials the expected composite will be manufactured.

Before hybrid reinforcement of nettle fiber and sisal fiber with E-glass fiber, matrix volume fraction and fiber volume fraction %wt of these composite material is estimated. Finally nettle, sisal and glass fiber with polyester resin hybrid composite is fabricated. As mentioned above composite materials can be prepared by different methods. However due to many reasons such as part size and shape, cost, familiarity with the technique and availability of tools, in this work composite was fabricated using hand layup techniques.

3.9 Concept of Hybridization

The combination of several different types of fibers into a single matrix has led to the development of hybrid bio composites. The behavior of hybrid composites is a weighted sum of the individual components in which there is a more favorable balance between the integral advantages and disadvantages. Also, using a hybrid composite that contains two or more types of fiber, the advantages of one type of fiber could balance with what are lacking in the other. They support each other. As a consequence, a balance in cost and performance can be achieved through proper material design.

3.9.1 Factor affects property of hybrid composite

- length of individual fibers
- fiber diameter or thickness
- Fiber selection
- Matrix selection
- fiber content/concentration/
- orientation of fiber
- degree of intermixing of fibers
- Interfacial strength/ fiber to matrix bonding.
- porosity
- Composite manufacturing process/method etc. **(Pickering, 2015).**

In this thesis work Bio fiber- Bio fiber Composite type is used by hybridizing nettle and sisal fiber in matrix system .The composite was prepared varying fiber orientation and by loading the amount of fibers in different ratio %w and fixing other parameter as specified in table below.

Table 3.3 General work specification

Factors	Specifications
Type of hybrid	Bio-fiber to bio fiber hybrid composite(nettle and sisal)
Matrix type	Polyester resin (Thermoset polymer)
Fiber/matrix volume content	Determined after fabrication
length of individual fibers	long fiber for both
Fiber to fiber ratio (%w)	(20NF,10SF,10G), (15NF,15SF,10GF), (10NF,20SF,10GF) for both $90^0/0^0$ and 45^0
Interfacial strength	Both fibers are treated

Composite structure	Intralayer
Fiber orientation	Bidirectional $0^0/90^0$ or $90^0/0^0$ and 45^0
Fabrication Method	Hand lay up

3.10 Fiber orientation

It is unusual for fibers in the composite laminate to be perfectly aligned. Woven fabrics introduce a crimp to fibers which causes misalignment of load paths. Even non-woven fabrics can suffer from some crimping around stitch points. The misalignment of fibers causes dramatic loss of mechanical properties, particularly in compression, due to the increased likelihood of buckling.

The fiber orientations in plants are optimized to the occurring forces, especially to the bending of plants by wind forces. To achieve multidirectional isotropic behaviors, proper fiber orientation in different angles is necessary, which can only be done by multiply laminate preparation. Fabric types are categorized by the orientation of the fibers used and by the various construction method used to hold the fibers together. The four main fiber orientation categories are:

1. Unidirectional,(0 or 90 degree)
2. 0/90 or bidirectional
3. Multiaxial and
4. Other/random

Better composite performance can be obtained where the load is applied in the direction of fiber orientation at (0^0), and this may be due to the ability of composite material to carry out loads in direction with reinforcement fibers, and this ability decreases with increasing of fiber orientation angle at (90^0) (**Madeh, 2016).**

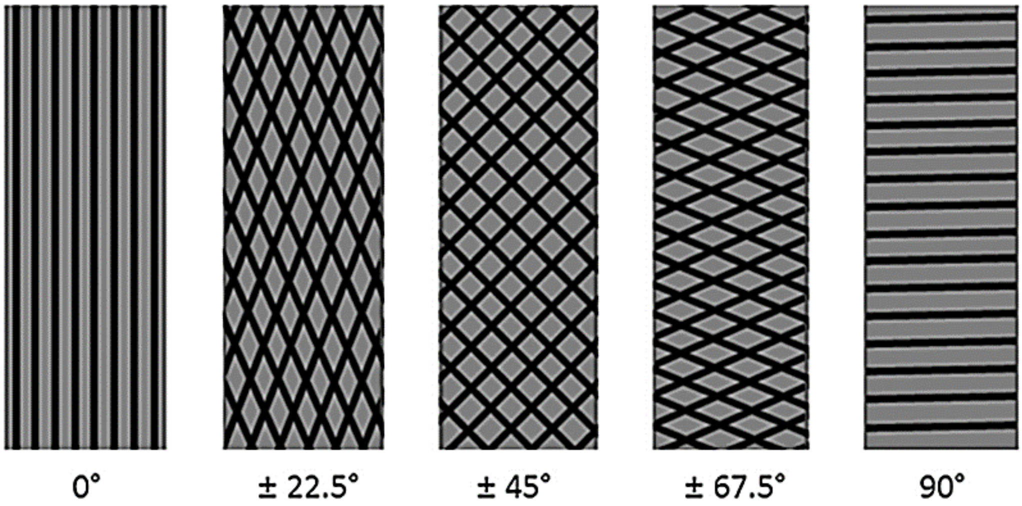


Figure 3. 10 Schematic illustrations of the composites with different fiber orientation (Michael et al, 2018)

3.10.1 Unidirectional fiber orientation

Unidirectional tapes have been the standard within the aerospace industry for many years, and the fiber is typically impregnated with thermosetting resins. Tape products have high strength in the fiber direction. The fibers are mixed with the resin.

3.10.2 Bi-directional fiber orientation

Most fabric constructions offer more flexibility for the layup of complex shapes than straight unidirectional tapes offer. Fabrics offer the option for resin mixed either by hot melt or the solution process. Generally, fabrics used for structural applications are like fibers or strands of the same weight or yield in both the warp (longitudinal) and fill (transverse) directions. For aerospace structures, tightly woven fabrics are used to save weight, minimizing size, and maintaining during the fabrication process.

Kumaresan et al. (2015) Samples of different orientations of sisal fiber-reinforced composites were fabricated by compression molding and investigated their mechanical properties like tensile strength and flexural strength. The work of this experimental study has been carried out to determine the mechanical properties due to the effect of sisal fiber orientations such as $0^0/90^0$, 90^0 and 45^0 orientation. The results of this study indicate the orientation 90 shows better mechanical properties compare to $0^0/90^0$ and 45^0.

Senthilkumar et al. (2016) The different types of oriented composites investigated were 90º/0 º /90 º, 0 º /90 º /0 º, 90 º /0 º /0 º /90 º, 0 º /45 º /0 º, 0 º /90 º /45 º /45 º /90 º /0 º, 0 º /45 º /90 º /90 º /45 º /0 º and these composites were subjected to tensile testing according to ASTM: D3039-08. The sisal fibers were arranged in various angles with the help of a specially designed mold. It was found that the tensile strength of sisal fiber composites improved when 0 º oriented fibers were positioned at the extreme layers of the composites compared to 90 º oriented fibers. The highest tensile strength among the types of composites was observed for 0 º /90 º /0 º.

Salman et al (2015). There work characterizes and evaluates the physical, mechanical, and morphological properties of plain woven kenaf fabric and its composites with three types of thermoset resin at $0^0/90^0$ and $45^0/-45^0$ orientation, to assess their suitability as lignocellulosic reinforced polymer composites. A vacuum infusion manufacturing technique was used to prepare the specimens with a fiber weight content of 35% ± 2%. Eight specimens were prepared for each test, and five replications were adopted. A total of 78 samples were tested in this study. The results show that the composites with $0^0/90^0$ had the highest tensile, flexural strengths, and modulus.

Table 3.4 shows that the number of layers used for composite production mechanical properties are affected by the fiber orientation, as test observation shows that [0/90]° have a higher mechanical strength (Ultimate Tensile Strength, Modulus of Elasticity and Ultimate Tensile Strain) compare to chopped strand mat (CSM) and [±45]° fiber orientation **(Jimit, May 2017,).**

Table 3.4 Effect of composites fiber orientation on mechanical properties

Orientation	UTS_{ave} MPa	εult_{ave} mm/mm	E_{ave}, MPa
CSM	71.6	0.11	995.2
$[0/90]^0$	166.2	0.21	1947.7
$[\pm 45]^0$	40.7	0.18	713.9

Hossain et al. (2013) studied that tensile strength and strain to failure are proportional with the fiber orientation angle; as lamina angle increases those properties decrease indicated.

As stated in Table 3.5 when several layers used for composite fabrication mechanical properties are affected by the fiber orientation, as test study shows that [0/90]° have higher mechanical strength (Ultimate Tensile Strength, Modulus of Elasticity and Ultimate Tensile Strain) compare to chopped strand mat (CSM) and [±45]° fiber orientation (**Jimit, May 2017**,).

Work specification

Table 3.5 General product specification

Sisal wt%	Nettle wt%	E-glass wt%	Resin wt%	Orientation	Product code (sample name)
10	20	10	60	0^0 /90^0	1
20	10	10	60	0^0 /90^0	2
15	15	10	60	0^0 /90^0	5
10	20	10	60	45^0	3
15	15	10	60	45^0	4
20	10	10	60	45^0	6

Weave preparation: - The weaves are prepared according to the work specification stated in the table above. Three of them are manufactured along 0/90 degree orientation of fibers and the left three of them are 45 degree orientation of fibers.

Figure 3. 11 $0^0/90^0$ and 45^0 woven preparations

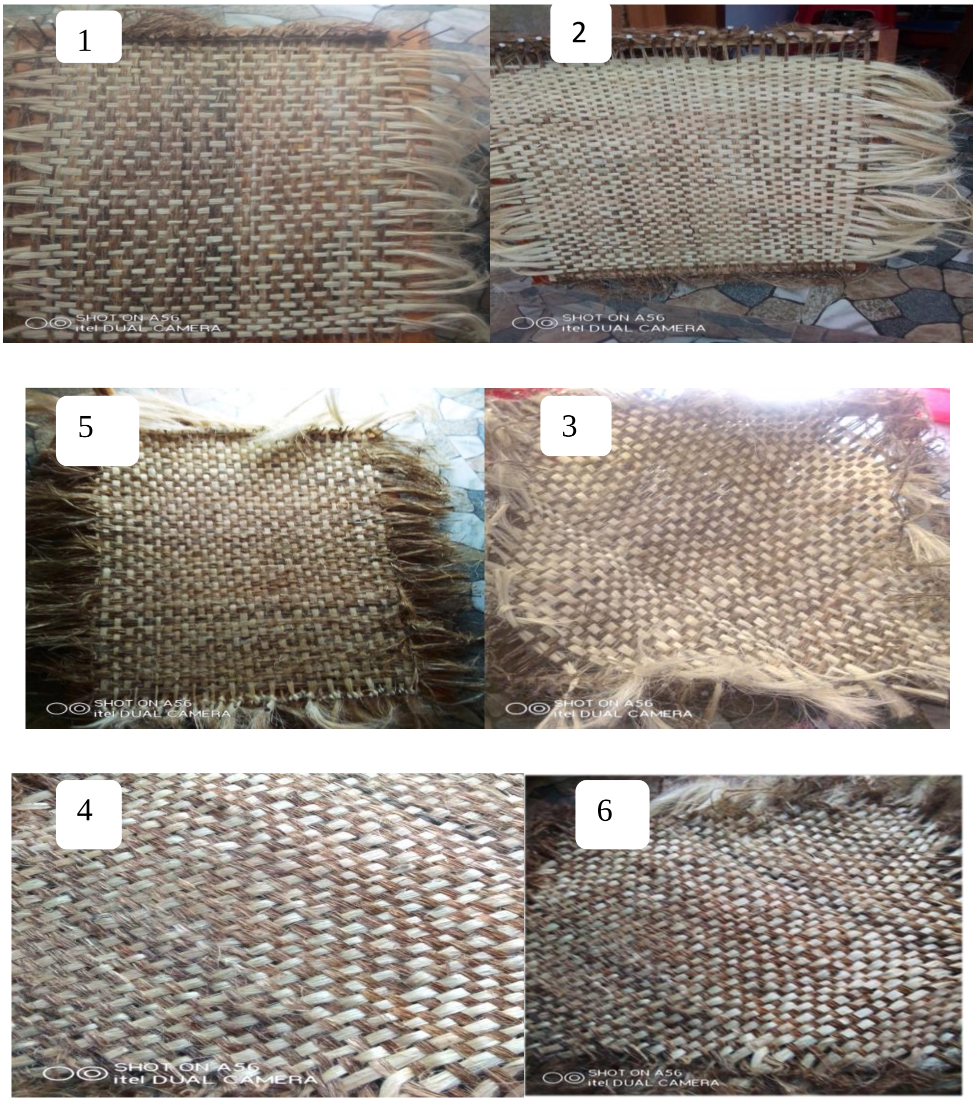


Figure 3. 12 Nettle and sisal bidirectional woven (1) nettle 20wt% and sisal 10wt% (2) nettle 20wt% and sisal 10wt% (5) nettle 15wt% and sisal 15wt% (3) nettle 20wt% and sisal 10wt% (4) nettle 15wt% and sisal 15wt% (6) nettle 10wt% and sisal 20wt%. NB: 1, 2 and 5 are $0^0/90^0$ orientation whereas 3, 4 and 6 are 45^0 fiber orientation.

In short the process to obtain both fibers mat (nettle and sisal) can be expressed pictorially as follows.

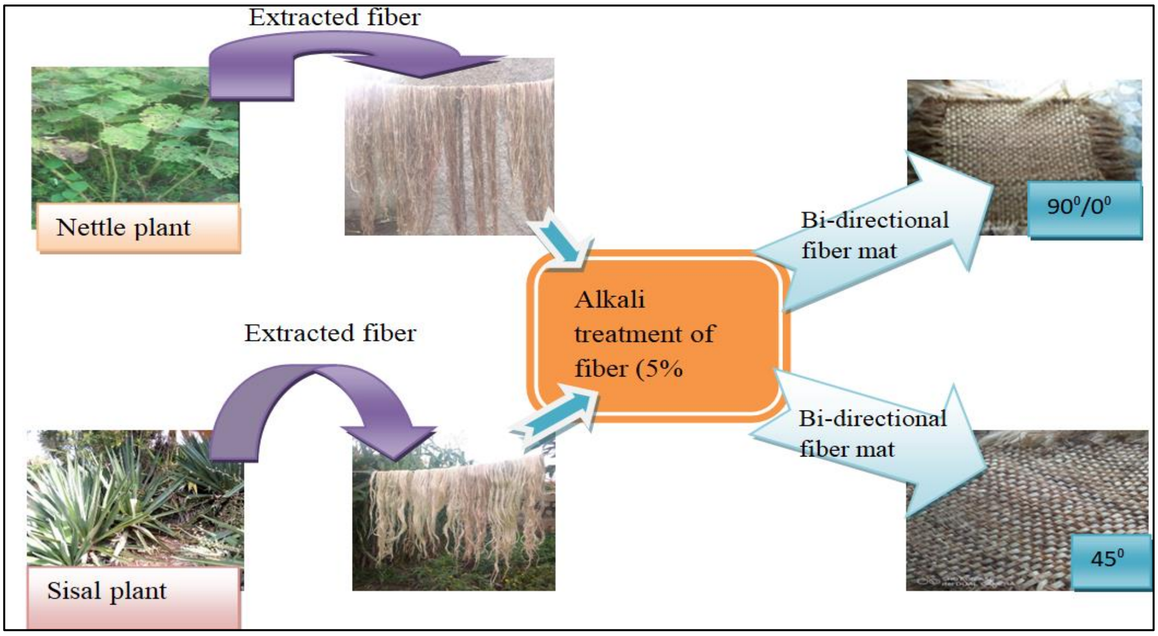


Figure 3. 13 Pictorial views for the process to make bi-directional mats (Nettle and sisal fiber).

Based on Table 4.1 the effect of orientation on mechanical properties. Test specimen plate was prepared in $90^0/0^0$ and 45^0 woven forms and its weight was measured in digital weight metering machine.

Figure 3. 14 Weighing of single mold size natural and synthetic fiber

3.11 Hand layup process

The composite was fabricated by using the hand layup technique. But the drawback of the process is negotiated.

