

**Extraction, Fabrication and Mechanical Property study of Palm, Pineapple
Fiber Composite Materials**



**School of Graduate Studies of Jimma University Faculty of
Mechanical Engineering, Master of Science in
Manufacturing System Engineering
Jimma Institute of Technology, Jimma University**

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JIMMA , ETHIOPIA

March - 2020

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A Thesis Submitted to

School of Graduate Studies of Jimma University Faculty of

Mechanical Engineering

For the Partial Fulfillment of the Requirements for the Degree of Master of

Science in Manufacturing System Engineering

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Declaration

I hereby declare that this thesis entitled “**Extraction, Fabrication and Mechanical Property study of Palm, Pineapple Fiber Composite Materials**” is composed by myself, with the supervision of Dr. Anil. Kumar (Asst. Prof), that the research presented here is my own except where clearly indicated such in the document, and that work has not been submitted for any degree or formal certification in whole or in part.

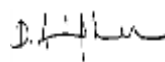
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Abstract

World is now focused on alternative, environmentally friendly and biodegradable material sources. Because of the growing natural concerns, bio composite produced from regular fiber and polymeric resin is one of the company's late advances and constitutes the current scope of experimental work. The use of composite materials is gradually increasing. The composite consists predominantly of two phases, matrix and fiber. Accessibility of characteristic fiber and ease of assembly have led scientists around the world to try and learn about the viability of protection resolves and the degree to which they fulfill the necessary specifications of broad enhanced polymer composite by regional standards.

Natural fiber-based composites are under intensive study due to their environmentally friendly nature and unique properties. The advantage of natural fibers is their continuous supply, easy and safe handling and biodegradable nature. While natural fibers exhibit admirable physical and mechanical properties, they vary with the source of plants, species, and geography. Pineapple and palm leaf fiber is one of Ethiopia's abundant materials and has not yet been studied as necessary. A detailed study of mechanical properties will bring out logical and reasonable utilization of palm and pineapple leaf fiber composite for various applications. In this research, covered the tensile, compressive, and bending stress ,young's modulus, elongation of palm and pineapple leaf fiber composite and compared with the corresponding properties with E and S glass fibers. Stress of material is (356-2097KPa) & (70-790KPa) for palm and pineapple leaf fiber epoxy composite respectively. Fiber extracted from Palm leaf have more strength as compared to pineapple leaf fiber. Tensile modulus of the material is (51-414KPa) & (4.81-459KPa) for palm and pineapple leaf fiber epoxy composite respectively. Young's modulus of pineapple leaf fiber is some more bigger as compared to palm leaf fiber due to it pineapple leaf fiber have large strain. Strain of the material developed is (5.07-6.97%) & (11.01-14.52%) for palm and pineapple leaf fiber epoxy composite respectively. Bending strength of the material is 13MPa and 24MPa for palm and pineapple leaf fiber epoxy composite respectively.

Keywords: Natural composite, Palm leaf fiber, Tensile strength, tensile modules, Strain.

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List of Abbreviations

Al	Aluminum
ASTM	American Society for Testing and Materials
BF	Bamboo Fiber
Co ₂	Carbon dioxide
Fe	Iron
HDPE	High Density Polyethylene
JRP	Jute Fibers Reinforced Composite
LDI	Lysine-Based Di Isocyanate
Mg	Magnesium
Na OH	Sodium Hydroxide
NF	Natural Fiber
PBS	Poly Butylene Succinate
PLA	Poly Lactic Acid
PMC	Polymer in Polymer Matrix Composites
PMMA	Poly Methyl Methacrylate
RHDPE	Recycled High Density Polyethylene
SEM	Scanning Electron Microscope
D	Depth
L	Length
V_f	Volume of Fiber
V_c	Volume of Composite
V_E	Volume of Epoxy
W	Width
$m_f * \rho_f$	Density of Fiber
$m_c * \rho_c$	Density of Composite
$m_E * \rho_E$	Density of Epoxy

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Published Article

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CHAPTER 1

1. Introduction

This chapter discusses about, background, statement of the problems, objectives, significance, limitations of the study.

1.1. Background

Material engineering plays a main role in the technological development of human beings and the world in particular. Composite materials are one of the advanced engineering materials that can have unlimited applications, For example, in the aerospace industry, the automotive industry, marine technology, civil engineering, electrical, sports, chemical sectors, medical sectors for various reasons, such as: medical devices, dressing, life support, diagnostics, etc. In reality, the use of composite materials compared to monolithic materials has led in significant cost savings, strength, weight, stiffness and life span. This is because monolithic materials alone will not have all the above-mentioned characteristics [1].

The term composite means "made up of separate parts." Generally, composite materials define which materials are made of two or more constituent materials with significantly different physical or chemical properties, which, when carefully combined, produce materials with superior properties than individual components. The main idea of composite materials is to produce an unusual combination of properties for different potential applications. Composite materials are primarily classified in three categories (i) Polymer Matrix Composites (ii) Metal Matrix Composites (iii) Ceramic Matrix Composites. Many composite materials have been produced in two phases. One is called a matrix, which is a continuous phase, the other is a reinforced phase.

In the developed world, it is known that rapid and continuous shifts in material science away from traditional engineering materials have largely been driven by the demands of emerging technologies for advanced and structurally sophisticated new materials [1].

In its essence, a composite material is a combination of two or more different materials that are chemically bonded together. Each of the components retains its identity in the composite and retains its distinctive structure and properties. In general, the structure of the composite consists of two phases, the matrix and the reinforcement. The matrix is a continuous phase and the reinforcement is a discontinuous phase. The obligation of reinforcements to achieve the strength

of the composite and the matrix has the responsibility of bonding the reinforcements. There is a recognizable interface between matrix and reinforcement materials. Composite materials, however, generally possess a combination of properties such as stiffness, strength, weight, high temperature performance, corrosion resistance, hardness and conductivity that are not possible with the individual components. In fact, composites are produced when two or more materials or phases are used together to produce a combination of properties that can not be achieved otherwise. Analysis of these properties shows that they depend on:–

- The properties of the individual components;
- The relative number of different phases;
- The orientation of the different components; the degree of bonding between the matrix and the reinforcements; and the size, shape, distribution of the discontinuous phase.

It may involve organic matter, metals or ceramics. There is therefore a wide range of freedom and composite materials can often be designed to meet the desired set of engineering properties and characteristics [2].

Natural fiber reinforced polymer composites attract highly fascinating manufacturers and designers because of their many advantages such as low weight, low cost, high availability, easy productivity, environmental friendliness and high specific mechanical performance. Natural fibers confirm advanced mechanical properties such as stiffness, flexibility and composite modules for glass fibers [3].

Their availability, recyclability, low density and price as well as acceptable mechanical properties make natural fibers an environmentally friendly alternative to glass, carbon and manmade fibers used in the manufacture of composites [4].

Natural fiber composites can be very cost effective for building and construction applications, partitioning panels, walls, floors, window and door frames, roof tiles, mobile or prefabricated buildings that can be used in times of natural calamities such as floods, cyclones, earthquakes, etc. [4]. As a general composite material can be classified as follows

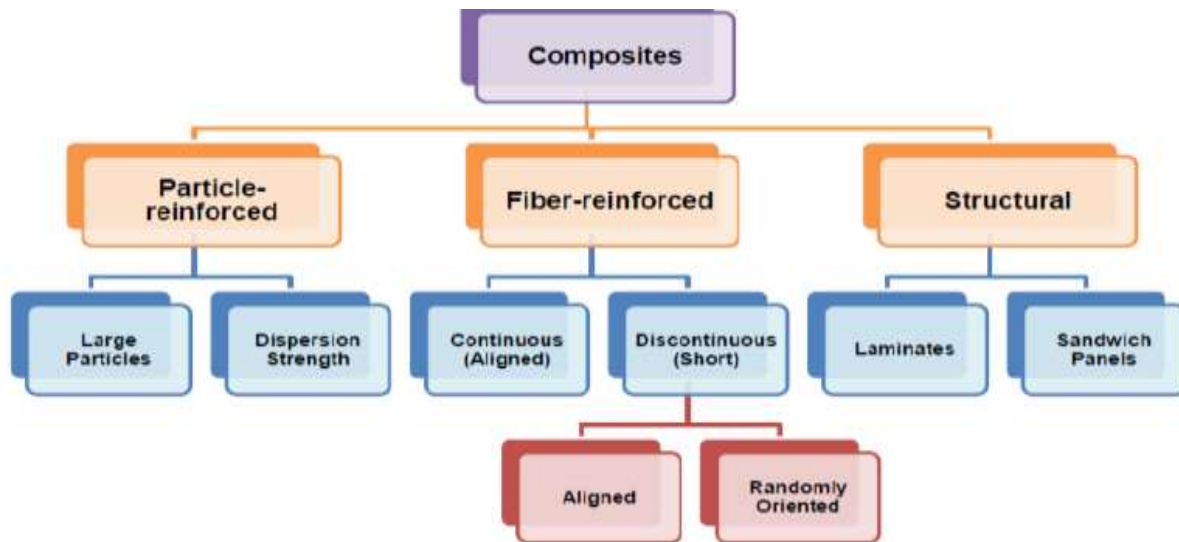


Figure 1.1.Composite classification [5]

Therefore, the present work focuses on the extraction, manufacturing and characterization of fiber reinforced composite materials for light weight applications. As a general practitioner, different researchers are doing a great job in addressing the contamination of the ecosystem by introducing natural fibers to replace the most commonly existing carbon fiber that is harmful to the ecosystem, as discussed in the literature [6-25]. There for, currently Ethiopian government is working on cleaning environment and ecosystems for safe. Hence, my study will contribute a lot in terms of creating green and ecofriendly environment by introducing new fiber sources to substitute the carbon fiber.