The mold was cleaned and (PVA) polyvinyl alcohol was applied to the surface of the mold. The mold realizing wax was used to make the product removal easier. A gel coat was applied on the prepared mold with the help of a brush with uniform thickness to get the better surface finish of the expected product. The general purpose resin matrix was prepared with a pre-determined composition of 1% with a catalyst which, facilitates the drying process of the composite. It was stirred with simple mechanical stirring to mix properly, till the mixture became warm (exothermic reaction).First, introduce a small amount of resin over the gel coat of the mold. And then laid E-glass fiber equivalently, then proceed to add an adequate amount of matrix while pushing with roller brush to spread properly and prevent the formation of a bubble. After checking as the resin spreads well, prepared nettle and sisal fiber bidirectional plain weave orientation layer over the resin. Again apply the matrix and swab very well to avoid trapped air and to prevent the formation of porosity which initiates crack for failure. The third layer (E –glass fiber) was added in, similar manner as previous. Finally, clamps were tightened to expel excess matrix material from the mold cavity to avoid the formation of voids that could be caused by air spaces.

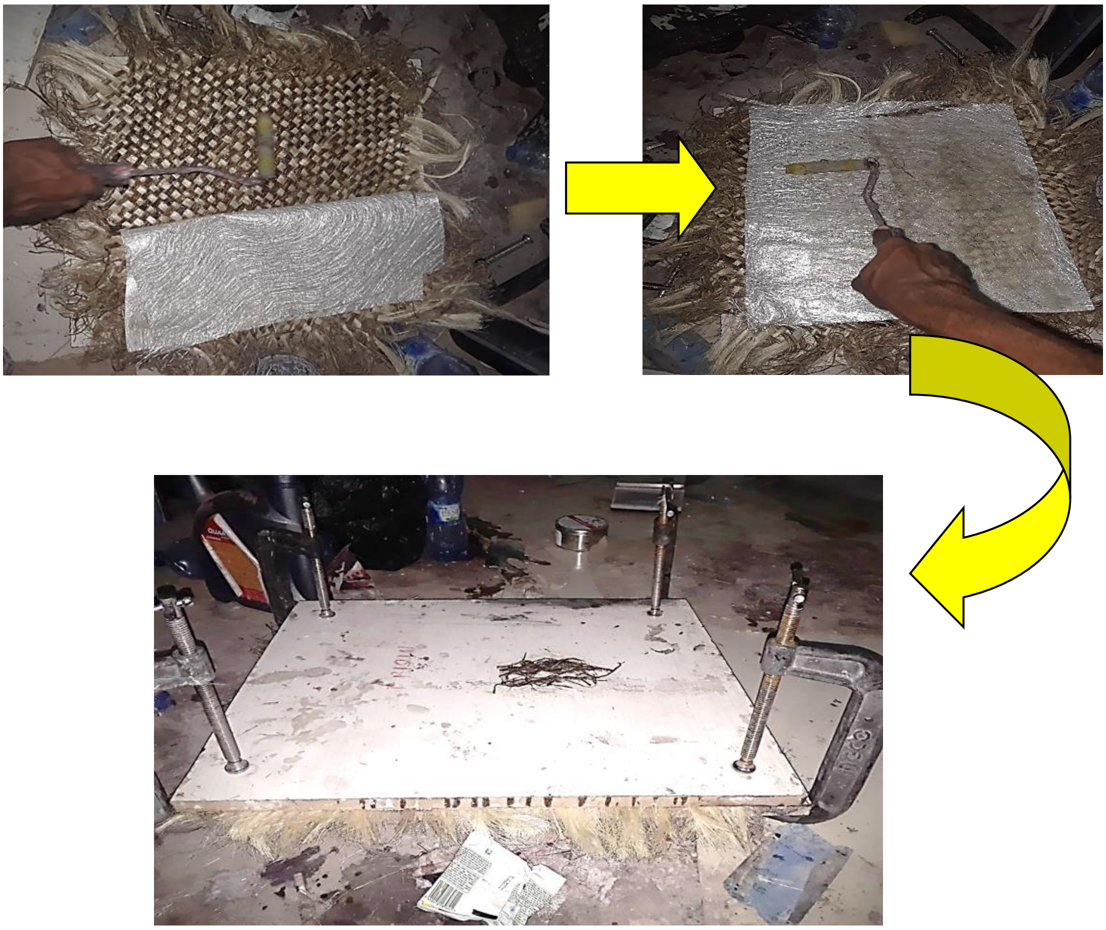


Figure 3. 15 Fabrication process of composite by hand layup process

The composites were removed from the mold and post cured in the air for 24 hours. And then specimens are prepared according to the ASTM standards machine specification to be tested.

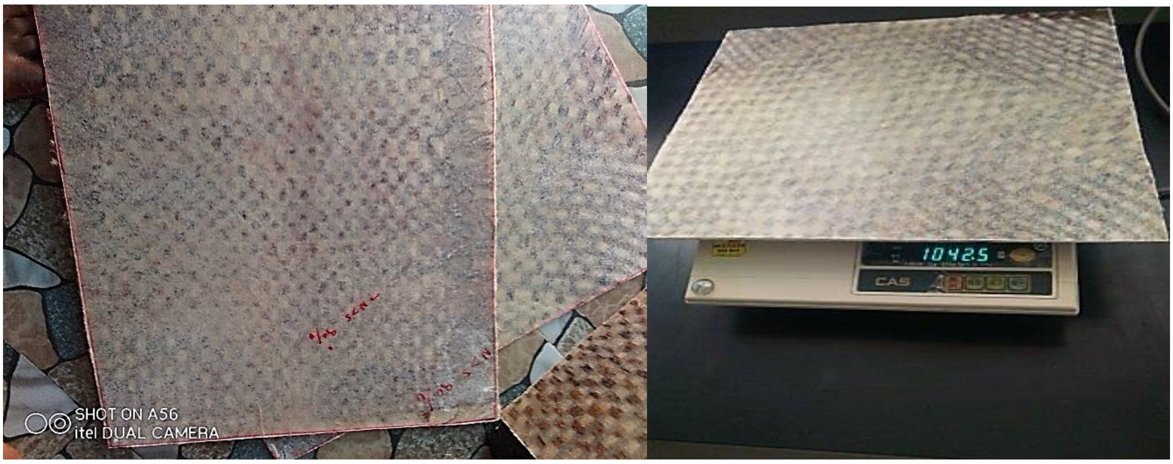


Figure 3. 16 Final product plates and its weighing

Generally, the natural fiber hybrid composite preparation was carried out through the following steps.

1. The chemically treated nettle and sisal fiber were arranged according to required fiber orientation, in this work two fiber orientation with better performance ($90^0/0^0$ and 45^0 woven) is used based on literature.
2. E-glass fiber woven was prepared for the size of the metal surface plate (mold). (Two E-glass woven was used for each product. Up and bottom)
3. Determine the weight of nettle, sisal fiber, and E-glass fiber to be used.
4. Polyester resin is mixed with 1% of catalyst and steered for 15min. These help to minimize the composites curing time.
5. Apply PVA and wax on the mold surface by using clean material respectively.
6. First single E-glass layer is placed on the mold. Then, the matrix is applied and, it was dispersed well with the help of brushes and roller as shown in Fig 3.14. After checking as the resin spreads well, put prepared nettle and sisal fiber bidirectional plain weave orientation layer over the resin. Again apply the matrix and swab very well to avoid trapped air with natural fiber to prevent the formation of porosity, which initiates crack for failure. The third layer was added similarly to the former.

7. Put the upper mold on the second E-glass fiber.
8. Finally the clamp was tightened lower and upper mold to remove excess resin and attain required thickness of the composite material.

3.12 Weight Composition:

After forming the required fiber orientation, each component was measured, except the resin. Two-layer glass fibers were used, with the sandwich of nettle and sisal natural fiber in the middle. To have the resin composition, it is possible by subtracting the summation of the three fibers from the product weight. As the measurement shows in Figure 3.14, that bidirectional nettle and sisal are woven fiber weights 211.6g, and a single layer of E-glass woven is 50.4g. But in composite plate production, two layers of glass fiber, one in the bottom and the other one at the top are used. So, the total mass of fibers used for this sample becomes 211.6g+2(50.4) = 312.4g. While the matrixes weight can be estimated, by subtracting from plate weight, which measures 1042.5g shown in Figure 3.16.

The weight composition (wt%) can be determined by using a mathematical approach between ingredients mass and total mass. Therefore wt% of fiber is calculated as follows. wt% of fiber=$((W_{fiber})/W_{composite})\times100$, finally wt% of fiber=(312.4g/1042.5g)×100= 29.96% the remaining weight fraction is the matrix one which is the weight fraction of polyester resin, numerically wt% of resin=(730.1g/1042.5g)×100= 70%. As many researchers agreed that to have a better mechanical properties of natural fiber composite the weight composition should be around 40/60 % to 30/70 % for fiber and matrix respectively.

The density of the material can be determined from this measured weight value and average dimension measurements. So the average dimension reading of a 1042.5g composite material is 450mmx400mmx5mm.

Therefore density can be calculated as follows ρ = (1042.5g/ (45×40×0.500) cm^3) = $1.158 g/cm^3$

3.13 Experimental Procedure and Setups

3.14 Preparation of specimen

ASTM was used to prepare and conduct a test of this nettle, sisal, and glass fiber reinforced hybrid composite. All the test pieces for tensile and other testing are based on the ASTM standard. But for impact test based on [ISO 9001:20001, 2010]

3.14.1Tensile test

The dog bone type of tensile test specimen was prepared. But some final specimen dimension measurements have a deviation from expected/ordered standards. These specimens were prepared depending on the ECAE's UTM machine standard dimension. From each fiber orientation composite plate, one test specimen ware required.

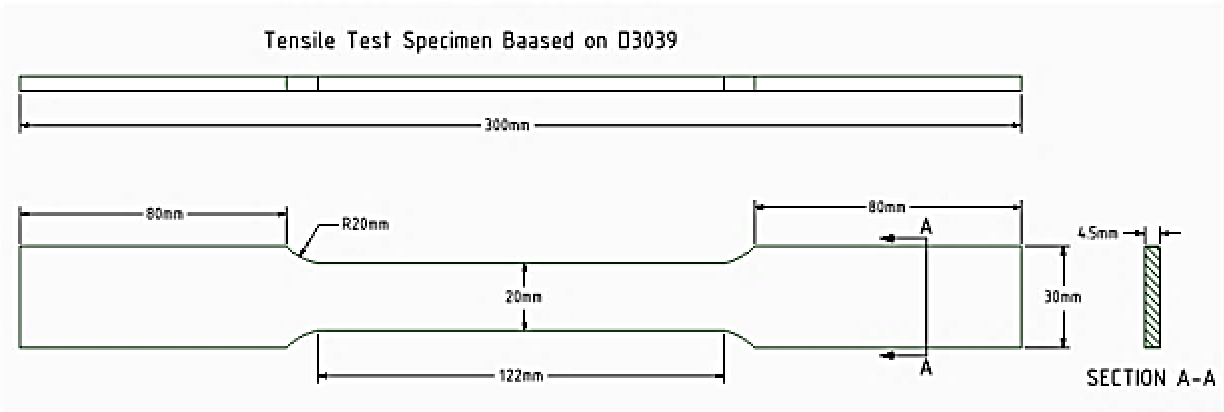


Figure 3. 17 Tensile test specimen

Specimens are designated as S1, S1', S2, S2', S3, S4, S5, S5' and S6 for researchers' identification.

Figure 3. 18 Tensile test specimens

Universal Testing Machine (UTM):-Tensile test was conducted in Ethiopian Conformity Assessment Enterprise in Addis Ababa, Ethiopia. The UTM is connected with a computer display which allows us to print the test output (stress-strain curve in this case). The machine has a strength correction factor after having direct computer printout data depending on the load applied to break the specimen. Specimen dimensions, speed of the machine, alignment and others were fixed before machine startup.

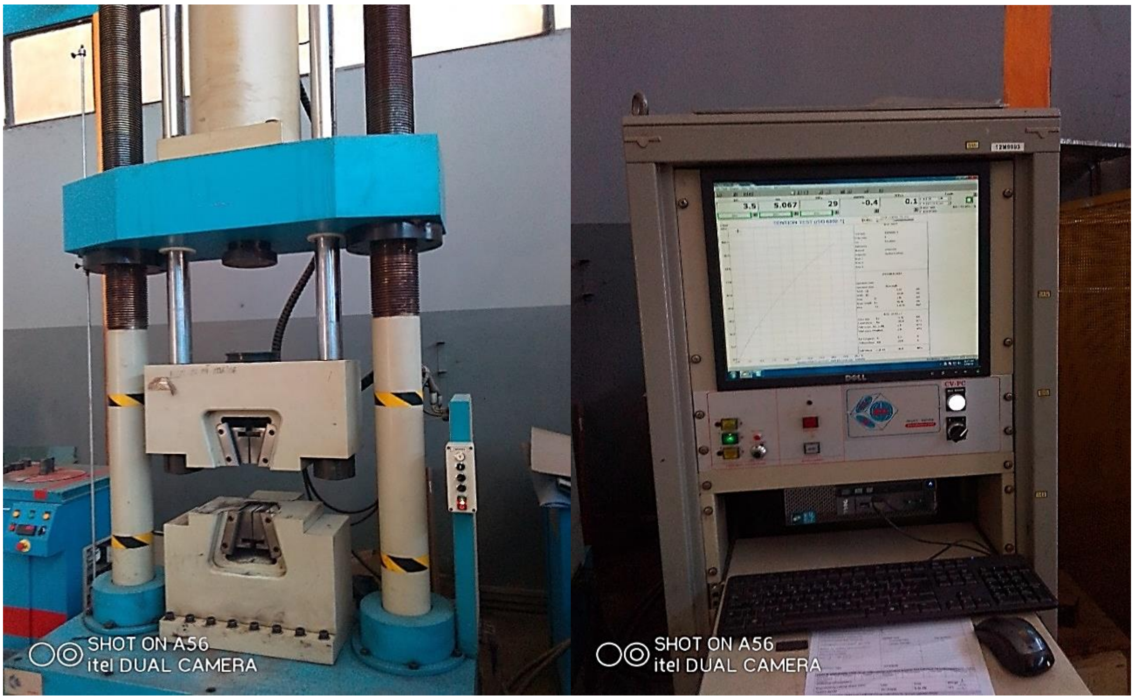


Figure 3. 19 UTM

The composites were then characterized for tensile properties using test method ASTM D3039. The specimens of each category were tested and the results were presented. For each composite specimen, the thickness was determined the thickness measurements were performed at 3 places along the length of each specimen. Overall sample thickness was determined by averaging measurements the specimens. The tests were conducted at a room temperature.

Tensile Strength Test:-Tensile strength is the measurement of the force required to pull something such as rope, wire, or a structural beam to the point where it breaks. The tensile strength of a material is the maximum amount of tensile stress obtained before failure. The specimen used for the tensile test is the flat type. During the tests, a uniaxial load is applied through both ends of the sample. The dimension of the specimen is (300 x 30 x 4.5) mm.

The specimen is tested under a universal testing machine (UTM). Then the samples are left to brake till the ultimate tensile strength occurs. The stress-strain curve is plotted, for the determination of ultimate tensile strength (UTS). It is plotted from the data generated directly from the machine for the tensile test. Typical points of interest when testing a material include ultimate tensile strength (UTS) or peak stress, offset yield strength (OYS) that represents a point just beyond the onset of permanent deformation, and the rupture (R) or fracture point where the specimen separates into pieces.

Figure 3. 20 UTM machine Sample loaded condition for tensile testing

3.14.2 Charpy Impact Test

The Charpy impact test is also known as the Charpy V- notch test. It is a standardized high strain-stress test that determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study \temperature –dependent ductile-brittle transition. It is widely used applied the industry since it is easy to prepare and conduct, results can be obtained quickly and cheaply. Figure 3.21 shows the dimension of the specimen for the impact test.