1.2. Statements of the Problem

In mechanical applications such as plastic industries, automotive industries and bottling and packaging industries needs light weight, high tensile strength and high specific tensile strength materials for use, this makes the basic requirement to using biodegradable and environment friendly materials for the use. Traditionally automotive body parts use high weight of conventional material, which have high impact on the environment and high cost of synthetic composite material, low tensile strength of single fiber reinforced epoxy material. Which was the basic draw back and gives motivation to work on biomaterials instead of using synthetic materials for such

applications. Having that in mind the main research question was palm plant and pineapple plant leaf not used in light applications because they are more bio diversified plants in our country, but they are used as the house for baboons and other wild lives as reported by different researchers. In Ethiopia application of natural composite material is not this much known, industry. So due to that there are a lot of visible problems in industries because of importing costly manufactured synthetic composites for their day to day manufacturing activities. But not only that such imported synthetic parts for example carbon epoxy, E. glass epoxy, that releasing carbon mono oxide to the environment and causing pollution and affecting the green environment. This is a big deal of the world now a days and government of Ethiopia in current time.

Hence, this research work will fill the identified reviewed literature gaps in [6-25] and that can address the United Nations goal, which is using biodegradable natural composites materials that are made of natural plants like palm and pineapple (leaf). Major problems in the world currently is using synthetic fibers for any application even affecting aquatic life's as shown in the Fig 1.2.and Fig 1.3



Figure 1.2.Effect of synthetic fiber on environment, on social life.



Figure 1.3. Effect of synthetic fibers on aquatic lives

1.3. Objectives

The objectives of this thesis work is consists of two parts which are discussed below:-

1.3.1. General Objective

The general objective of the thesis is extraction, fabrication and mechanical property study of palm and pineapples leaf's for light weight mechanical applications.

1.3.2. Specific objectives

- ✓ To Extract and fabricate palm and pineapples fiber reinforced epoxy composite material.
- ✓ To characterize mechanical properties of fabricated composite material by using tensile, compression, and bending test.
- ✓ To compare the mechanical properties of palm and pineapple leaf fiber composite with existing literatures.

1.4. Significance of the Study

In rural part of Ethiopia palm plant can be used as tool to construct different homemade equipment's, as house roofs in rural areas, most literatures say palm plants are using as baboons house specially around awash areas in Ethiopia. Some of the homemade applications of palm leaf's as shown in Fig 1.4.



Figure 1.4.Home made use of palm leaf.

Hence, the paper will address to produce ecofriendly, more abundant, consume less fabrication energy, nontoxic, biodegradable, and easily modifiable. And also, both physically and chemically light in weight, non-abrasive, combustible, cheap, abundantly available and recyclability compared to synthetic composite.

1.5. Scope of the Study

This research work addresses the extraction, mechanical property characterization, and fabrication of the palm and pineapple leaf fiber. But the paper has the following limitations such as:

- The study is limited to address extraction of fibers from the plant stem and root.
- Thermal properties of the fiber are not studied.
- Effect of fiber orientation and length of fiber is not considered due to the fibers from the leaves part is difficult to get lengthy fibers, hence not considered.
- The thesis paper address extraction, fabrication and characterizing mechanical properties of palm and pineapple leafs fiber for light mechanical applications.

1.6. Organization of the Paper

This report focuses on the extraction, property characterization and fabrication of chopped palm and pineapple leaf fiber reinforced epoxy composite, and results discussion. The thesis paper comprises of five chapters.

Chapter 1:- Introduces the background of natural fiber composite materials and this project's Statement of problem, objectives, significance of the study, Scope of the study is discussed.

Chapter 2:- Reviewed all relevant research papers regarding natural fiber composite materials, ranging from polymer types, fiber types, and composite's chemical, mechanical properties, researches on natural fiber reinforcement on are widely and deeply reviewed.

Chapter 3:- Material and methods used during the research work is studied and the steps used for conducting the experiment is putted with the corresponding machine setup.

Chapter 4:- The result and discussion of the experimental work is discussed briefly.

Chapter 5:- According to the result obtained in the above chapter's conclusion and recommendation were made, finally the future working areas are put as the directions.

CHAPTER 2

2. Literature Review

This chapter consists of introduction, relevant literatures, types, advantages, disadvantages and some applications of natural fibers, finally limitations of recent relevant researches are discussed.

2.1 Introduction

It is believed that source of petroleum based products are limited and uncertain. So an alternative with cheap sustainable and easily available raw material is required. The countries growing plant and fruit are not for only agricultural purpose but also to generate raw materials for industries.

Most of the developing countries trade lignocellulosic fibers for improving economic condition of poor farmers as much as country support. Recently polymer composites containing cellulosic fibers are under focus in literature as well as industries [5].

A composite is a material prepared by combining two or more different materials in such a way that the resulting material is capable of having properties that are more advanced than any of its parent materials. Their advanced properties are usually applied in fields such as defense, aerospace, automotive, engineering, sports, etc. Natural fiber composites are currently in high demand due to their eco-friendly properties. Natural fibers such as sisal and bamboo have the potential to be used as a replacement for traditional reinforcement materials in composites for applications requiring a high strength to weight ratio and further weight reduction. Natural fibers such as jute, sisal, bamboo and silk are cheap, abundant and renewable, lightweight, low density, high strength and biodegradable.

In addition, the study will introduce a new source of natural fiber extracted from pineapple and palm leaves. The following section will cover the state of the art and the various related works of extraction, characterization and manufacture of lightweight materials from different natural fibers.

2.2 Previous Research Works

The most recent research articles, journal papers, books and conference papers are reviewed under this sub-theme. This study is similar in many aspects to the studies discussed below, but the following point makes the study different from the literature reviewed below, such as the study area, the novelty of the work.

According to the paper reported and presented by [6], Composite materials produced by a combination of natural fiber have good mechanical properties, which make the majority of researchers pay attention to natural composites for different applications. In this paper, mechanical properties (tensile, flexural, compression and hardness) are tested for sisal / coir; sisal / hemp and sisal / flax fiber reinforced epoxy hybrid composites are tested according to the ASTM standard. The traditional hand-lay-up method was used for the preparation of a hybrid composite. Lignin, pectin and dirt have been removed by the Na OH treatment of the fibers. Experimental results show that sisal / hemp fiber reinforced hybrid composites exhibit more tensile and flexural strength, while sisal / coir fiber reinforced hybrid composites exhibit more compressive strength and durability.

[7], This paper examines the properties of reinforced bamboo composites from a number of Bamboo characterization studies available in the literature. The review is based on characterization studies of several types of reinforced bamboo composites, such as laminated bamboo reinforced fiber composite, randomized bamboo reinforced composite, hybrid fiber reinforced composite, bamboo reinforced bio-composite and bamboo sandwiched fiber composite structure. It can be said that the laminated bamboo composite generally has higher mechanical properties compared to other structural bamboo composites. The specific tensile properties of the laminated bamboo reinforced composites are at the same level as the glass reinforced composites, while the mechanical properties of the reinforced bamboo fiber composites are comparable to the mechanical properties of the best natural fiber reinforced composites.