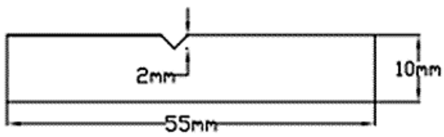


Figure 3. 21 Impact test specimen dimension

Figure 3. 22 Impact test specimen

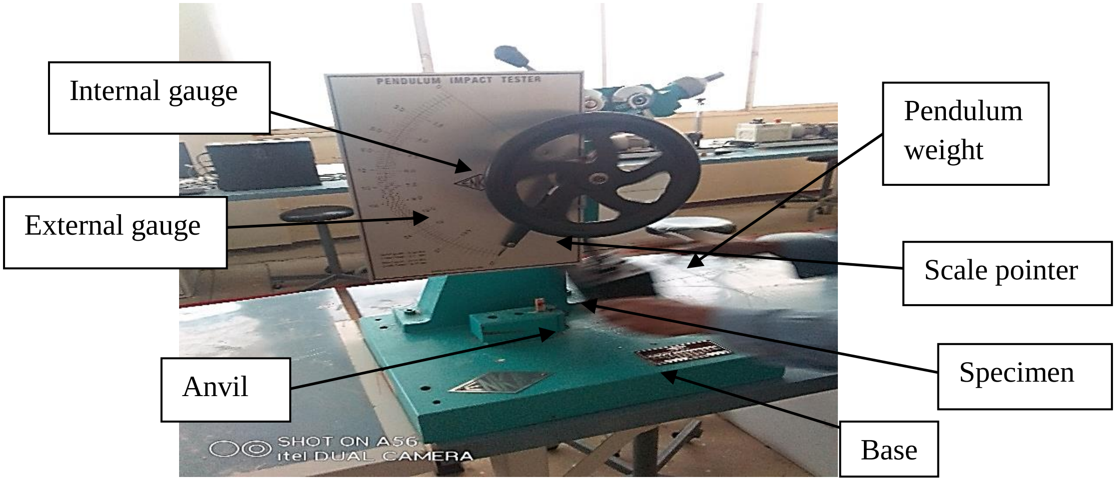


Figure 3. 23 Specimen set up and parts of pendulum impact tester machine

Impact strength test (ISO 9001:2001):-The impact test was performed over the samples of length 55 mm, width 10 mm & thickness 5.5 mm, as shown in Fig 3.22. The impact speed of the hammer is 3.8 meters per second with a 30-kilogram weight mounted pendulum. The notch cut on the specimen shall be facing the opposite direction of the striker. The quantitative result of impact tests the energy needed to fracture material and can be used to measure the toughness of the material.

Figure 3. 24 Fixing test condition

3.14.3 Microstructures of composite

In this test the effect of fiber orientation on the microstructure of the composite mechanical properties such as Vickers Hardness test was examined. Both physically and mechanically were determined using standard methods and the microstructure of the samples examined using Optical microscope equipped with camera, with others such as Vickers Hardness, polishing machine, Grinding machine and others.

Figure 3. 25 Fixing of test condition for micro structure under optical microscope

3.14.4 Hardness Test

The hardness of a material is a poorly defined term many meanings depending upon the experience of the person involved. In general, hardness usually implies a resistance to deformation. There are three general types of hardness measurements depending upon the manner in which the test is conducted. These are (1) scratch hardness, (2) indentation hardness, and (3) rebound, or dynamic, hardness. Only indentation hardness is of major engineering interest The Vickers hardness test uses a square-base diamond pyramid as the indenter. The included angle between opposite faces of the pyramid is 136°. Because of the shape of the indenter, this is frequently called the diamond pyramid hardness test. The diamond-pyramid hardness number (DPH), or Vickers hardness number (VHN, or VPH), is defined as the load divided by the surface area of the indentation. In practice, this area is calculated from microscopic measurements of the lengths of the diagonals of the impression

Figure 3. 26 Vickers hardness test machine

3.14.5 Water absorption test

Standard ASTM570 was used in this work to study the water absorption characteristics of nettle/sisal fiber reinforced hybrid unsaturated polyester composite. Samples were removed at regular intervals and weighed immediately after wiping away water from the surface, and a precise 4-digit balance was used to find out the content of water absorbed. Water absorption test was done in Adama science and Technology University, chemical science engineering department

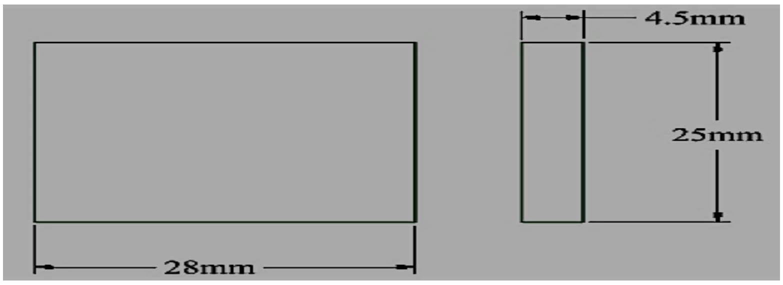


Figure 3. 27 Water absorption test specimen dimension

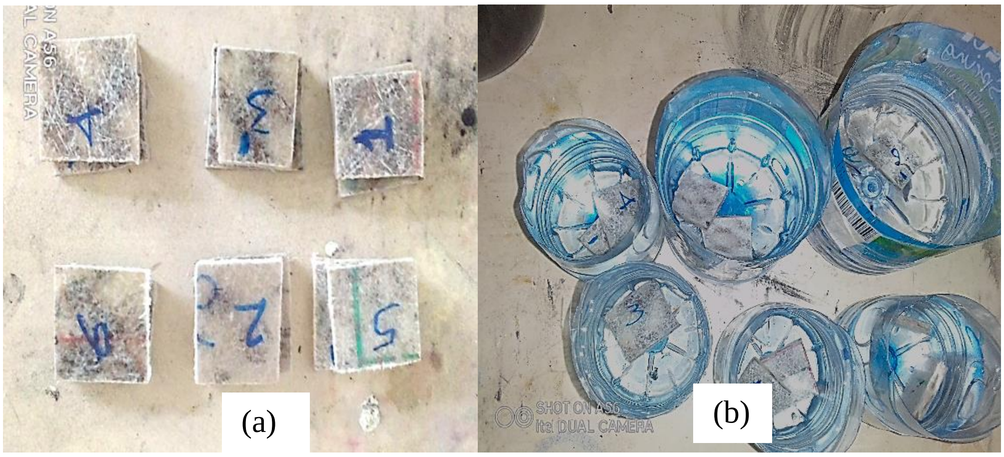


Figure 3. 28 (a) water absorption test specimens and (b) the specimens soaked in water for absorption test

3.14.6 Machinability test

After fabricating composites, the different machining operation is required. Drilling, counter boring, and countersinking are often required processes for preparing composite parts for joining and assembly. Performing machinability tests after fabrication of the polymer-based composites material are necessary. It helps to minimize the failures on composite material during a machining operation. Different sizes of fabricated composite were used for this operation under a drilling machine.

3.14.7 Drilling of fabricated composite materials

The heat generated due to drilling operation may damages the surface of the drilled composite. To avoid these problem cutting speed and feed rate was controlled. The drilling operations, take place with a bench type drill machine, with a diameter of the drill bit 7mm, 11mm, and 13mm. 200 rpm, 2 mm per second speed, and 0.5 revolutions per minute feed rate of the drilling machines were operated. The purpose of drilling is to observe the surface finish through hole. It helps to identify the materials surface finish. The other main purpose of drilling the fabricated composite was to check whether it shows good strength through hole during riveting or tightening by bolt.

Figure 3. 29 Bench type drilling machine

3.14.8 Morphology under SEM

Morphological analysis under SEM was carried out, for S1, S3, and S5. The reason to select these samples was that S1 and S5 show good mechanical properties when compared to the other. On the other way, S3 was taken to observe the morphological structure of 45^0 fiber orientation.

Figure 3. 30 SEM specimen

Figure 3.31: Specimen after tensile and impact test respectively

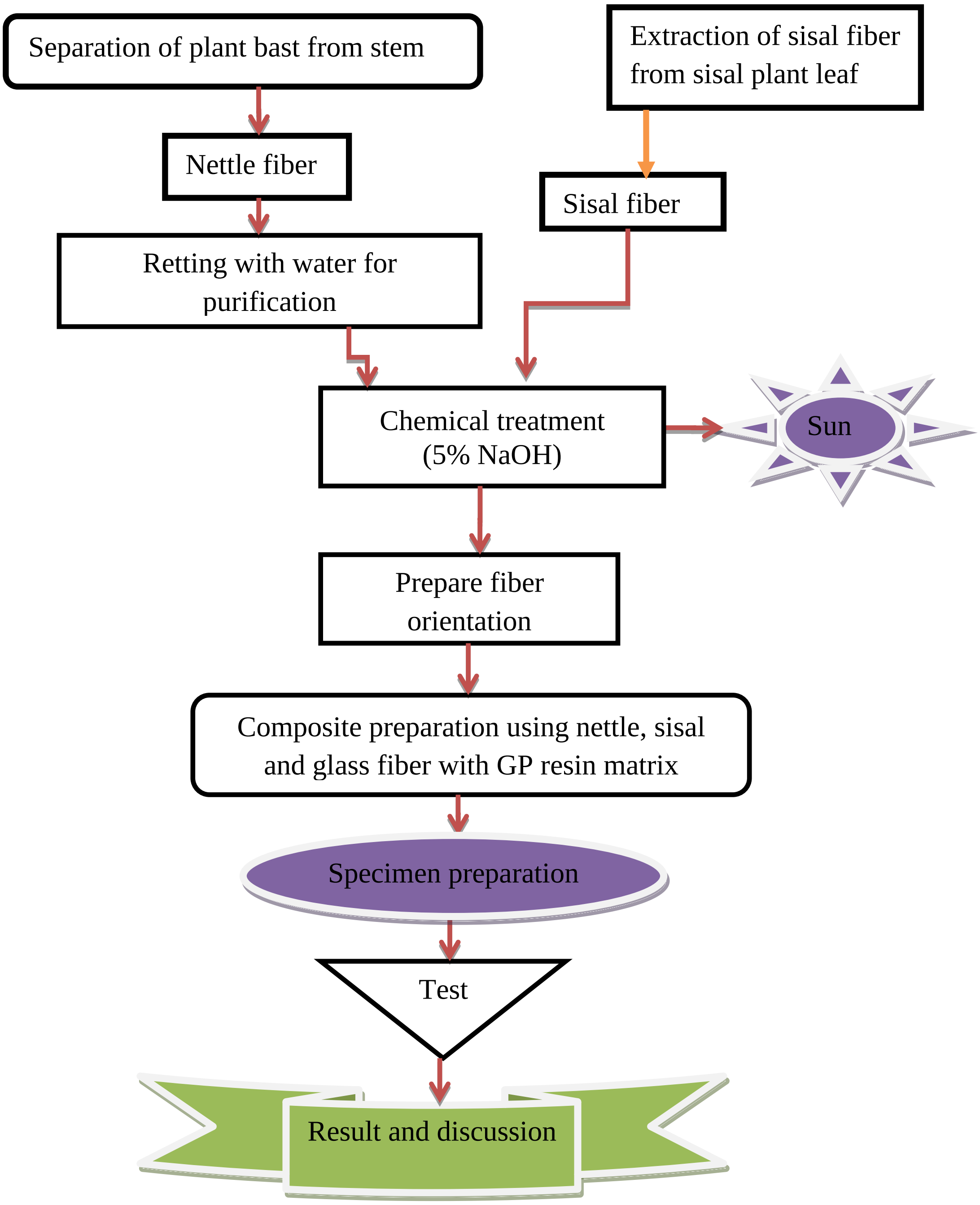


Figure 3. 32 Methodology of the work

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Test Results

All results of the test carried out under chapter three were displayed under this chapter. Some discussions were also put.

4.1.1 Tensile Test

Nettle, sisal, and glass fiber reinforced hybrid composite was fabricated with 40 % fiber volume fraction and 60 % matrix volume fraction in a [$0^0/90^0$ and 45^0] orientation structural composite. Based on mass wt% 20NF, 15NF, 10NF, and 10SF, 15SF, 20SF with 10GF were used for each preparation of the composite respectively. Nine specimens were used for this typical test. For $90^0/0^0$ fiber orientation (Sample 1, 2, and 5,) two, two specimens were tested for each. The reason was to test through sisal and nettle fiber longitudinal direction. But for 45^0 fiber orientations (sample 3, 4, and 6,) one, one specimen was tested for each because the load applied during the test can meet both fibers.

The graph reading $90^0/0^0$ fiber orientation composite in Figure 4.1, 4.2, and 4.3 show that the fabricated composite with nettle, sisal, glass fiber, and polyester resin has a tensile strength of 99 MPa, 74 MPa, 97 MPa with a percent of elongation 21.0%, 6.2%, and 6% respectively. In Figure 4.1, the nettle fibers longitudinal direction arrangement is perpendicular to that of the applied force vector and the sisal fiber longitudinal direction arrangement is parallel to that of the applied force vector. The matrix, force transmitting component from one fiber layer to another is expected to fail early due to layer separation. The arrangement of the fibers for Figures 4.2 and 4.3 (samples 2 and 5,) were the same as arrangement of sample 1.

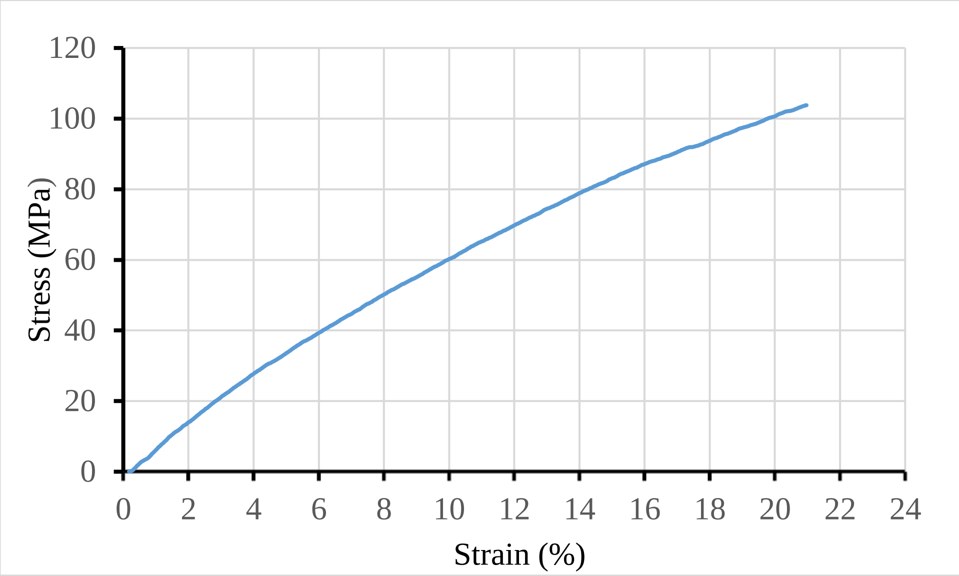


Figure 4. 1 (S1) test for $90^0/0^0$ orientation nettle perpendicular and sisal parallel to applied load

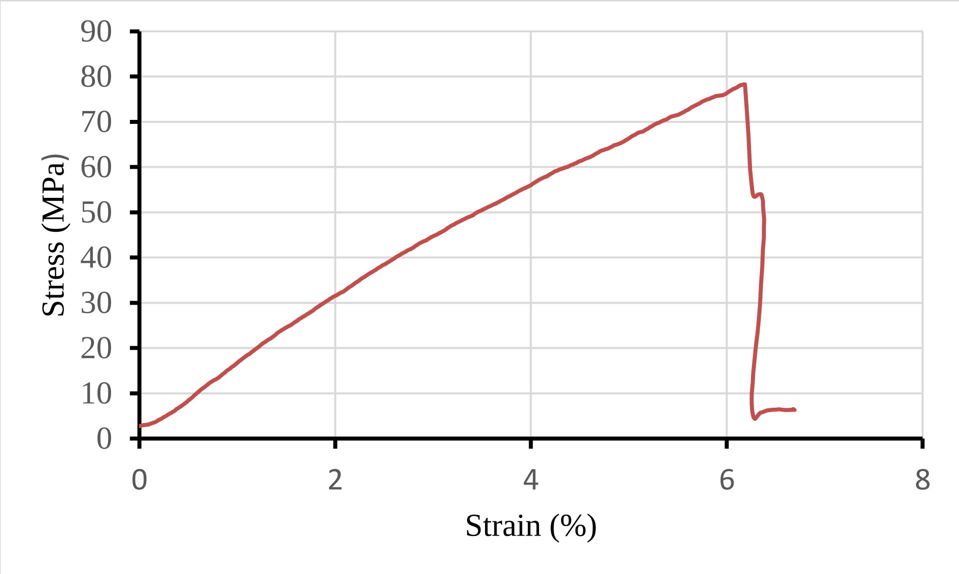


Figure 4. 2 (S2) test for $90^0/0^0$ orientation nettle perpendicular and sisal parallel to applied load