[8], Bio-based hybrid green composites in unidirectional configuration have been prepared using kenaf, bamboo and coir fibers to reinforce poly lactic acid (PLA) polymer matrix. Three types of hybrid green composites, kenaf-coir / PLA, bamboo-coir / PLA and kenaf-bamboo-coir / PLA composites, were examined for tensile and flexural testing. The tensile strength of the kenaf-bamboo-coir / PLA composites was higher than the bamboo-coir / PLA and kenaf-coir / PLA. Young's moduli of the three composites were low, and high flexural strength was obtained in both + e and higher flexural modulus. It was found that the combination of high strength and stiffness of bamboo and kenaf fibers and high ductility of coir fiber improved tensile strength compared to single fiber green composites.

[9], His studies investigate the effect of boosting sisal and hemp fibers, either alone or simultaneously, on the tensile behavior of the polymer matrix containing 50-50 mixtures of fresh and recycled high density polyethylene (HDPE). Before the production of composites, the fibers Na OH and Maleic Anhydride (Coupling Agent) were chemically treated. The tensile strength of sisal-hemp / HDPE hybrid composites is observed to be higher than that of single-fibre (hemp / sisal) reinforced HDPE composites. Sisal fiber appears to be the primary reinforcement agent and dominates hemp fiber by controlling the tensile strength of hybrid composites. The tensile strength of the hybrid composite increases with an increase in sisal content from 5% to 20% but decreases with an increase in hemp fiber content from 5% to 20%. The operative failure modes in the composites are observed to be fiber pull out and fiber breakage.

[10], Hybrid fiber composites made of polyester reinforced with sisal fiber, jute fiber and glass fiber and evaluated their mechanical properties such as tensile strength, flexicurity and impact strength. Sisal fiber and jute fiber have been shown to be capable of alternating glass fiber to reinforce polyester and improve its flexural and tensile strength. SEM results also revealed a breakage in sisal/jute fibers.

[11], Tries to compare the mechanical properties of jute-reinforcement and reinforced glass, and the results show that jute fibers, when introduced as reinforcement in the resin matrix, significantly improve the mechanical properties, but the improvement is much lower than that achieved by the introduction of glass and other high-performance fibers. The jute fibers can therefore be used as reinforcements where modest strength and modulus are required. Another potential use for jute fibers is that it can be used as a filler fiber to replace both glass and resin in the filament wound component. The main problem with the current work has been that it is difficult to introduce a large quantity of jute fibers into JRP laminates because jute fibers, unlike glass fibers, absorb a large amount of resin. This problem is partly overcome when 'hybrid singing with glass fibers is carried.

[12], They also tried to visualize composite materials for biomedical applications. They investigated and presented different types of composites for different biomedical applications.



Figure 2.1.Composite materials for biomedical applications [12].

The work reported by Jorfi and Foster [13], Reflects developments in the design and manufacture of advanced Nano cellulose-based biomaterials (cellulose Nano-crystals, bacterial Nano-cellulose, and cellulose Nano-fibrils) that are promising for biomedical applications. They also discussed the material requirements for each application, along with the challenges that the materials may face. Finally, they provide an overview of the future directions for biomedical materials based on Nano cellulose.

A prospective analysis about the future trends of natural fibers applications and the required developments to broaden their applications is also presented by [14]. One of the problems with natural fibers is the scattered information and the differences in the reported mechanical properties. Furthermore, the lack of standards for both producers and users of these materials concerning methods for collecting, processing, processing and post-processing natural fibers adds to the complexity of the selection process. These issues are, in fact, critical disincentives for the widespread use of natural fibers in various applications.

According to the study presented by [15], the general public's environmental awareness of the reduction of carbon footprints and the use of non-naturally decomposed solid waste has resulted in an increased use of natural materials, biodegradable and recyclable polymers and their composites for a wide range of engineering applications. Due to the complexity of the fiber structures, different mechanical properties of the composites are achieved even with the use of the same fiber types with different matrices. However, their study focuses on the different manufacturing processes and their suitability for natural fiber composites, based on the materials, the mechanical and thermal properties of the fibers and matrices.

[16], Improved the tensile, flexural strength and stiffness of Jute-Epoxy composites by treating silane fibers. Found that bleaching delineation produces better interfacial bonding between jute fiber and polyester matrix and therefore improves the mechanical properties of composites.

The study reported by [17], the search for materials with a potential to be applied to automotive body panels in the near future. With the technical information on bio-polymers and natural reinforcements, a database was created with the mechanical performance of several possible components for the prospect of green composites. In that study, the renewable materials for matrix and reinforcement are screened accordingly in order to identify which materials hold both adequate strength and stiffness performance along with affordable cost so as to be a promising proposal for a green composite.

Natural and man-made cellulose fiber reinforced plastics, may be used in this group of materials. The physical properties of natural fibers are mainly determined by the chemical and physical composition, such as the structure of fibers, cellulose content, angle of fibrils, cross-section, and by the degree of polymerization [18]. Only a few characteristic values, but especially the specific mechanical properties, can achieve comparable values for traditional reinforcement fibers. This article gives a survey about physical and chemical treatment methods which improve the fiber matrix adhesion, their results and effects on the physical properties of composites. These different treatments, among others, change the hydrophilic nature of the natural fibers to reduce the effects of moisture in the composite.

The study reported and presented by [19], increased demand for new food packaging materials that meet human requirements has given impetus to the advancement of nanomaterial science. Inherent permeability of polymeric materials to gasses and vapors; and poor barrier and mechanical properties of biopolymers have increased interest in developing new strategies to improve these properties. Research and development in polymeric materials coupled with appropriate filler, matrix filler interactions and new formulation strategies to develop composites have potential applications in food packaging.

Composites based on recycled high-density polyethylene (RHDPE) and natural fiber were produced by melting and compression molding. The effects of the fibers (wood and bagasse) and the type / concentration of the coupling agent on the composite properties were studied [20]. Much work has been done on virgin thermoplastic and natural fiber composites, which have successfully

proven their applicability to various fields of technical application, particularly for load-bearing applications.

[21], The study showed that natural fibers (sisal, kenaf, hemp, jute and coir) reinforced polypropylene composites were processed by compression molding using a film stacking method. The mechanical properties of the different natural fiber composites have been tested and compared as shown in Table 2.1. A further comparison was made with the corresponding properties of glass reinforced polypropylene composites in open literature. In most cases, the specific properties of natural fiber composites have been favorably compared with glass.

Table 2.1. Comparison between natural fiber and glass fiber [21]

	Natural fiber	Glass fiber
Density	Low	High
Cost	Low	Low but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO ₂ neutral	Yes	No
Abrasion to machine	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

The mechanical properties of the natural fiber composites tested were found to be favorable in comparison with the corresponding properties of the polypropylene glass material. In some cases, the specific properties of natural fiber composites were better than those of glass. This suggests that natural fiber composites have the potential to replace glass in many applications that do not require very high load bearing capacity.

[22], This paper presents the possibility of using renewable natural materials (hemp fibers and wood cellulose) in the preparation of lightweight composites. One of the main objectives of the construction industry is to reduce the production of carbon dioxide during the manufacture of cement. The effect of the use of different binding agents in combination with hemp slices in composites has therefore been examined. The experimental examination of selected mechanical properties indicated that the use of zeolite as a cement replacement does not appear to produce

mechanically stronger hemp concrete. Wood cellulose is another very interesting material as a possible reinforcement of cement; it is a biodegradable, renewable, cheap, readily available natural resource and contributes to the reduction of greenhouse gases.

[23], Their study, essentially for the purpose of this study, is to introduce the theory of percolation in this field and to carry out some preliminary work. In the first place, two new concepts, accessible fiber ratio and diffusion-permeability coefficient, were defined; in the second place, a percolation model was developed to estimate the critically accessible fiber ratio; finally, the moisture absorption and electrical conductivity of composites with different fiber loads were investigated. At high fiber loading, when the accessible fiber ratio is high, the diffusion process is the dominant mechanism; while at low fiber loading near and below the percolation threshold, percolation is the dominant mechanism.

[24], Effects of lysine-based diisocyanate (LDI) as a coupling agent on the properties of bio composite poly (lactic acid) (PLA), poly (butylene succinate) (PBS) and bamboo fiber (BF) were investigated. Tensile properties, water resistance and interfacial adhesion of both PLA / BF and PBS / BF composites have been improved by the addition of LDI, while thermal flow has become somewhat difficult due to crosslinking between the polymer matrix and the BF. Proteinase K and Lipase PS have been investigated for enzymatic biodegradability of PLA / BF and PBS / BF composites, respectively. Both composites could be rapidly decomposed by the enzyme and the addition of LDI delayed degradation. The tensile properties and water resistance obtained have been significantly improved by this mechano-chemical reactive processing, which will be of value for industrial applications.