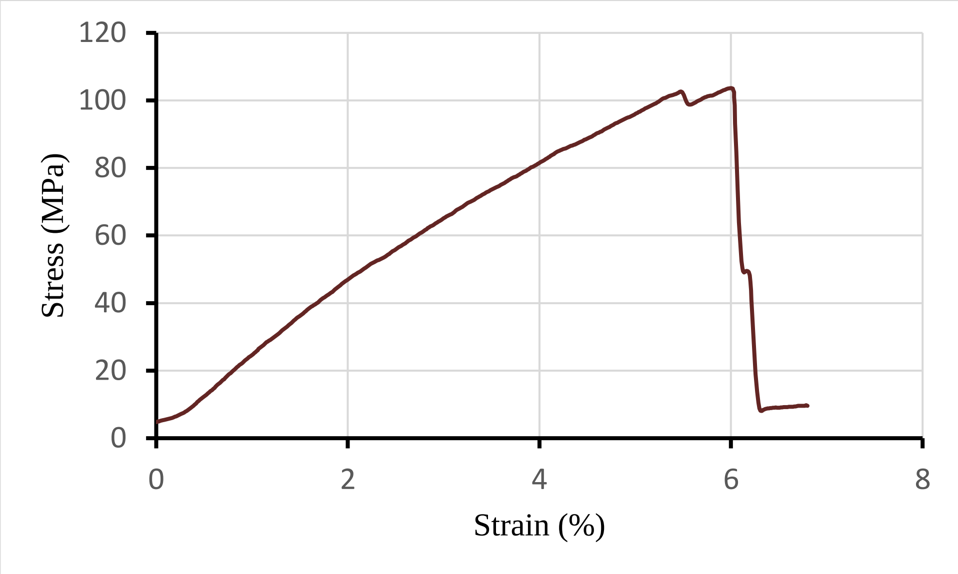


Figure 4. 3 (S5) test for $90^0/0^0$ orientation nettle perpendicular and sisal parallel to applied load

Similarly, the graph reading $90^0/0^0$ fiber orientation composite in Figure 4.4, 4.5, and 4.6 (sample 1', 2' and 5') show that the material with nettle, sisal, glass fiber, and polyester resin composite has a tensile strength of 57 MPa, 57 MPa, 91 MPa with a strain of 4.1%, 1.5%, and 18.6% elongation respectively. In this case of fiber orientation, the nettle fibers longitudinal direction arrangement is parallel to that of the applied force vector and the sisal fiber is perpendicular to the applied force. The matrix force transmitting component from one fiber layer to another is expected to fail early due to layer separation.

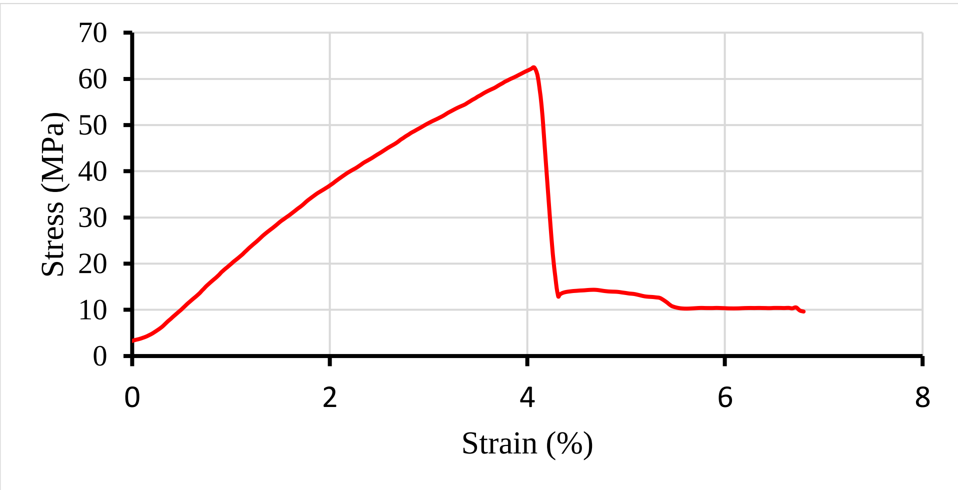


Figure 4. 4 (S1') test for $90^0/0^0$ orientation nettle parallel and sisal perpendicular to applied load

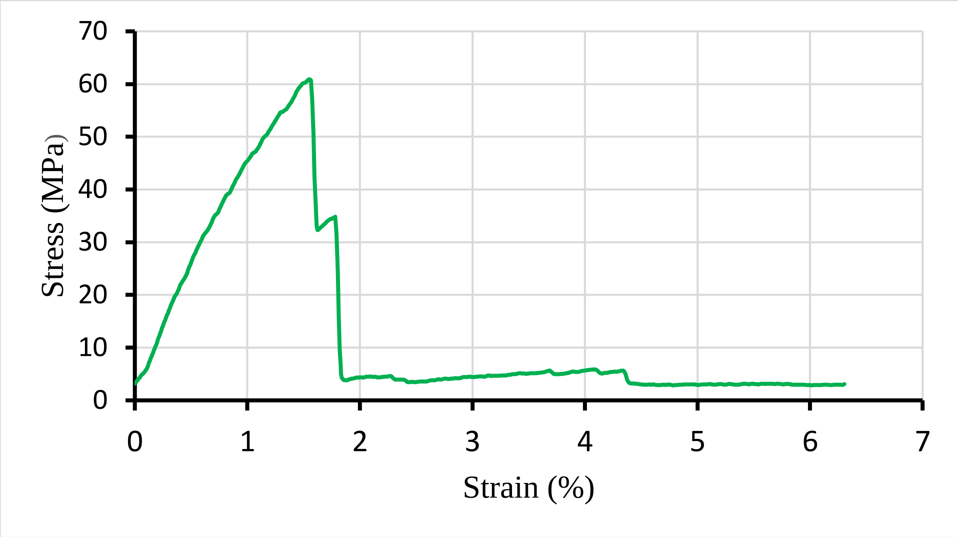


Figure 4. 5 (S2') test for $90^0/0^0$ orientation nettle parallel and sisal perpendicular to applied load

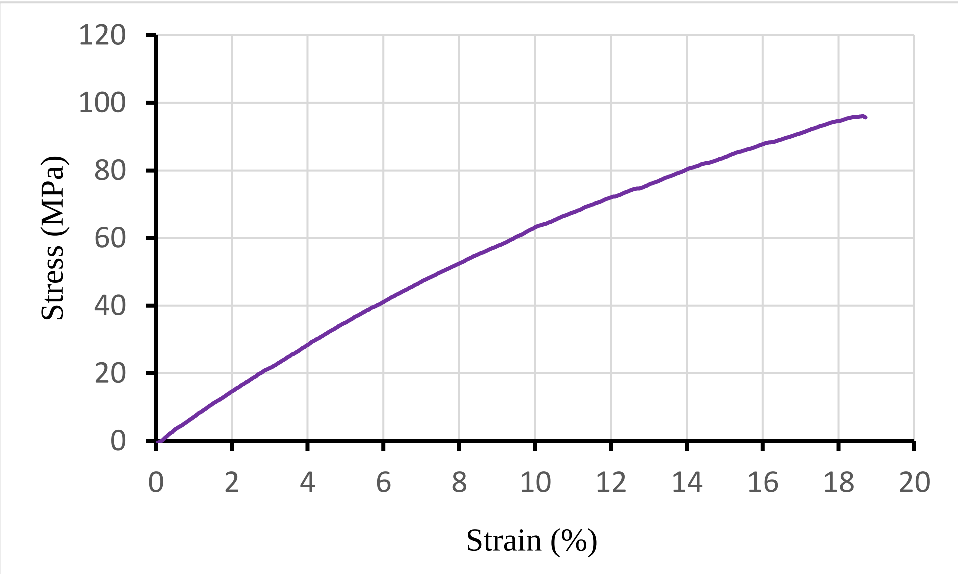


Figure 4. 6 (S5') test for $90^0/0^0$ orientation nettle perpendicular and sisal parallel to applied load

Finally, the graph reading 45^0 fiber orientation composite in Figure 4.7, 4.8, and 4.9 shows that the material with nettle, sisal, glass fiber, and polyester resin composite has a tensile strength of 52 MPa, 59 MPa, 83 MPa with a strain of 5.0%, 5.4%, and 6.3% elongation respectively. The matrix force transmitting component from one fiber layer to another is expected to fail early due to layer separation.

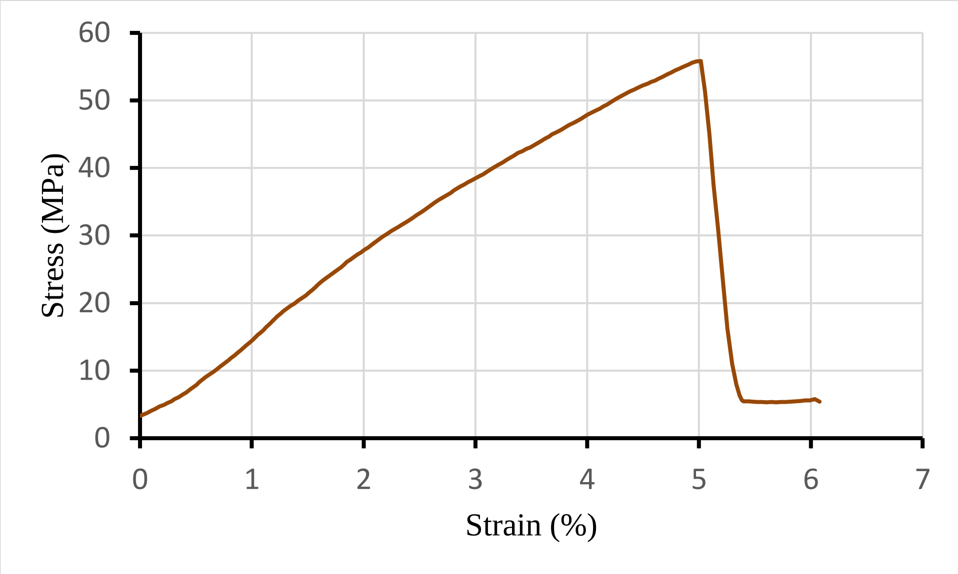


Figure 4. 7 (S3) 45^0 orientation of nettle and sisal fiber

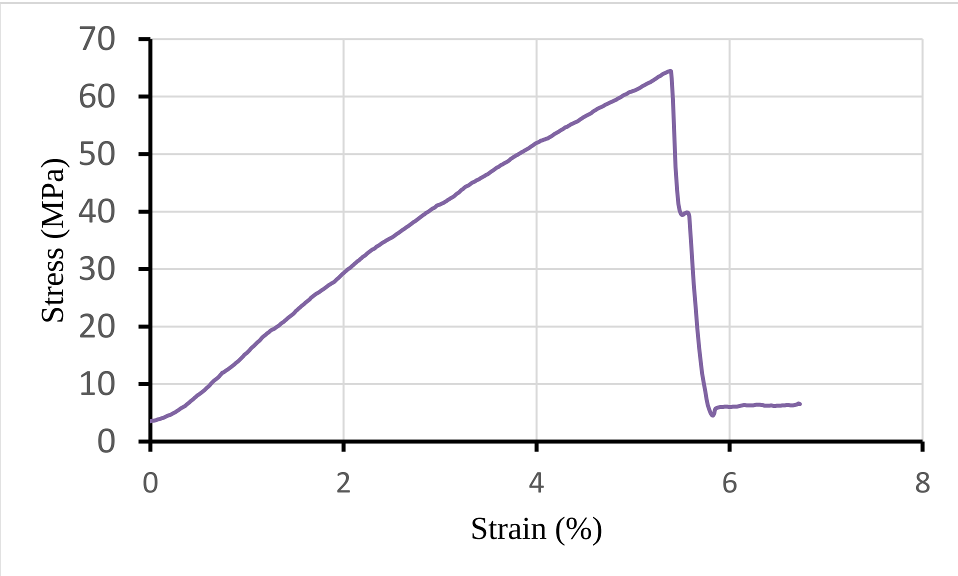


Figure 4. 8 (S4 45^0 orientation of nettle and sisal fiber

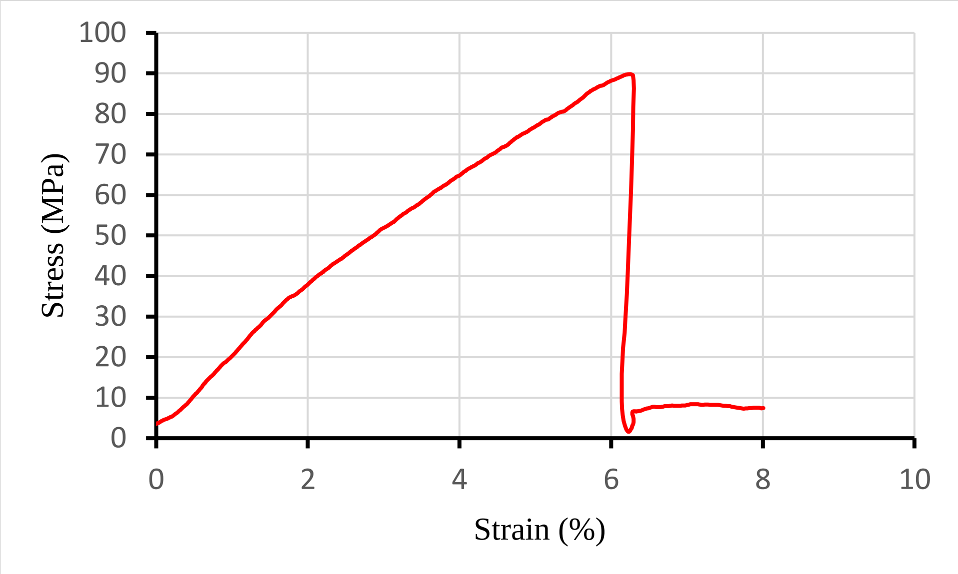


Figure 4. 9 (S6) 45^0 orientation of nettle and sisal fiber

4.1.2 Impact test

Table 4.1 shows the results of impact test of two fiber orientation of nettle, sisal/glass fiber hybrid composite.

Table 4.1 Impact test result

Sample	Orientation	Composition wt%	Load direction	Impact energy (joule)
1		20NF,10SF, 10GF	Parallel to SF	8.7
1’	$90^0/0^0$ Bidirectional plain woven	20NF,10SF, 10GF	Parallel to NF	6.6
2		10NF, 20SF, 10GF	Parallel to SF	7.8
2’		10NF, 20SF, 10GF	Parallel to NF	7.5
5		15NF,15SF,10GF	Parallel to SF	6.6

5’		15NF,15SF,10GF	Parallel to NF	8.4
3	45^0 bidirectional plain woven	20NF,10SF,10GF	-	6.9
4		15NF, 15SG,10GF	-	6.3
6		10NF,20SF,10GF	-	5.7

4.1.3 Hardness test

The results obtained during hardness test on composite specimen of different fiber orientation are summarized in table 4.2

Table 4.2 Experimental result for hardness test

Fiber orientation	Composition wt%	No: of trials	Value	Average
		t1	17.5	
$90^0/0^0$	20NF, 10SF and 10GF	t2	26	21.06
		t3	19.7	
		t1	18	
$90^0/0^0$	10NF, 20SF and 10GF	t2	14.8	15.8
		t3	14.6	
		t1	11.3	
45^0	20NF, 10GF and 10GF	t2	14.6	14.37
		t3	17.2	
		t1	15.2	
45^0	15NF, 10SF and 10GF	t2	15	15.8
		t3	17.2	
		t1	15.4	
$90^0/0^0$	15NF, 15SF and	t2	13.9	15.4

	10GF	t3	17	
45^0	15NF, 15SF and 10GF	t1	17.4	
		t2	16	16.87
		t3	17.2	

4.1.4 Water absorption test

The result obtained from water absorption test are shown in the Table 4.3. The weight of each sample soaked in the water was weighted by the interval of 24 hrs. (24, 48, 72, 96 and 120 hrs.). The result recorded was the average of those time.