[25], The availability and accessibility of plant fibers is the main reason for an emerging new interest in sustainable technology. While focusing on composite materials, the main points to be considered are environmental friendliness and light weight, with high specific properties. This century has witnessed remarkable achievements in green technology in the field of materials science through the development of high-performance materials made from natural resources that are growing worldwide.

To summarize the above relevant literature different researchers have done a great job on composite materials as a general and excellent work is still being done on natural composites, due to the abundance of species of plant researchers addressed only some of them, therefore this

research will fill gaps in knowledge and research gaps by studying such a new source of materials for light mechanical applications.

2.3 Natural Fiber and Its Characteristics

The manufacture of materials currently used is quite difficult in terms of energy consumption, raw materials and costs. Efforts are therefore being made to find suitable alternative material resources, while local, easily renewable resources are to be an advantageous alternative, on the condition that they are subsequently processed with low energy requirements. One solution method is the use of naturally available agricultural fibrous resources. Natural fiber is a type of renewable source and a new generation of reinforcements and complements for polymer-based materials see Table 2.2. The development of natural fiber composite materials or environmentally friendly composite materials has recently been a hot topic due to increasing environmental awareness.

Table 2.2.Summary of Natural Fibers characteristics [21]

Fibers	Descriptions
Banana	Abaca, also known as manila hemp, is closely related to bananas. The plant of Abaca looks similar but, unlike bananas, its fruit is not for human consumption and is not economically viable. In contrast to bananas, abaca grows only for the production of fiber
Bamboo	Bamboo has received interest because it has a high strength to weight ratio, one of the fastest growing plants, requires less water, no use of pesticides or herbicides, and is harvested at its base, leaving the root untouched. Furthermore, the surface of the fiber is round and smooth and the ratio of l/d is high. It's lighter, stiffer and stronger than U.S. glass fiber.
Coir	Coir is very attractive because it is more durable than most natural fibers, free from chemical treatment, its high resistance to salt water and its availability.
Cotton	Cotton fiber has excellent absorbency, while Cotton accounts for 46% of the world's production of natural and chemical fibers.
Jute	Jute fiber has a high aspect ratio (l/d), a high strength to weight ratio and good insulation properties.
Kenaf	Kenaf fibers have low density and high specific mechanical properties.
Sisal	Sisal is easily cultivated with short periods of renewal. The fiber has a high tensile strength and tensile strength, abrasion resistance, salt water resistance, acid and alkali resistance.

There are several studies that point to the lower cost of natural fibers compared to synthetic fibers, but a proper comparison must be made in their application in part, considering the cost or impact of their production and life cycle as shown in Table 2.3. Different mechanical properties will

require different mass of each fiber, different fiber quality and reliability will cause different waste and scrap during the production of composites and different needs for parts to be replaced during life.



Figure 2.2.a). Glass fiber b). Carbon fiber c). Natural fiber [21]

Table 2.3. Energy and cost of different fibers [21].

	Fibers	Cost (US\$/ton)	Energy (GJ/ton)
a	Glass fiber	1200–1800	30
b	Carbon fiber	12,500	130
c	Natural fiber	200–1000	4

Following those authors natural fibers cost much less and require very less energy to produce which leads to cost and energy advantages over traditional reinforcing fibers such as glass and carbon fiber (Table 2.4).

Table 2.4. Summary of characteristics of properties of natural and manmade fibers [21].

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

2.4 Advantages and Applications of Natural Fiber

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

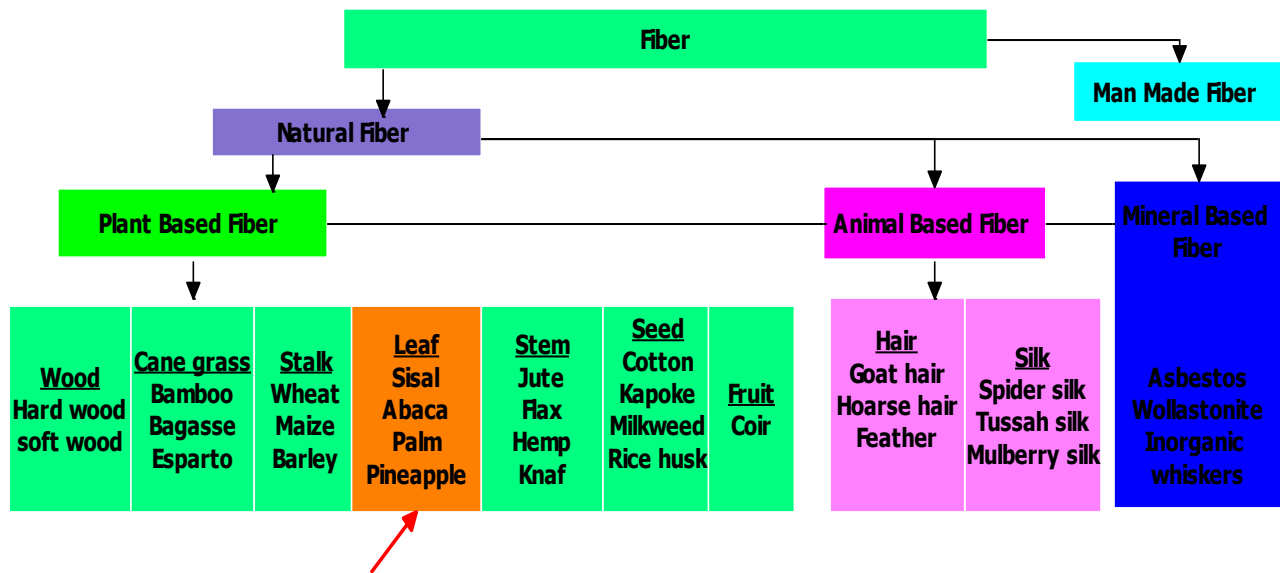


Figure 2.3. Natural fibers are classified on the basis of the origin of source, into three types [16].

2.4 .1 Plant Fibers

Plant fibers are usually made up of cellulose, such as cotton, jute, bamboo, flax, ramie, hemp, coir and sisal. Cellulose fibers are used in a variety of applications. The category of these fibers is, as follows, the seed fibers which are obtained from the seed, e.g. Cotton and Kapok. These fibers have superior tensile properties to other fibers. Because of this, these fibers are used in a number of applications, such as packaging, paper and fabric. Fruit fibers are generally obtained from the fruit of the plant, e.g. banana fiber and coconut fiber. In the same way, stalk fibers are the fibers obtained from stalks (rice straw, bamboo, wheat and barley). Leaf fibers are the fibers that are produced from the leaves (agave and sisal). The skin fibers are the fibers that are produced from the stem of the plant.

Generally, plant fibers, they are the most widely accepted fibers by the industry and the most analyzed by the research community. This is mainly due to the short growth period, the ability to renew and the wider availability [26]. The vegetable fibers are made up of cellulose, hemicellulose and lignin, which can be extracted from the stem, leaf, seed, fruit, wood, stalk and grass.

2.4.2 Mineral Fibers

Mineral fibers are the ones that come from minerals. These are naturally occurring fibers or slightly changed fibers. It has different classifications that they take after: asbestos is the main characteristically occurring mineral fiber. Variations in mineral fiber are serpentine, amphiboles and anthophyllitis. Ceramic filaments are made of glass fiber, aluminum oxide and boron carbide. Metal filaments are made of aluminum strands [26].

2.4 .3 Animal Fibers

Animal fiber consists mainly of proteins; cases, silk, alpaca, mohair, downy. Animal hair is the strands of creatures, e.g. Sheep's downy, goat hair, horse hair, alpaca hair, and so on. Silk fiber is a filament that is collected from a dry saliva of bugs or creepy creeps during the planning of coconuts [4].

Natural fiber compounds used for structural, but typically synthetic, thermoset matrix drives, which, of course, bound environmental benefits. Nowadays, the application of natural fiber composites is usually found in the construction and automotive industries and the place where dimensional constancy under humid and high thermal conditions and load bearing capacity is of importance [2], [27].

Composite materials could be referred to as those materials which are synthesized by two or more materials with diverse properties. Large, composite materials have a strong load bearing material that is embedded in weaker lattice materials. The primary component of the composites has a non-stop stage, which is the significant part of the composite that is called the matrix. Matrix is by and large more ductile and less hard and generally either inorganic or natural. The optional component of the ductile composites is called reinforcement and is implanted in the matrix.