Table 4.3 Water absorption test result

Sample	orientation	Time (hour)	Average (dry) w_d	Average (wet) w_w	w_w-w_d/w_w
1	$90^0/0^0$	120	4.660	4.719	1.25
2	$90^0/0^0$	120	5.531	5.653	2.15
3	45^0	120	6.286	6.392	1.66
4	45^0	120	5.273	5.362	1.65
5	$90^0/0^0$	120	5.430	5.510	1.45
6	45^0	120	4.531	4.621	1.95

4.1.5 Machinability test result

Visual inspection method was used to analyze the drilled surface of the fabricated composite material. The image of drilled surface were shown in Figure. 4.10

Figure 4. 10 Drilled surface of sample 1 and 5

4.2 Discussion

4.2.1 Tensile Test

The test results are tabulated (see appendix A) and presented in the Fig.4.11 based on the values of the specimens for each test condition.

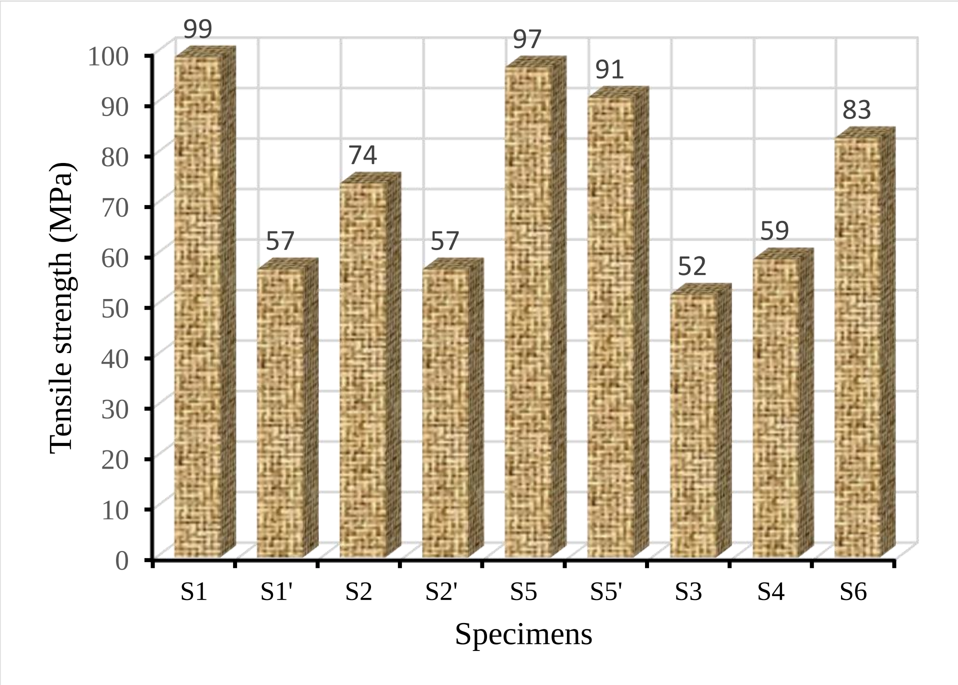


Figure 4. 11 Comparison of tensile strength for two fiber orientation

As observed from the graph of Fig. 4.1 and bar graph of Fig. 4.11 sample 1 (specimen S1) $90^0/0^0$ fiber orientation was composed of 20NF, 10SF and 10GF wt% have maximum tensile strength. This maximum tensile strength was obtained when the applied load is oriented only parallel to sisal fiber or perpendicular to nettle fiber. But when the direction of applied load is changed the tensile strength was reduced to 57 MPa (Fig4.11, specimen S1'). This result implies that if composition wt% of nettle fiber increased it is better to orient 0^0 rather than 90^0. For the same orientation but different composition wt% Fig. 4.3 (specimen S5) withstands 97MPa tensile strength when the load is applied parallel to sisal fiber and perpendicular to nettle fiber. For the same sample (specimen S5') but in a different direction of applied tensile load, the output tensile strength was 91MPa. It was a nearer value for both directional applied load on nettle and sisal fiber. The composition wt% of both fibers for this sample was equal. In S2 of fig. 4.2, the tensile reduced to 74MPa. This may be occurred due to loading sisal fiber by reducing nettle fiber. The same is true for S2'. When comes to S3, S4, and S6 (Fig. 4.7, 4.8, and 4.9), the composition wt% of the sample were the same, but in different orientations (45^{0}). They scored minimum tensile strength. This orientation may be proved by increasing nettle fiber composition wt%. Generally, from this study, it is better to put two or more discussions.

- $90^0/0^0$ fiber orientation gives better strength for hybrid nettle, sisal and glass fiber polymer reinforced composite.
- Loading and unloading natural fiber affects tensile property of composite materials.

4.2.2 Impact test

The impact test was carried out with charpy machine, results are presented in table 4.1 and the corresponding graphs have been plotted (Fig.4.12).

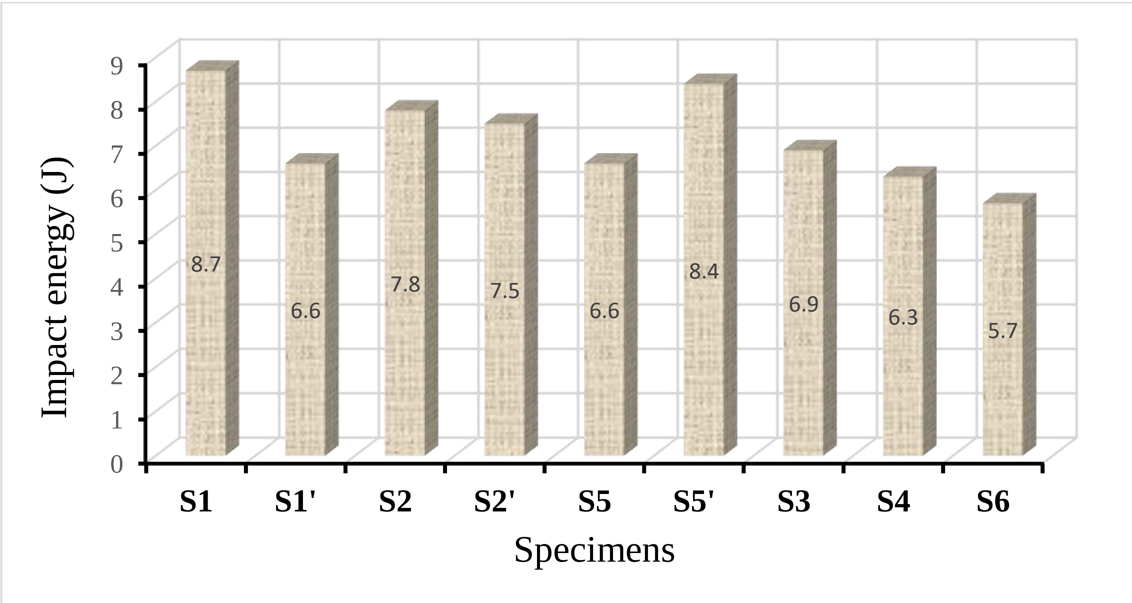


Figure 4. 12 Comparison of impact strength

From Fig. 4.12, S1 impact strength was found to be 8.7 joules. But in the case of S1' and S5, the impact energy was 6.6J, which was a second minimum result of impact energy for 90/0 degree orientation. This may due to surface curing problems in case S5 and due to the strength of the materials manufactured in case S1'. As observed from Figure 4.12 except S1' and S5 all sample impact results for $90^0/0^0$ fiber orientation found to be better than that of 45-degree orientation for the same composition wt%. This difference occurs may be due to the effect of fiber orientation and the amount of nettle fiber composition. The same as tensile strength, it can be concluded that increasing nettle fiber wt% through $90^0/0^0$ orientations can withstand high impact strength. The optimum fiber and matrix interaction, fiber-matrix stress transfer efficiency, and fiber dispersion and distribution were good for S1. For the same fiber orientation, S2 and S5 but different composition wt% observed 7.8 J and 6.9 J respectively. The difference was occurred due to fiber composition ratio and due to fiber and matrix interaction.

The results indicate that the impact strength value of natural fiber hybrid composite was affected by fiber orientation. $90^0/0^0$ fiber orientation gives better impact strength than 45^0 orientation, even for the same fiber composition wt%. For the same fiber orientation, the variation of the value may also occur due to curing time.

4.2.3 Hardness test

The Vickers hardness value of the material depends on indentation area. The value depends on test force applied due to test and surface area of indentation. It is given by the equation:

$$\text{Vickers hardness (HV)} = \frac{test\ force}{surface\ area\ of\ indentation} \quad \text{---------------- (4.1)}$$

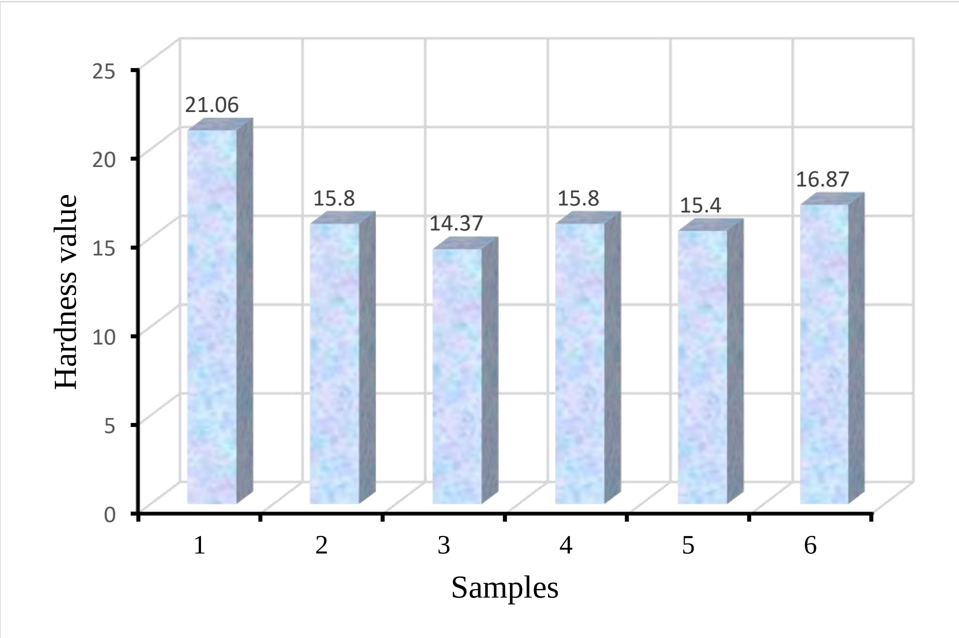


Figure 4. 13 Comparison of hardness test for the composition and the two fiber orientation

According to the Vickers hardness equation, it implies that if the material under test surface area of indentation increases, then the value of hardness will decrease. This means the surface area of indentation directly affects the hardness property of the expected materials. Therefore sample1 Fig. 4.13. Shows maximum hardness value. Because the indentation surface area of the sample covered a small area. The remaining sample 2 and 5 for the same orientation but different composition ratio wt% exhibited less hardness value.

These were due to the large surface area of indentation. Again sample 3, 4, and 6 (45^0) exhibited less Vickers hardness value. The reason was the same to sample 2 and 5, that the recorded high surface area of indentation.

In other ways, the strength property and hardness property of materials have direct relation. As the amount of nettle fiber increases, then the value of tensile strength of the composite (sample1) increases implies that the hardness of the composite also increases. From the experiment, it is better to say that as the volume content wt% of nettle fiber ($90^0/0^0$) orientation increases then mechanical hardness also increases. But if the volume content of nettle fiber ($90^0/0^0$) decreases then the corresponding hardness value also decreases. In the case of sample 2 and sample 5, it may be because of the surface finish of the test specimen taken for the hardness test. Additionally, the fiber orientation also affects the hardness of the expected composite. The result of samples 3, 4, and 6 oriented in 45^0 shows that.

Finally, reducing nettle fiber weight percentages reduces the hardness value of composite materials by reducing load transfer and an interfacial bond between matrix and fiber for samples 1, 2, and 5.

4.2.4 Microstructures of composite

A microscopic view of the two fiber orientations is shown in Figure 4.14. Simple visualization of the composite material is taken under an optical microscope. As observed from Figure 4.14 (a) the surface finish of sample one (1) was good. It shows that as wt% of nettle fiber increased, then the interaction between fiber and matrix was best rather than decreasing wt% of nettle fiber. In samples 2, 3, 4, 5, and 6 Figure 4.14, there was an accumulation of matrix on a different surface of the product. This may occur due to the surface interaction of the reinforcement and the matrix.

In other ways, the distribution and homogeneity of the reinforcement in sample one (1) and sample two (2) looks good as observed from Fig. 4.14 (a) and (f). These results were may be due to better adhesion between fiber and matrix. It can be generalized that interaction between fiber and matrix was better when composition wt% of nettle fiber is greater than or equal to composition wt% of sisal fiber.

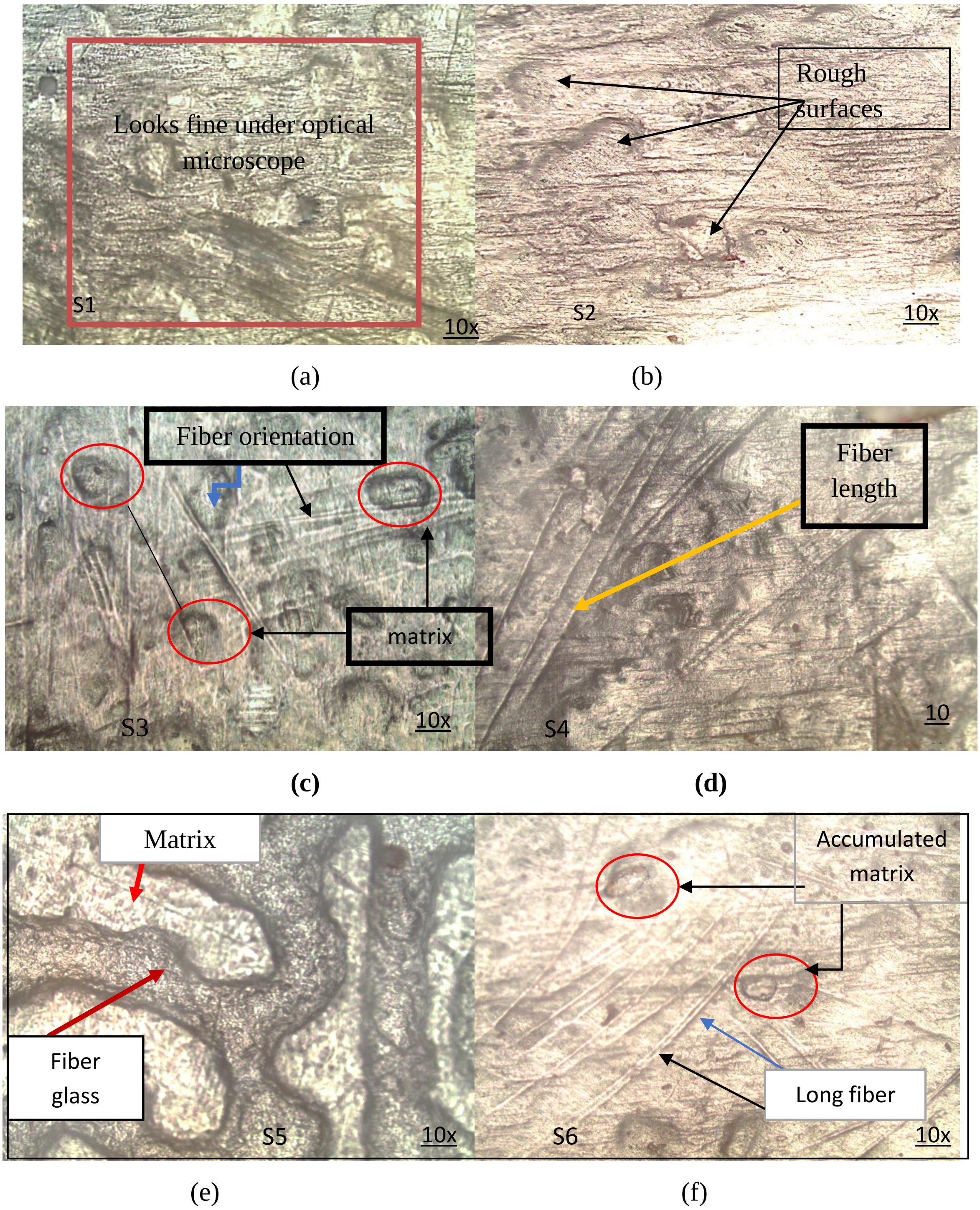


Figure 4. 14 Micro structure of fabricated composite (all sample under 10x)

4.2.5 Water absorption test result discussion

The water absorption behavior of fibers reduces the bonding between the matrix and fibers. And it leads to a decrease in the properties of composites. Like this problem of fiber can be reduced by using chemical treatment. The amount of water absorption of S2 and S6 were 2.15% and 1.95% respectively. But S1 and S5 absorb a small amount of water. This shows that the bonding between the matrix and the reinforcement or the fibers was best.