The components of the composite materials have their property, however, when they are consolidated together, they give a blend of properties that the singular cannot have the capacity to give. Generally, composite materials are arranged on the basis of matrix materials such as:

1. Ceramic Matrix Composites, 2. Polymer Matrix Composites, 3. Metal Matrix Composites

1. **Ceramic matrix composite:** Composite consisting of ceramic combined with a dispersed ceramic phase. Due to the availability of new technologies, the demand for high-performance products and methods of processing have together improved the growth of advanced ceramic products, but the fragility of ceramics remains a major disadvantage.
2. **Polymer matrix composite:** Polymer matrix composites are recognized as a more conspicuous class of composites when contrasted with artistic or metal lattice composites once in business requirements. It includes a thermoplastic matrix (polystyrene, nylon) or thermosetting matrix (epoxy, non-saturated polyester) or an inserted steel, carbon glass or kevlar strand.
3. **Metal matrix composite:** Composites consisting of a metal matrix, such as Mg, Al, Fe, are called metal matrix composites. Interest in metal matrix composites is due to a number of reasons, such as their engineering properties. They have good stiffness, light weight and low specific weight compared to other metal alloys and metals. Although it has many advantages, low cost remains a key point of interest for a number of applications.

Polymer matrix composites are the most commonly used composites among all types of composites, due to their advantages such as high strength, low cost and simple manufacturing. The demand for polymer material in this modern dynamic world is increasing day by day because it has a wide range of advantages over traditional material in terms of high strength to weight ratio, cost, high strength, high tensile strength and high creep resistance to temperature increases. Polymer matrix composites have three types of polymer that have been used as matrix. These are thermoplastics, thermoplastics and polymer elastomers.

Elastomer is a type of polymer determined by flexible polymer, often used in conjunction with the term elastic, despite the fact that the latter is preferred when referring to vulcanizations. Elastomers have numerous properties which have a low density and a high deformation strain compared to other materials. Reinforcement is the other type of components of composites. Reinforcements are generally used to upgrade the general mechanical properties of the matrix and to offer composite quality.

The reinforcement of the composites is either fibrous or non-fibrous. Fibrous composites are either natural fiber reinforced or synthetic fiber reinforced composites. There are many factors affecting

the properties of fiber reinforced polymer composites such as fiber parameters, matrix fiber matrix interfacial bonding, etc. A great deal of work has been done on the different kinds of natural fiber-based polymer composites [27]. The present work is to study the potential utilization of palm and pineapple fiber as a reinforcing material in epoxy composites and to investigate their mechanical behavior.

➤ **Advantages of Natural Fibers**

Natural fibers are commonly referred to as having several advantages over synthetic fibers such as availability, low cost, low density, acceptable modulus-weight ratio, high acoustic damping, low production energy consumption, low carbon footprint and biodegradable. Some researchers state evidence of clear benefits, for example, that natural fibers cost much less and require much less energy to produce than traditional reinforced fibers such as glass and carbon [28]. However, the negative aspects of natural fibers are due to their low consistency of properties and quality. These fibers have higher variability in physical and mechanical properties, higher absorption of moisture, lower durability, lower strength and lower processing temperatures.

- ✓ Natural fiber composites are likely to be environmentally superior to glass fiber in most cases because;
- ✓ Carbon dioxide fixation of natural fibers is an important issue in the reduction of the greenhouse effect;
- ✓ In many bulk composite's applications, natural fiber composites have higher fiber content for equivalent performance, reducing more polluting base polymer content;
- ✓ The light-weight natural fiber composite in comparison with classical materials, e.g. steel, improves fuel efficiency and reduces emissions in the use phase of the component, especially in automotive applications;
- ✓ The end of life incineration of natural fibers results in recovered energy and carbon credits; being basically carbon neutral;

Finally, their production has a low environmental impact compared to the production of glass fibers, particularly due to low energy utilization. During the production of natural fibers, the energy consumption required for the production of natural fiber materials, including cultivation, harvesting and extraction of fiber, is just less than one-fifth of the energy required for the production of glass fiber.

Environmental advantages of palm and pineapple plantations and their use as reinforcement in composite materials for their beneficial properties compared to glass fibers, e.g. CO₂ and energy consumption.

➤ **Application of Natural Fibers**

Natural fiber reinforced polymer composites have attracted a great deal of attention and interest among materials scientists and design engineers in recent years due to the consideration of developing environmentally friendly materials and partially replacing currently used glass or carbon fibers for reinforcement of composites. The use of natural fiber reinforced polymer composites and natural resins to replace existing synthetic polymer or glass fiber reinforced materials in large quantities. The automotive and aircraft industries have been actively developing different types of natural fibers, mainly for hemp, flax and sisal and bio-resin systems for their interior components. They are high specific strength and modulus materials, low prices, recyclable materials, easily available in some countries, etc.

Several industries such as automotive, construction, energy and aerospace, among others, are being challenged by society and governments to make products that are more environmentally friendly and reduce their dependence on fossil fuels.



Figure 2.4. Application of fiber reinforced composite [29].

In this scenario, as shown on figure 2.4, natural fiber is an attractive option for industries to meet socio-economic and environmental challenges. Furthermore, the use of natural fibers would create opportunities for employment in rural and less developed regions, thus helping to achieve the UN's

sustainable development goals, namely poverty eradication, inclusive and sustainable industrialization and innovation, sustainable cities and communities, and responsible production and consumption [29].

Natural fibers will therefore play a crucial role in the socio-economic development of our society. This section presents and discusses applications where natural fibers are already in use and where they can be used and what the future holds for their applications across a wide range of different industries.

2.5 Fiber Characterization and Limitations

Natural fibers such as cotton, sisal, jute, abaca, pineapple and coir have already been studied as a reinforcement and composite filler. Among the various natural fibers, palm and pineapple fiber is considered a potential reinforced in polymer composites due to its many advantages, such as easy availability, low cost, comparable strength properties, etc. Generally, natural fibers are made up of cellulose, lignin, pectin, etc. The detailed composition/characterization of few commonly used natural fibers is shown in Table 2.5.

Table 2.5. Commonly used natural fibers [23]

Fiber	Cellulose (wt %)	Hemicellulose (wt %)	Lignin (wt %)	Pectin (wt %)	Moisture (wt %)	Waxes
Cotton	85-90	5.7	-	0-1	7.85-8.5	0.6
Bamboo	60.8	0.5	3.2	-	-	-
Flax	71	18.6-20.6	2.3	2.2	8-12	1.7
Hemp	70-74	17.9-20.4	3.7-5.7	0.9	6.2-12	0.8
Jute	61.1-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5
Kenaf	45-47	21.5	8-13	3-5	-	-
Ramie	68.6-76.2	13.1-16.7	0.6-0.7	1.9	7.5-17	0.3
Sisal	66-78	10-14	10-14	10	10-22	2
Coir	32-43	0.15-0.25	40-45	3-4	8	-
Banana	63-64	19	5	-	10-12	-

➤ Moisture Absorption

The effect of moisture on the mechanical properties of natural fiber composites during long-term outdoor service or exposure to moist conditions is currently an active field of research. This results in moisture absorption and may cause dimensional instability (swelling) in the parts produced, create some stress at the interface and prevent the properties of the fiber from being transferred to the composite. Absorption of moisture by composites containing natural fibers has several adverse

effects on their properties and therefore affects their long-term performance. For example, increased moisture decreases their mechanical properties, provides the necessary condition for biodegradation, and changes their dimensions [23]. A number of efforts have been made to address this issue. Coupling agents, compatibilizers or other chemical modifications are used to improve the resistance of composites to moisture. However, the moisture absorption of composites is still a major concern, especially for their outdoor application. Moisture absorption increases with increased loading of fiber.

2.6 Pineapple and Palm Plant

Pineapple is one of the most widely cultivated tropical fruits in the world for its fruit. Pineapple leaves, the main part of the plant that is currently unused needs global attention for commercial exploitation. After harvesting the fruit, the leaves are discarded by burning or decomposing. This happened because of the outdated technology involved and the ignorance on the part of farmers and local communities about the existence of commercial uses of pineapple leaves [30].

In pineapple cultivation, pineapple leaves can be further processed for the production of value-added products. The waste from pineapple is no longer something that is unwanted. Recently, it has been seen as a resource for economic development. The conversion of pineapple leaves into wealth not only makes good environmental sense, but also turns "cash" into "cash"[30]. In our endeavor to develop pineapple leaf fiber diversification, introduced a new technology for sustainable pineapple leaf fibers productions.

Palm plants in Ethiopia is used as a traditional application starting from making house hold equipment's but still using as house of wild life.

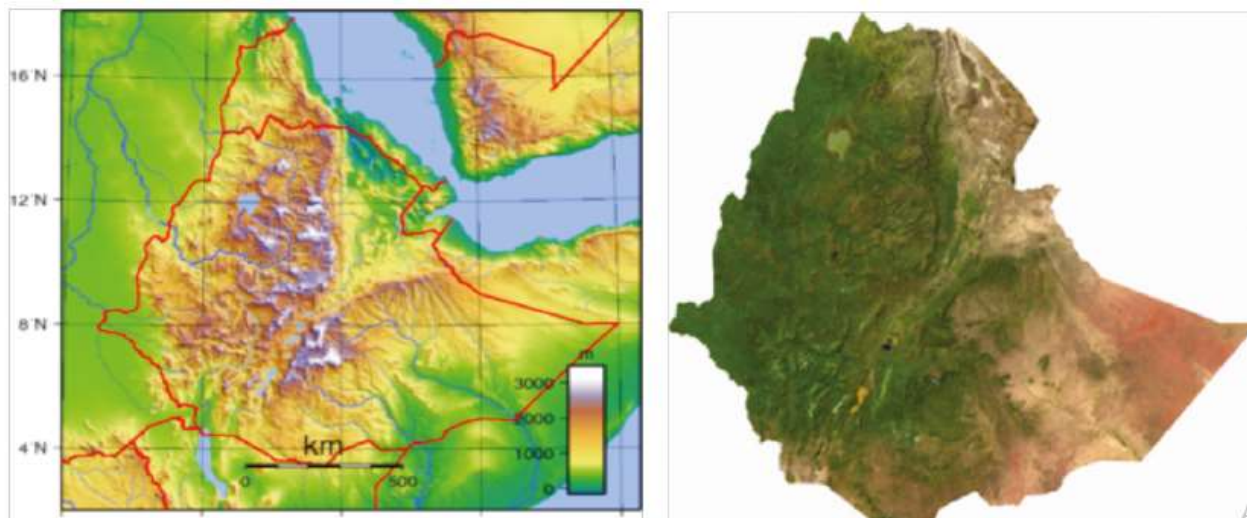


Figure 2.5. Ethiopian highland areas suitable for palm and pineapple plant growth



Figure 2.6. Gathering of pineapple leaf from around Jimma Ethiopia



Figure 2.7. Gathering palm leaf around Jimma, Ethiopia.

2.7 Literature Gap

As reviewed on the above relevant literatures [6-30], the following research gaps are observed: -

- Due to massiveness of the verity of species of plants still most plant fibers are not yet studied, for example pineapple and palm leaf are not studied as fiber source, May they studied for other applications for example palm oil, pineapple juice, which shows still there is gap in using them as fiber source.
- During mold preparation the techniques used is manual hand layup, it has an influence on prepared test specimens, which can affect the studied characters.
- Applicability of external lubrication increases environmental issues and process cost.

CHAPTER 3

3. Materials and Methods

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

3.1 Materials

3.1.1 Matrix

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

I. Thermosetting polymers, II. Thermoplastic polymers.

I. Thermosetting Polymers

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

II. Thermoplastic Polymers

Thermoplastic polymers are made to soften / melt on heating. These polymers are primarily suitable for the formation of liquid flow. Many thermoplastic polymers have a high molecular weight. Intermolecular force acting between polymer chains, which is rapidly weakened by

temperature increases, produces a viscous liquid. Thermoplastics may be reformed by heating and are typically used to produce different parts by several polymer processing methods, such as injection molding, compression molding and extrusion. Examples of thermoplastic polymers include high- and low-density polyethylene, polystyrene and poly methyl methacrylate (PMMA).

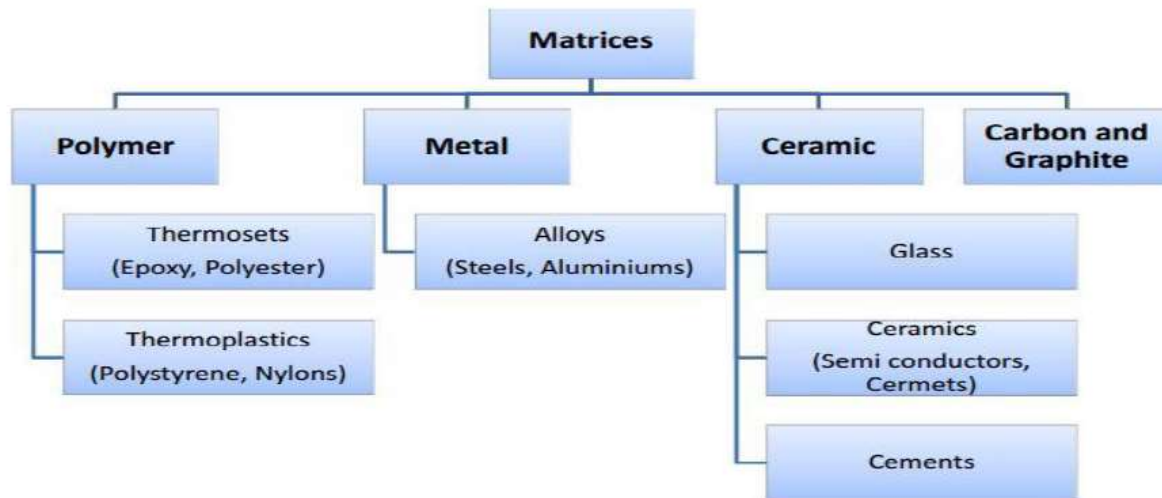


Figure 3.1. Classification of matrices [20].

- **Epoxy Resin:** - For this research work, epoxy resin was used as a matrix with the system name OCPOL-711N epoxy resin, which is purchased from the local fiberglass manufacturing industry in Gurd shola, Addis Ababa, Ethiopia. Epoxy resin is one of the most exciting polymer types and is used in advance to produce composite materials with different reinforcement elements. Their extensive use is mainly due to their superior mechanical properties, excellent adhesion, and good use of additional reactions, low cure shrinkage and low cost.
- **Hardener:** - Epoxy resin is cured by adding a catalyst that causes a chemical reaction without altering its own composition and properties. The catalyst initiates a chemical reaction from the liquid to the solid state of the epoxy resin and the monomeric ingredient. Therefore, the hardener (curing agent) used for this specific research work is hardener with the system brand name #2060 hardener, which is purchased from the local fiberglass manufacturing industry in Gurd shola, Addis Ababa, Ethiopia.

3.1.2 Palm and Pineapple Leaf Fiber

The required amount of palm and pineapple leaves for this thesis work is collected from the southwestern part of Jimma Ethiopia after harvesting at the base and the fibers are extracted manually from the plant using a knife. Initially, the leaves were trimmed in longitudinal direction into strips for easy extraction of the fiber. The peel is clamped between the wooden leaf and the knife and gently pulled in the longitudinal direction, removing the resinous material as shown in the Fig 3.2. After the extraction process, the extracted fiber washed with pure water to remove and separate unwanted dust from the fiber and dried with sunlight, and the required fine fibers are finally obtained. This fiber is now ready for the production of the test specimen.



b).



c)



Figure 3.2.Fiber extraction process of palm and pineapple leaf

In this thesis work estimation, extraction of palm and pineapple leaf's fiber, manufacturing and characteristic mechanical properties of palm and pineapple leaf's fiber reinforced with resin epoxy.