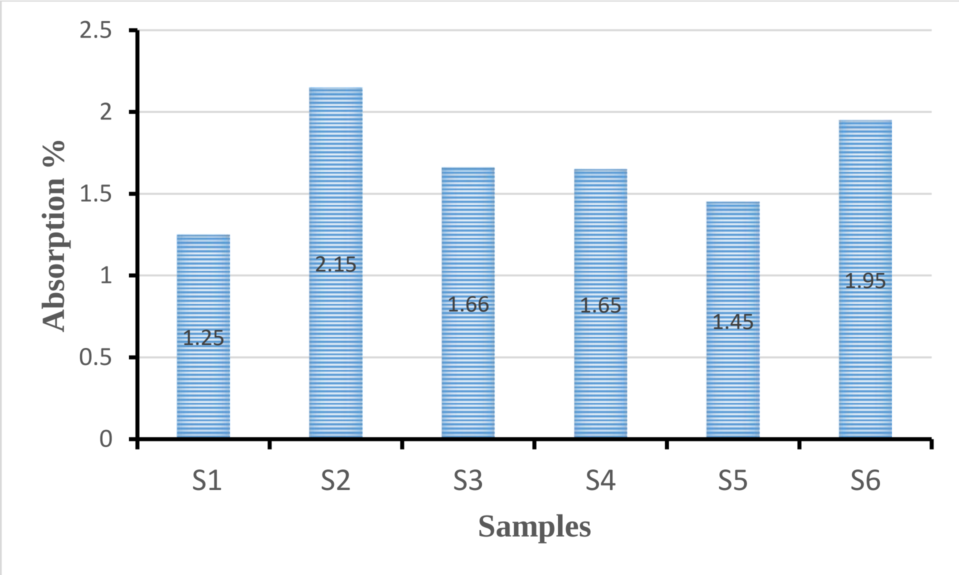
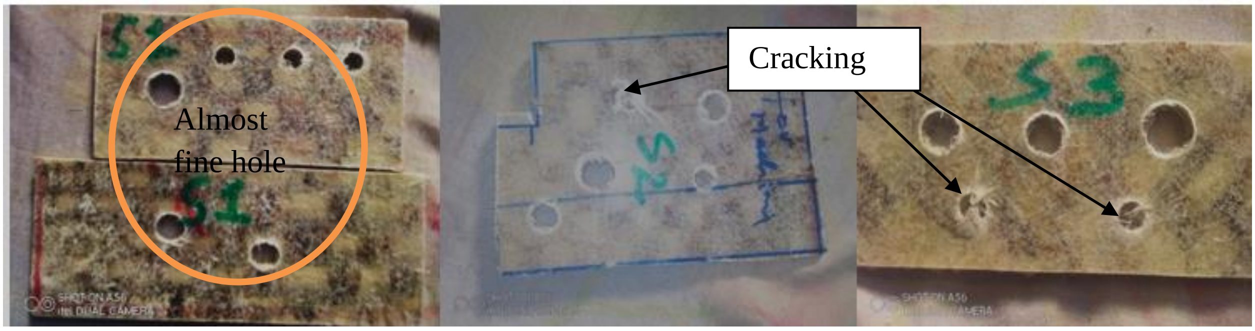


Figure 4. 15 Test samples and water absorption percent

4.2.6 Machinability test

The result under the machinability test shows that the different surfaces of machined fiber pull out and fiber fracture occurred around the drilled hole of some manufactured composite materials. Figure 4.16 shows drilled hole on the surface of the composite. Samples were drilled with different size diameters of drill bit but under the same speed and feed rate. The best surface finish was obtained for sample five (S5), which was composed of equal fiber wt% composition with $0^0/90^0$ orientation. The result shows that the different problem of machining composites like cracking, fiber fracture, fiber pullout from the matrix, plastic flow in the matrix and delamination is improved hybridizing nettle and sisal fiber in equal wt% composition and 0/90 fiber orientation.



(1) (2) (3)

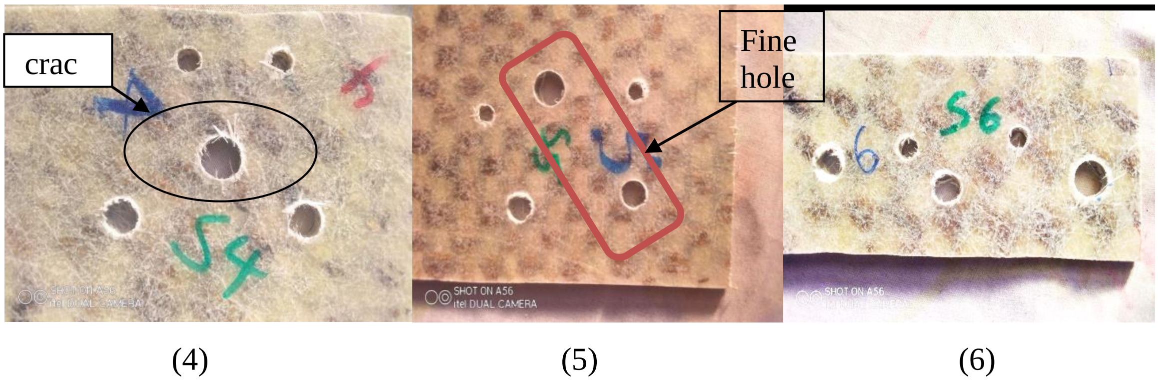


Figure 4. 16 Image of all samples after drilled under three different size drill bit

4.2.7 Morphological structure

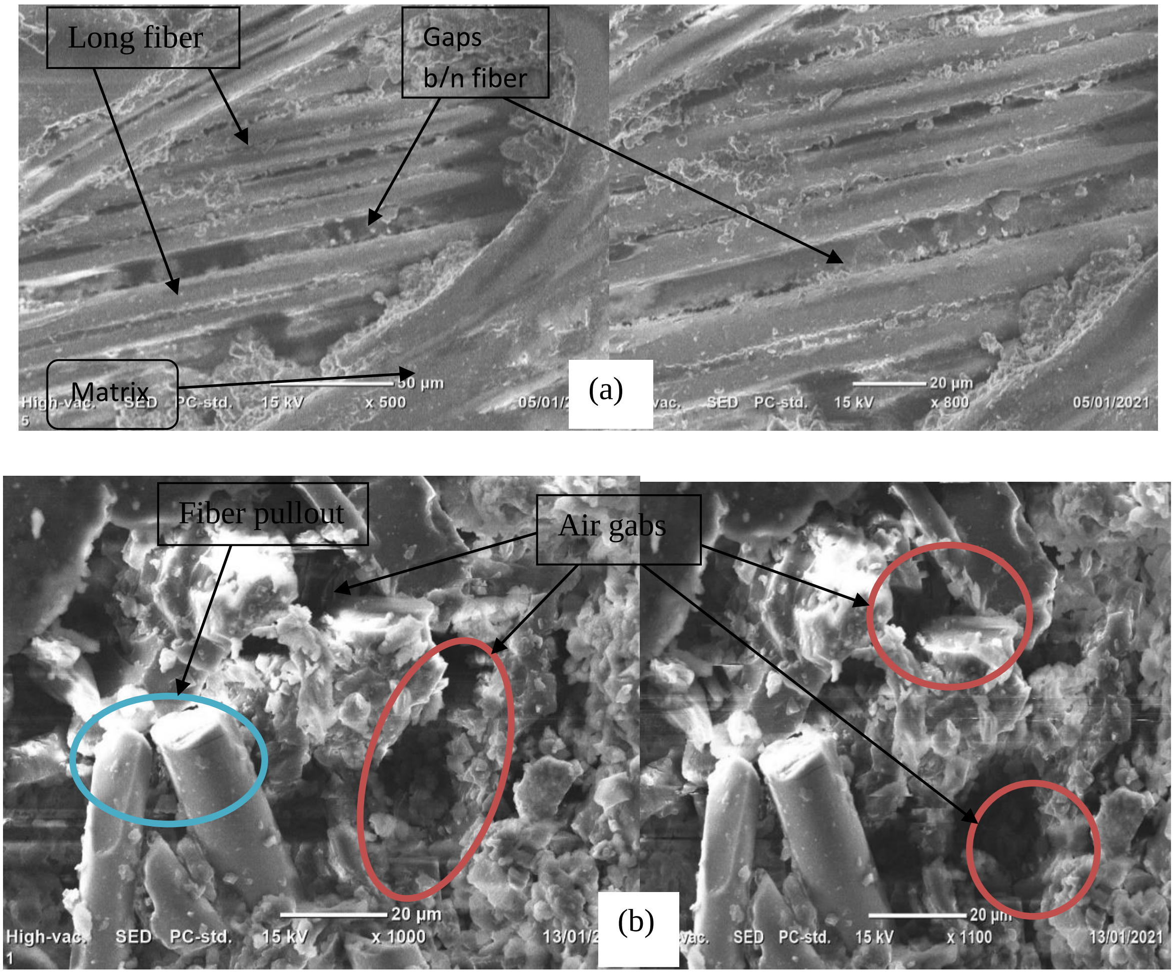


Figure 4. 17 SEM image of S1 and S5

Figure 4.17 (a) shows the morphological structure of S5 under SEM. It is a very smooth surface when compared with S1 Fig. 4.17 (b). This SEM result show that as the amount of both fibers are nearer to each other, means that by mass then the interaction between reinforcement and matrix will increases. This was the result of the interaction between fiber and matrix because of the appropriate proportion ratio and fiber orientation. In case of sample one (1) SEM value shows that some air gaps between fiber and matrix which was occurred due to curing.

4.5 Application of the product

Depending on the mechanical property the fabricated composite shows, there are many field of applications.

- ✓ Chair, table, desk, shelf, box
- ✓ For ceiling
- ✓ For partition
- ✓ For car body. Example dashboard
- ✓ For drawing and art materials etc.

CHAPTER FIVE

5. CONCLUSSION AND RECOMMENDATION

5.1. Summary

In this thesis work, hybrid polymer reinforced composite material from nettle (Ethiopian origin stinging nettle) fiber and sisal fiber was fabricated. The fabricated composite development started from plant collection followed by its fiber extraction. Both fibers were treated with NaOH to increase their surface roughness to have better bonding capability with a matrix. Ethiopian origin stinging nettle fiber and sisal fiber were used with E-glass fiber as reinforcement whereas, the polyester resin was a matrix. Properties like: - tensile strength, impact strength, hardness test, microstructure, water absorption test, and machinability test through-hole during drilling of the manufactured composite were tested as per ASTM standard.

5.2. Conclusion

Nettle is a plant that has more than 40 species in the world and didn't study in detail yet. Ethiopian origin stinging nettle has a fiber, which can give composite materials with comparable mechanical properties. According to the investigation, there are no detailed studies regarding nettle in Ethiopia. This means that studies are not available about composite material using Ethiopian origin stinging nettle fiber rather than used for textile raw materials. A researcher only tries to analyze its properties related to textile production. In other ways, sisal plants grew abundantly in different countries including our country Ethiopia. Researchers study the different mechanical properties of sisal fiber. They hybridized this plant fiber with many other plant fibers. But according to an investigation, there is no study regarding the hybrid composite of sisal and nettle plant yet. This is the reason why this study focused on the hybrid of nettle and sisal fiber with glass fiber reinforced polymer composite.

After determining the material properties of nettle/sisal fiber reinforced hybrid composites with two different fiber orientation and six different fiber composition of the composite materials, then following conclusions can be drawn:-

1. This work shows that successful fabrication of composites with different fiber composition and orientation is possible by hand lay-up process.

2. Different mechanical properties of the product were determined from different fiber orientation
3. In tensile test, 20NF, 10SF and 10GF (1) composition and ($90^0/0^0$) degree orientation of specimen shows highest or good tensile strength of 99MPa. But the result was obtained if the load applied is through longitudinal direction of sisal fiber. When the direction of applied load was changed then the tensile strength was reduced. Sample 5 which was composed from fiber wt% 15NF, 15SF and 10GF and oriented ($90^0/0^0$) orientation was withstands best tensile strength even if the applied load was applied through both fiber longitudinal direction.
4. In charpy impact test, sample 1 shows highest impact strength of 8.7J. The impact strength of sample 5 was also good.
5. Similarly for the characterization of hardness test, sample1 specimen shows highest hardness value of 21.06 HV. But in case of sample 5, the hardness value was not that much good. This was due to surface finish of the sample taken for this test.
6. The mechanical property of the composite was affected due to the fiber orientation and composition wt%, as observed from microscopic view.
7. It was concluded that a combination of two natural or natural/synthetic fibers enhanced the mechanical properties of the composites with values higher than those obtained for the individual fiber reinforced polymer composites.

5.3 Recommendation

- Traditional extraction method of nettle and sisal fiber influences the mechanical property of hybrid composite. So it is recommended that the fiber must be extracted in a better way, to that fiber with uniform diameter and length, which gives strength.
- It is also, recommended to use local nettle plant fiber as reinforcement during hybridization of composite with other natural plant fibers such as banana, jute etc.
- Using more accurate composite manufacturing technics may increase the performance of output like resin transfer method, Vacuum Bagging, vacuum assisted hand layup and etc.

5.4. Future work

- Design of natural fibers extraction processing machine
- Compare and contrast the property of chemically treated and untreated nettle fiber composite.
- Try to fabricate composite material from the waste of nettle and sisal fiber during purification.

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APPENDIX

Appendix. A

Tensile test

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Ethiopian Conformity Assessment Enterprise

ECAE
ኢተምድ

ቁጥር(No) 2/8/16-2/2505/2020
ቀን (Date) 16 DEC 2020

To: Buzuwork Abebe

Adama

On your request dated December 15, 2020 you have requested for the analysis on Composite.

Accordingly, the analysis is completed as per your request and hence you find the report attached here with.

Regards,

For

Solomon Mulubirhan
Customer Service Manager

Enc: 3 Page of test reports MTR/2576-2578/13

CC. ECAE

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ወደ ላቀ ብቃት የሚያደርሶ!
Moving you forward!