1. Estimation volume ratio of fiber to matrix
2. Extraction and Fabrication

3. Characteristic Mechanical Properties

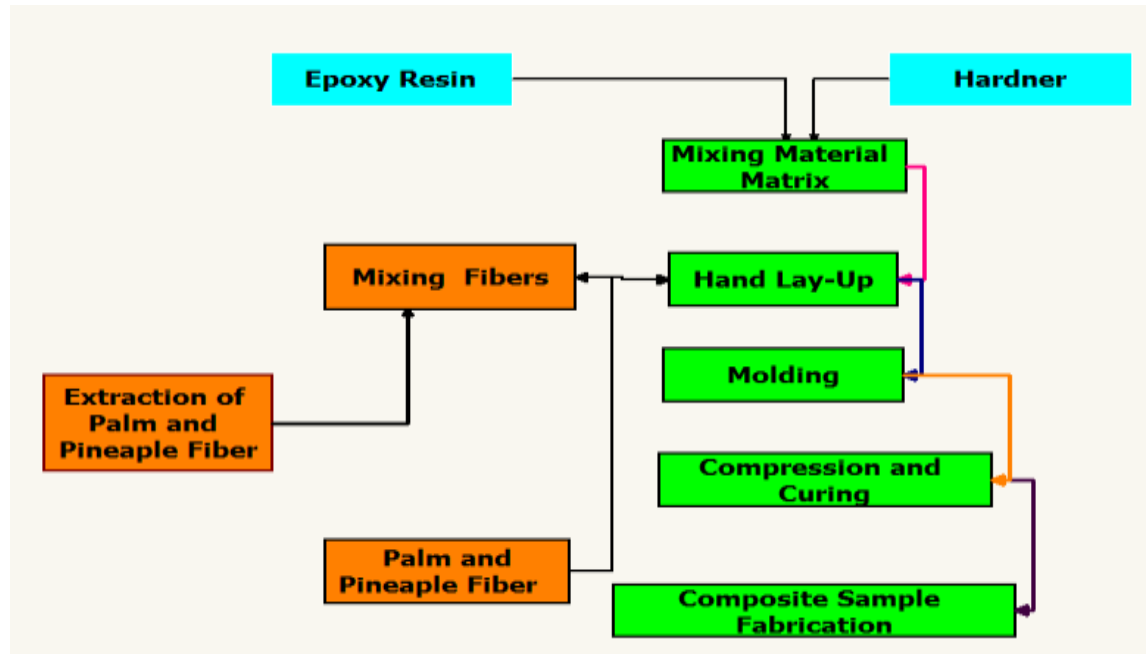


Figure 3.3.Schematic flow of fiber extraction

3.2.Methods for Sample Preparation

3.2.1. Preparation of Palm and Pineapple Leaf Fiber

In this thesis, a study was conducted to characterize the mechanical properties of palm and pineapple leaf fiber. Chemical treatment helps improve the interfacial interaction between the fiber and the matrix by removing hemicellulose, lignin, wax and other impurities, leading to good bonding of the fiber / polymer matrix [14]. Before chemical treatment, palm and pineapple leaf fiber may be washed with a mild detergent solution and then reined in distilled water to remove dust and other impurities that may be present on the fiber. Therefore, the given palm fiber has been cut into 20 mm fiber length using a pair of scissors and finally the chopped fiber has been produced.



Figure 3.4. Chopped fiber has been produced

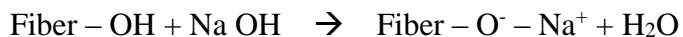
3.2. 2. Alkali Treatment

I. Sodium Hydroxide

Sodium hydroxide, also known as lye or caustic soda, has a molecular Na OH formula and is a highly caustic metal base and alkali salt. Pure sodium hydroxide is a white solid, available in pellets, flakes, granules and as a 50 percent saturated solution. Sodium hydroxide is soluble in water, ethanol, and methane. This alkali is delicious and readily absorbs moisture and carbon dioxide in the air. Although molten sodium hydroxide has properties similar to those of other forms, its high temperature limits its application. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents [13]. In this work, Na OH was used in the form of pellets, purchased from local suppliers in Kera Addis Ababa with the brand name and code of RANKEM, S0290, and chemical treatment of palm and pineapple fibers.

Alkalization cannot be considered as an authentic physical modification since the chemical composition of the plant fiber is altered after treatment, nor can it be classified under the pure chemical methods, because no additional coupling agent is introduced into the composite. The alkalization process (mercerization) is one of the most commonly used chemicals for bleaching or cleaning the surface of plant fibers, where the fibers are immersed in a Na OH solution at specific concentration for a specific period of time.

This chemical treatment produces modifications on the fibers related with the surface morphology and fiber internal structure that will be reflected in the mechanical properties of the composite material. The following reaction takes place as result of alkali treatment.



According to Literature, alkali solution has a good effect on the treatment of natural fibers. In this study, 10% Na OH solution was used for the treatment of raw palm and pineapple fiber. In order to improve adhesion between the fibers and the matrix, the fibers underwent surface treatment. Sodium hydroxide is the most commonly used chemical for cleaning / bleaching the surface of cellulose fibers. The chopped palm and pineapple fiber have been soaked in 10% Na OH solution for 24 hours. The treated fibers were washed in distilled water to neutralize excess Na OH. This treated palm and pineapple fiber has been dried in sunlight for two days before being used as reinforcement in composite synthesis.

To perform this treatment efficiently following the following step is recommended.

1. Wash the chopped palm and pineapple fiber with in distilled water at for 1hrs and dry it in sunlight for a days.



2. The second step is palm and pineapple fiber mercerization. It is a process of treating palm and pineapple fiber after oven with 10wt% Na OH solution at room temperature for 24hrs.



3. Next rinse the fiber (palm and pineapple fiber) with water to remove the soda excess until PH ~ 7 will reach.



4. Finally, the fiber has been dried by sun light.



II. Chopped Fiber Mass Composition

For different fiber- matrix ratio the mass composite of the composite material has been summarized in the Table 3.1. The fiber used were chopped due to that fiber orientation is not considered/difficult to consider, while characterization but the most literatures use epoxy to fiber composition, maximum amount was for epoxy and lesser amount was fiber due to epoxy were reinforcing part of the matrix and studying the effect of other composition is future work for other researchers.

Table 3.1. Fiber- Matrix Mass Composition

Designation	Composition (%)			Mass (gram)			Samples #
	Epoxy	Palm	Pineapple	Palm fiber	Pineapple fiber	Epoxy	
ST(F) 15	85	15	15	399	456	360	18

In this thesis, chopped (short) palm and pineapple fibers were used, with a fiber length of 5 mm and composite material samples were prepared 15/85 fiber-matrix volume compositions see Table 3.1. Palm and pineapple reinforced epoxy fibers are used for fiber matrix ratios of 15/85, for palm and pineapple fiber composites. Fiber thickness identified was 2.32-2.52mm & 2.8-3.26mm respectively.

3.2.3. Preparing the Sample

A. Preparation of Epoxy and Hardener

OCPOL-711N epoxy resin, mixed with SYSTEM #2060 hardener, is used for the preparation of a composite plate. The ratio of weight to mixing epoxy and hardener is 10:1. The hardeners include anhydrides, amines, polyamides, dicyandiamide, etc. Mixing is done in the mixing containers (bowl) the bowl is made of nickel to prevent the melting of the bowl during the exothermic reaction with the tongue depressor the mixture is done slowly so as not to induce any excess air bubbles in the resin.

B. Hand Lay-Up

Hand-lay-up method was used to fill the prepared mold with an appropriate amount of epoxy resin mixture and layers of random (chopped) palm and pineapple fibers, starting and ending with resin layers. The quantity of accelerator and catalyst added to the resin at room temperature was 1% by volume of resin each. Fiber deformation and movement should be minimized to produce high quality, random fiber composites. As a result, at the time of curing a compression pressure of 50 bar (5MPa) was applied to the mold and the air gaps formed by the fibers were gently pressed out by the hydraulic press to force the air between the fibers and the resin, and kept for several hours to obtain the perfect samples, the processed wet composite was then pressed hard and the excess resin was removed and dried.

Fiber configuration and volume fraction are the two most important factors affecting the properties of the composite.

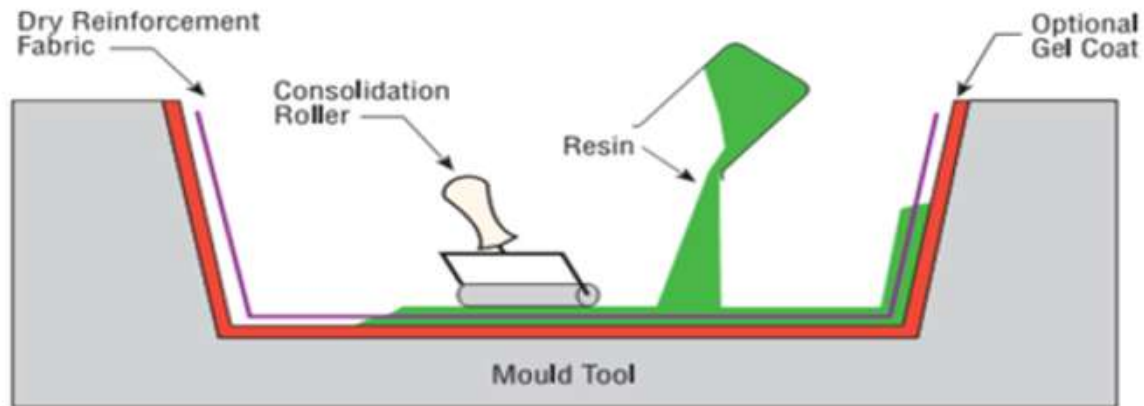


Figure 3.5. Hand layup [4]

C. Materials Requirements of Hand-Lay-Up Method

➤ Mold preparation

The pattern is made of sheet metal with a thickness of 300* 250* 20 mm and contains basic parts such as base plate, cover frame and mold release. The base plate is a very thin plate, which is placed inside the entrance. The mold surfaces of the lid and base plate and the walls are coated with a remover and allowed to dry. The functions of the lid and base plates are to cover, compress the fiber after the epoxy has been applied, and also to prevent debris from entering the composite parts during the curing period.