ECAE ኢትምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No. TLD/F7.08-1	
		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1	Effective Date: 19 Aug 19

Name and address of client:	Buzuwork Abebe, Adama	Test Report No:	MTR/2577/13
Tel:	+251-919-77-23-70	Test Order No:	-
Fax:	-	Reported date:	16/12/2020
E-mail:	-	Date of sampling	Not specified
Date sample Received:	15/12/2020	Place of sampling:	Not Specified
Client Sample code:	1, 1', 5'	Sampled and submitted by:	Client
Type of sample:	Composite	Date tested:	16/12/2020
Laboratory Designation Number: 13096002		Method Specification:	Not specified

S/N	Characteristics tested	Client Sample code	Test Method / Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
1.	Tensile strength (Mpa)	1	ES ISO 6892-1:2018	-	-	-	99	-
		1'		-	-	-	57	-
		5'					91	

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Habtamu Mihret, Position Analyst II, Sign. for

11145 ☎ 011 6 51-64-68, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com

BOLE SUBCITY, WOREDA 6, ADDIS ABABA, ETHIOPIA

ECAE ኢትምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No. TLD/F7.08-1	
		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1	Effective Date: 19 Aug 19

Name and address of client:	Buzuwork Abebe, Adama	Test Report No:	MTR/2576/13
Tel:	+251-919-77-23-70	Test Order No:	-
Fax:	-	Reported date:	16/12/2020
E-mail:	-	Date of sampling	Not specified
Date sample Received:	15/12/2020	Place of sampling:	Not Specified
Client Sample code:	2',5,2	Sampled and submitted by:	Client
Type of sample:	Composite	Date tested:	16/12/2020
Laboratory Designation Number: 13096001		Method Specification:	Not specified

S/N	Characteristics tested	Client Sample code	Test Method / Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
1.	Tensile strength (Mpa)	2'	ES ISO 6892-1:2018	-	-	-	57	-
		5		-	-	-	97	-
		2					94	74

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Habtamu Mihret, Position Analyst II, Sign. for

11145 ☎ 011 6 51-64-68, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com

BOLE SUBCITY, WOREDA 6, ADDIS ABABA, ETHIOPIA

ECAE ኢተምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No. TLD/F7.08-1	
		Copy No: -	Rev No: 0
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1	Effective Date: 19 Aug 19

Name and address of client:	Buzuwork Abebe, Adama	Test Report No:	MTR/2578/13
Tel:	+251-919-77-23-70	Test Order No:	
Fax:	-	Reported date:	16/12/2020
E-mail:	-	Date of sampling	Not specified
Date sample Received:	15/12/2020	Place of sampling:	Not Specified
Client Sample code:	3, 4, 6	Sampled and submitted by:	Client
Type of sample:	Composite	Date tested:	16/12/2020
Laboratory Designation Number:	13096003	Method Specification:	Not specified

S/N	Characteristics tested	Client Sample code	Test Method / Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
1.	Tensile strength (Mpa)	3	ES ISO 6892-1:2018	-	-	-	52	-
		4		-	-	-	59	-
		6					83	

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Habtamu Mihret, Position Analyst II, Sign. for

TENSION TEST (ISO 6892-1)

Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993

ECAE Ethiopian Conformity Assessment Enterprise

TEST DATA

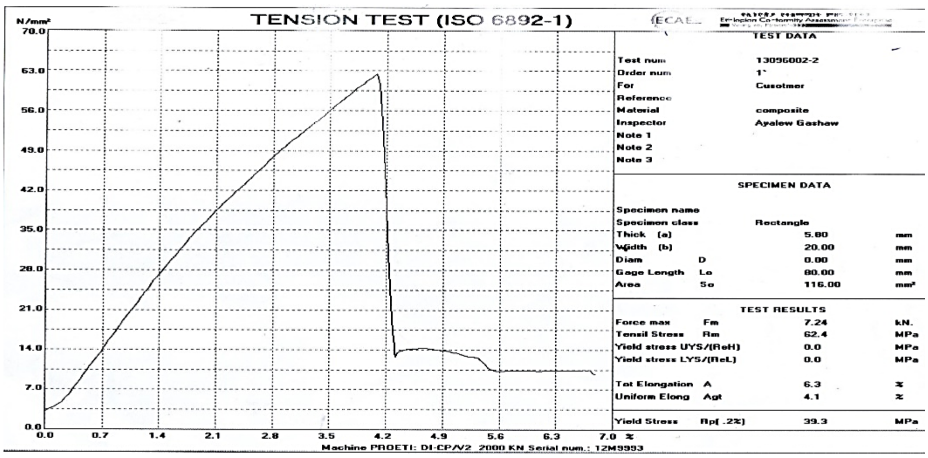
Test num	13096002-1
Order num	1
For	Cusotmer
Reference	
Material	composite
Inspector	Ayalew Gashaw
Note 1	
Note 2	
Note 3	

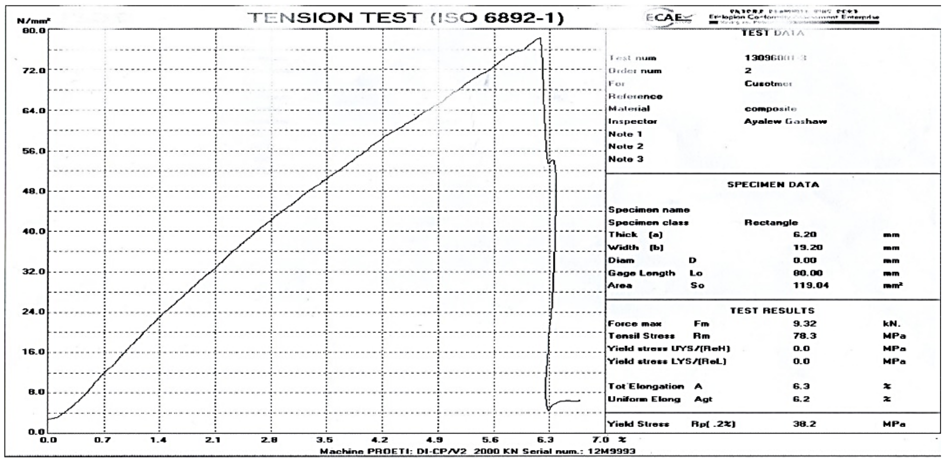
SPECIMEN DATA

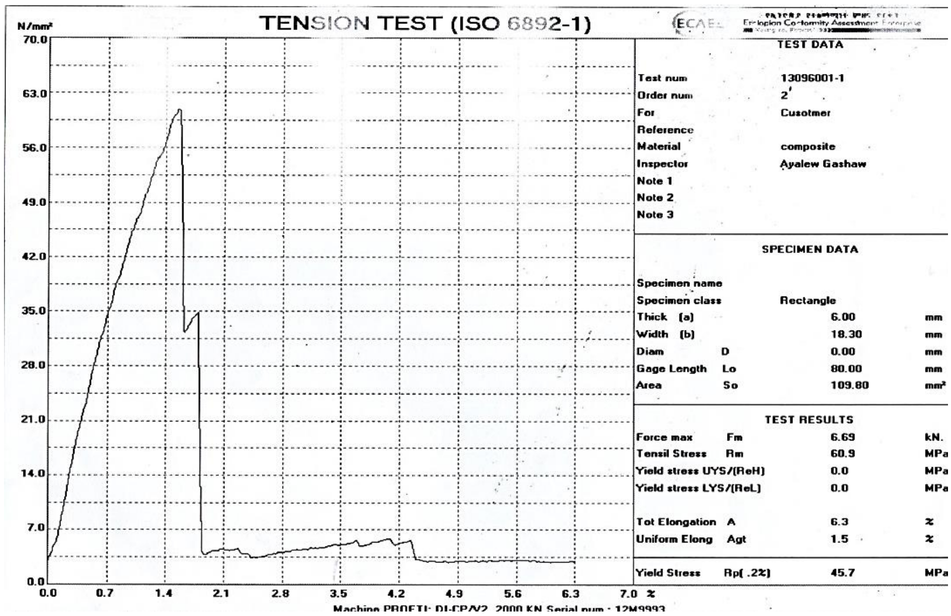
Specimen name			
Specimen class		Rectangle	
Thick (a)		6.25	mm
Width (b)		19.00	mm
Diam	D	0.00	mm
Gage Length	Lo	80.00	mm
Area	So	118.75	mm

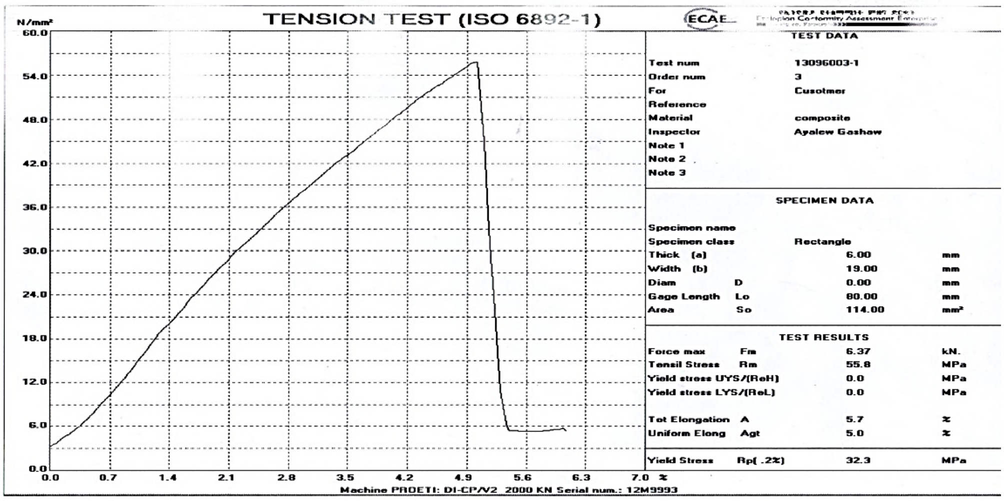
TEST RESULTS

Force max	Fm	12.32	kN.
Tensil Stress	Rm	103.8	MP.
Yield stress UYS/(ReH)		0.0	MP.
Yield stress LYS/(ReL)		0.0	MP.
Tot Elongation	A	6.2	%
Uniform Elong	Agt	21.0	%
Yield Stress	Rp(.2%)	31.8	MP.


TENSION TEST (ISO 6892-1)
TEST DATA
Test num 13096002-2
Order num 1
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 5.80 mm
Width (b) 20.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 116.00 mm²
TEST RESULTS
Force max Fm 7.24 kN.
Tensil Stress Rm 62.4 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 6.3 %
Uniform Elong Agt 4.1 %
Yield Stress Rp(.2%) 39.3 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
TEST DATA
Order num 2
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.20 mm
Width (b) 19.20 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 119.04 mm²
TEST RESULTS
Force max Fm 9.32 kN.
Tensil Stress Rm 78.3 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 6.3 %
Uniform Elong Agt 6.2 %
Yield Stress Rp(.2%) 38.2 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
TEST DATA
Test num 13096001-1
Order num 2
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 18.30 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 109.80 mm²
TEST RESULTS
Force max Fm 6.69 kN.
Tensil Stress Rm 60.9 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 6.3 %
Uniform Elong Agt 1.5 %
Yield Stress Rp(.2%) 45.7 MPa


TENSION TEST (ISO 6892-1)
ECAE
N/mm²
TEST DATA
Test num 13096003-1
Order num 3
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 19.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 114.00 mm²
TEST RESULTS
Force max Fm 6.37 kN.
Tensil Stress Rm 55.8 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 5.7 %
Uniform Elong Agt 5.0 %
Yield Stress Rp(.2%) 32.3 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993

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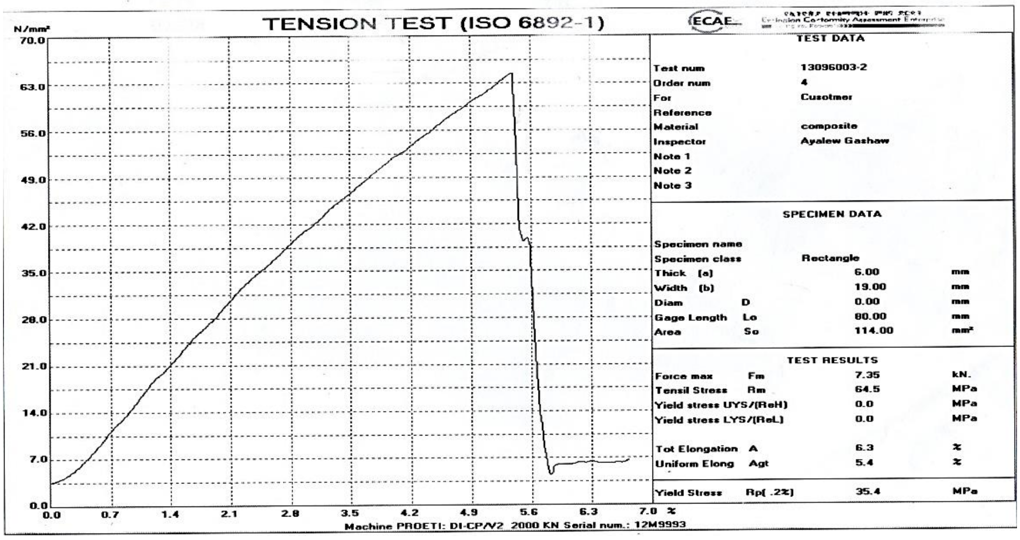
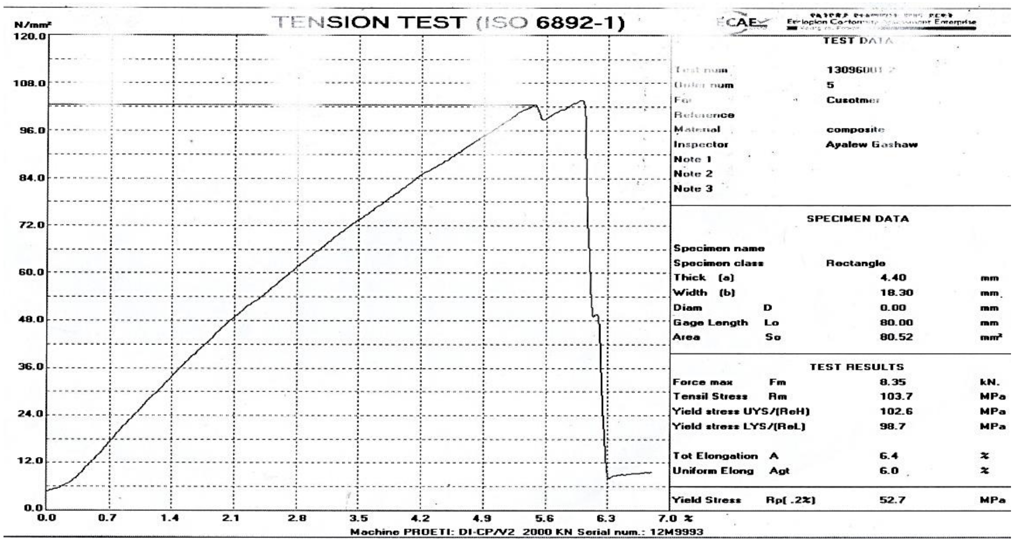
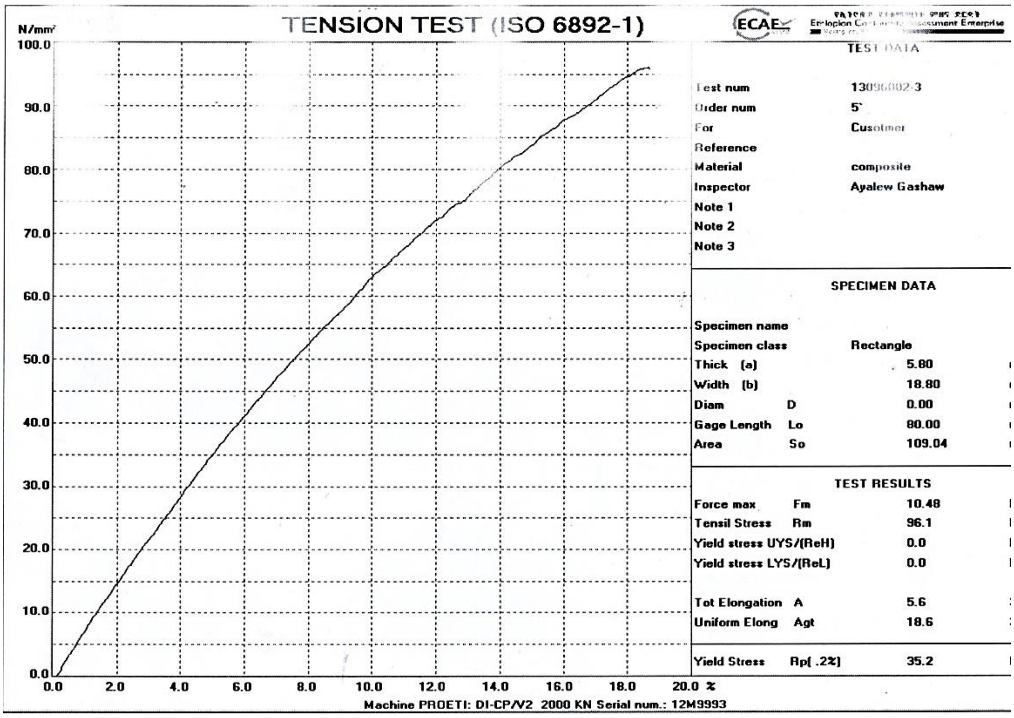
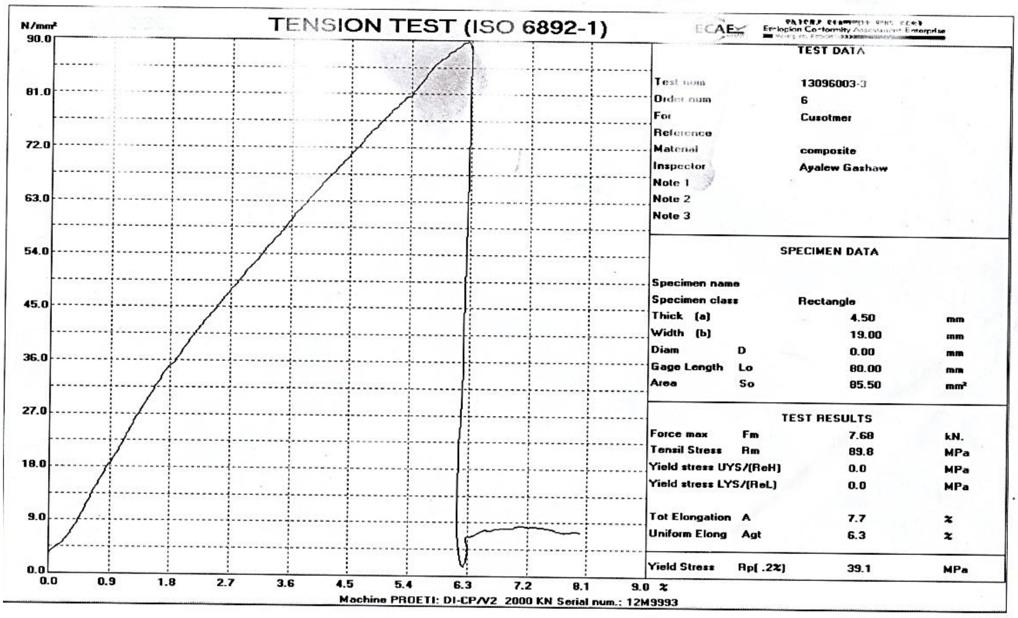

TENSION TEST (ISO 6892-1)
ECAE
N/mm²
TEST DATA
Test num 13096003-2
Order num 4
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 6.00 mm
Width (b) 19.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 114.00 mm²
TEST RESULTS
Force max Fm 7.35 kN.
Tensil Stress Rm 64.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 6.3 %
Uniform Elong Agt 5.4 %
Yield Stress Rp(.2%) 35.4 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
ECAE
N/mm²
TEST DATA
Test num
Order num 5
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.40 mm
Width (b) 18.30 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 80.52 mm²
TEST RESULTS
Force max Fm 8.35 kN.
Tensil Stress Rm 103.7 MPa
Yield stress UYS/(ReH) 102.6 MPa
Yield stress LYS/(ReL) 98.7 MPa
Tot Elongation A 6.4 %
Uniform Elong Agt 6.0 %
Yield Stress Rp(.2%) 52.7 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
N/mm²
ECAE
TEST DATA
Test num 13096002-3
Order num 5
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 5.80
Width (b) 18.80
Diam D 0.00
Gage Length Lo 80.00
Area So 109.04
TEST RESULTS
Force max Fm 10.48
Tensil Stress Rm 96.1
Yield stress UYS/(ReH) 0.0
Yield stress LYS/(ReL) 0.0
Tot Elongation A 5.6
Uniform Elong Agt 18.6
Yield Stress Rp(.2%) 35.2
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
N/mm²
ECAE
TEST DATA
Test num 13096003-3
Order num 6
For Cusotmer
Reference
Material composite
Inspector Ayalew Gashaw
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name
Specimen class Rectangle
Thick (a) 4.50 mm
Width (b) 19.00 mm
Diam D 0.00 mm
Gage Length Lo 80.00 mm
Area So 85.50 mm²
TEST RESULTS
Force max Fm 7.68 kN.
Tensil Stress Rm 89.8 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 7.7 %
Uniform Elong Agt 6.3 %
Yield Stress Rp(.2%) 39.1 MPa
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993

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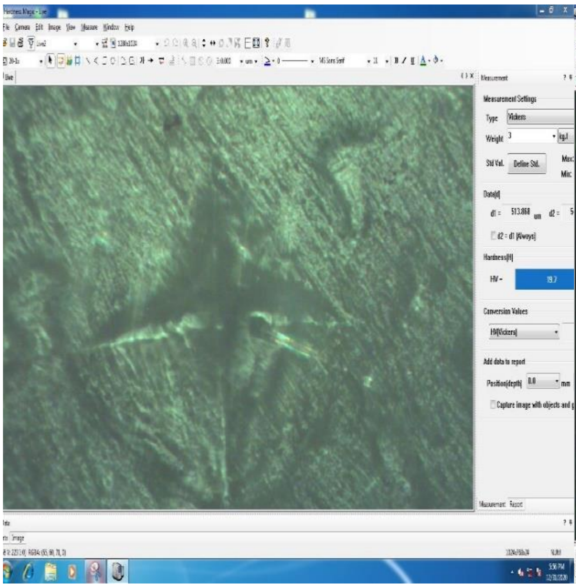
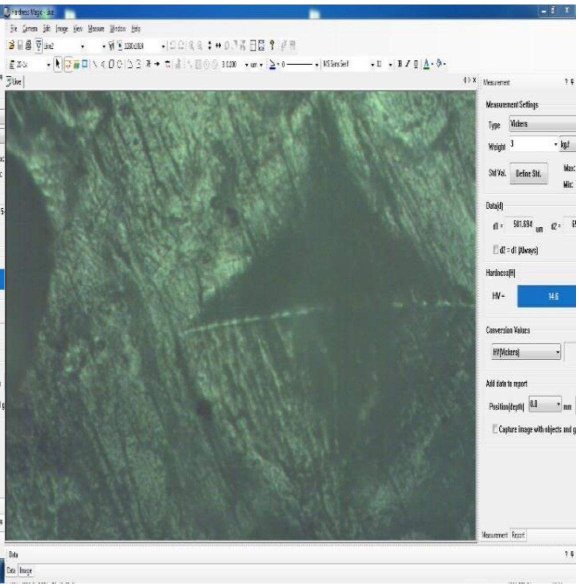
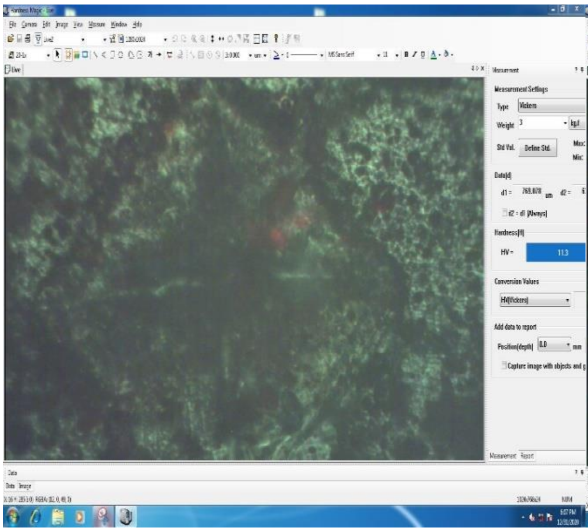
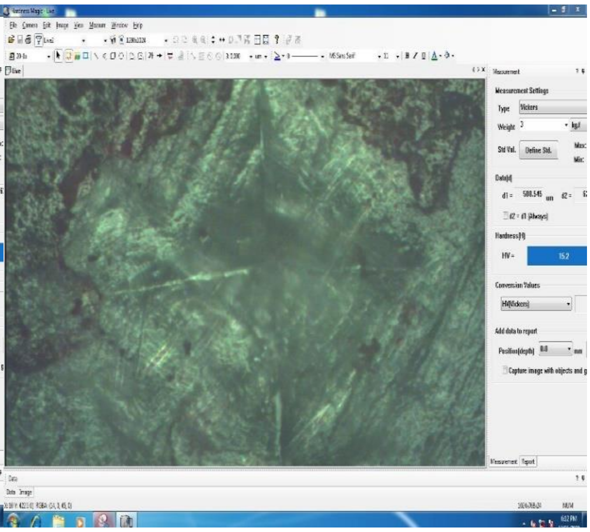
Appendix. B

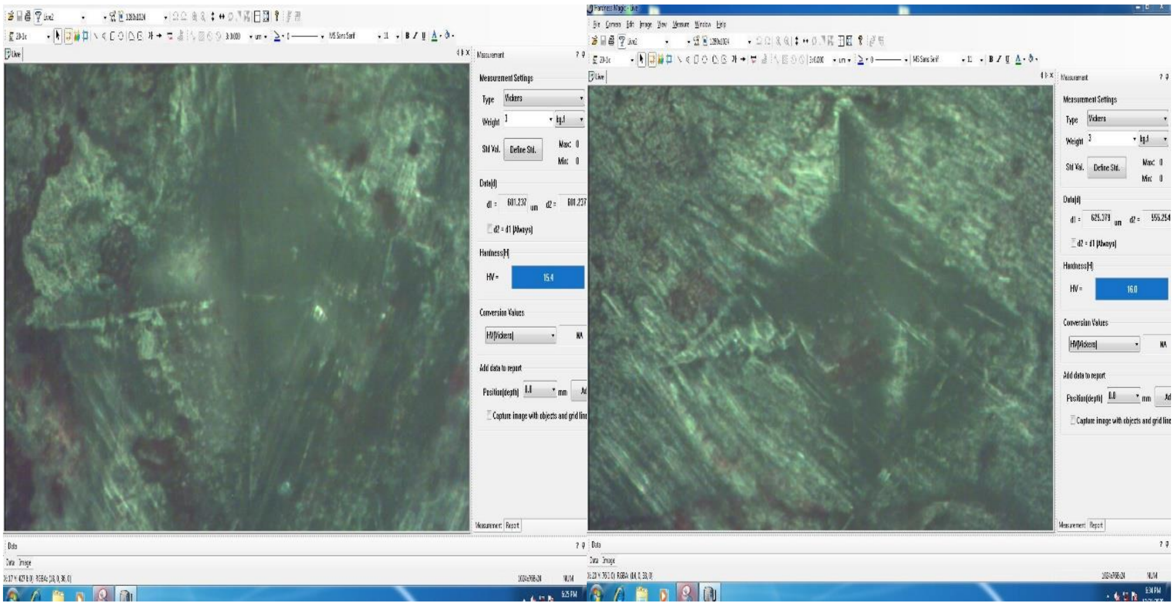
Hardness test





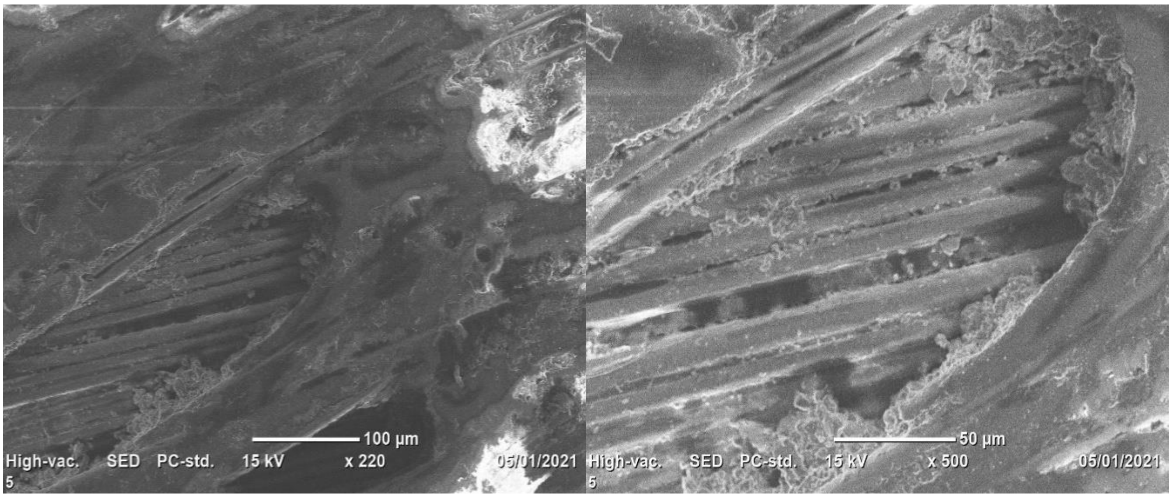


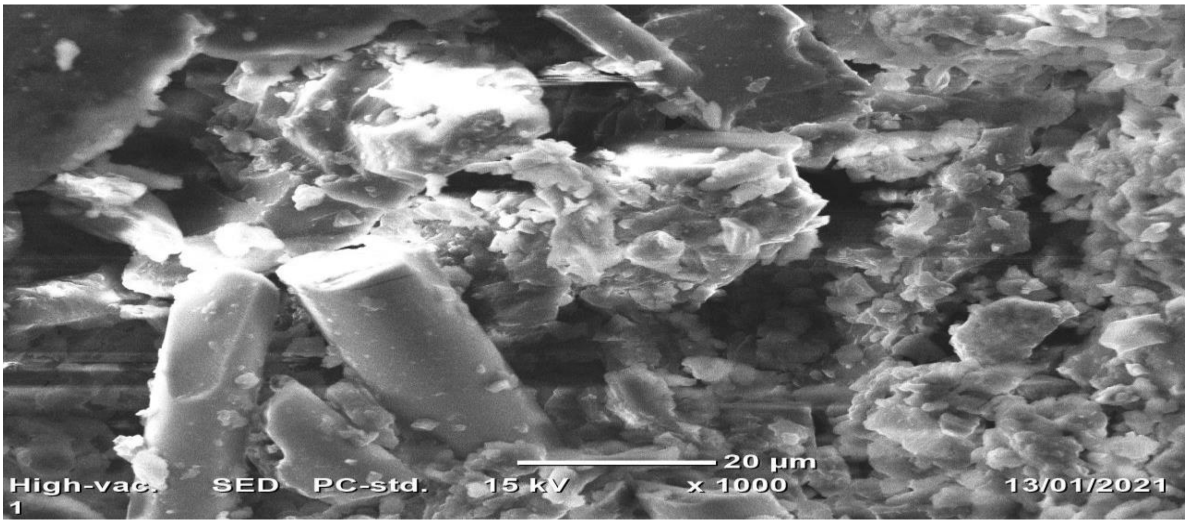




Appendix C

Morphology





Appendix D

Submitted journal

Journal of Composite Materials

The Effect of Fiber Orientation and Composition on Mechanical Properties of Hybrid Natural Composite of Nettle, Sisal and Glass Fibers

Journal:	*Journal of Composite Materials*
Manuscript ID	JCM-21-0068
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	19-Jan-2021
Complete List of Authors:	Jiru, Moera; Adama Science and Technology University, Mechanical design and Manufacturing Engineering
Keywords:	Hybrid composites, Nettle fiber (NF), Sisal fiber (SF), glass fiber (GF), Hand Lay-up, Polyester
Abstract:	Majority of the conventional materials have been replaced by Natural fiber composites due to their high strength to weight ratio, biodegradable, eco-friendly environment. Based on various literature surveys, natural fibers are a very good alternative for the Engineering and Manufacturing industries. The main goal of this work is to investigate the effect of fiber orientation and wt.% composition on mechanical properties. Fabrication of the composite was made from a hybrid polymer matrix reinforced with nettle fiber(NF), sisal fiber (SF), and glass fiber (GF). Different compositions wt.% of nettle and sisal fiber were used with 00/900 and 450 orientations. A 5% NaOH was used for both fibers to remove further lignin, hemicellulose, and other fiber remnants. The total volume fraction of the fiber was 40 wt.%. From this wt.% of nettle and sisal fibers were hybridized as 20NF:10SF, 15NF:15SF, and 10NF:20SF through 00/900 orientation by keeping wt.% glass constant. The mechanical property results for those samples were very good. In this case, the tensile load and impact force was applied in the direction of both fibers sample S5 and S5'. In the case of S5, the load was applied longitudinally to SF. Whereas in S5' the load was applied longitudinally to NF. Tensile and impact strength of S5 and S5' were 97MPa, 8.4J, and 91MPa, 6.9 J respectively. Therefore it is possible to say that hybrid composite which shows good mechanical property can be manufactured from locally available nettle fiber which is not well known in composite and sisal plant fiber.

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