➤ Mold Release

The release of the mold is essential to prevent the epoxy from sticking to the mold when the composite is separate. Although several types of mold releases are used depending on the mold material and the desired characteristics of the finished part, the most common type used for this work is paste wax (oil) and polyethylene plastic for better surface finishing of the composite.

➤ During Sample Preparation

First of all, the mold surface was covered by aluminum foil and the overall mold surface was painted with a mold release agent (oil), then some mixture of epoxy resin poured on the prepared mold surface and the chopped palm and pineapple fibers were arranged on this surface according to each specific fiber / matrix ratio as shown in Fig. 3.6 When we press the mold on the consolidation press and leave this sample for 2-3 hours. The composite is dried within 2-3 hours in which the fibers of the palm and pineapple and the polymers adhere tightly in the presence of a hardener.

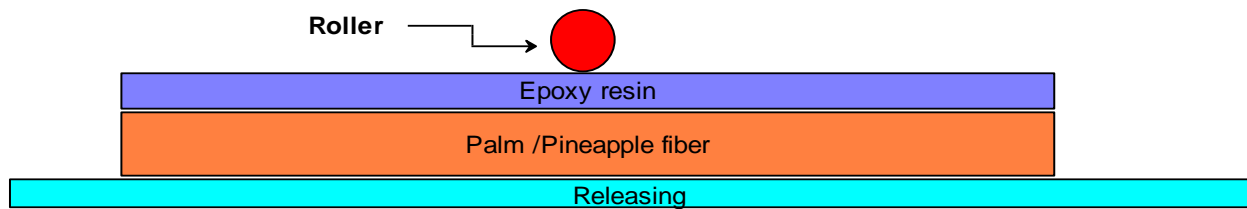


Figure 3.6. Palm and Pineapple fiber reinforced epoxy composite molding sketch map

Eventually the required composite material was produced.



Figure 3.7 Palm and Pineapple fiber- epoxy resin mixture in the mold surface at African bamboo lab

➤ **Compression and Curing**

Pressure was maintained at 5Mpa and required 2-3 hours to be cured at room temperature. After the curing period, the polymer matrix fibers of the palm and pineapple were removed from the mold. The typical hydraulic press used for the treatment of fiber on KANG is shown in Fig 3.8.



Figure 3.8. Standard Hydraulic Press for curing in African bamboo



Figure 3.9. Releasing the cured sample from the mold plate and removing aluminum foil from sample



Figure 3.10. Prepared samples from pineapple and palm leafs

3.3. Experimental Procedures and Steps

In order to evaluate the tensile, compressive and bending strength, chopped palm and pineapple fiber reinforced epoxy resin composite material, a compact voltage specimen sample was developed using ASTM standard. And the tensile test was carried out for the sake of the young module assessment, the paper work needs a total of 9 test specimens for each fiber and 18 total samples for the mechanical properties of the different fiber matrix composition also prepared for the investigation. The test specimens were prepared with the appropriate size using the band saw.

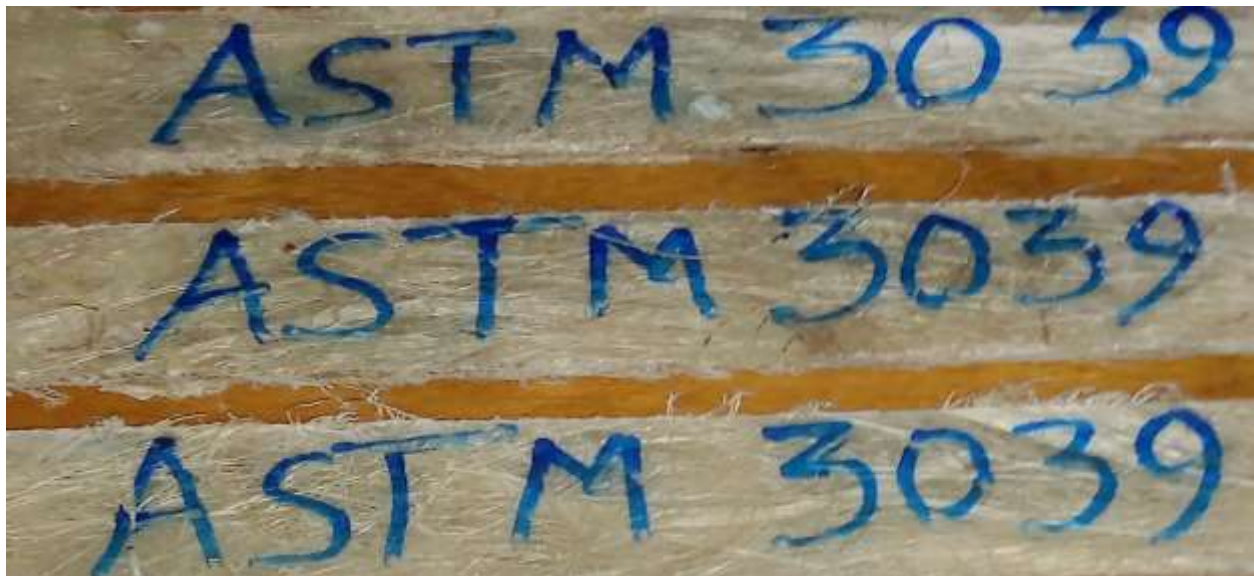


Figure 3.11. Test specimens were prepared using the band saw in African bamboo

3.3.1 Dimension for Test Specimen

Appropriate American Society of Testing Materials (ASTM) standard, ASTM D-3039, was followed during preparation of tensile test specimens for palm and pineapple fiber reinforced epoxy composite test and shown in the Fig 3.12.

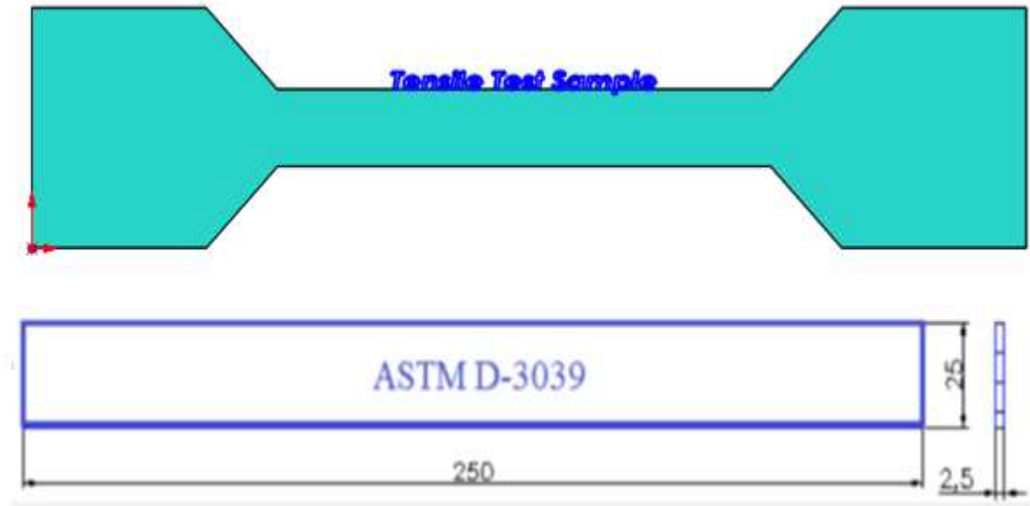


Figure 3.12. ASTM D-3039 Standard for tensile test sample prepared.

Based on the respective standards for weight ratio of 15/ 85percent, tensile strength test was performed using the UTM machine after the chopped palm and pineapple fiber reinforced epoxy composite specimen was cut to the desired size.

3.3.2. Universal Testing Machine (UTM) Testing System

UTM Testing Systems are highly integrated testing packages that can be configured to meet different test needs. Each includes a load unit with an integral actuator and servo valves, a hydraulic power unit and a control system as shown in the Fig.3.13. The control system consists of three main components: the system software running on a personal computer, the digital controller and the remote-control panel. These functions work together to provide fully automated control of the test.

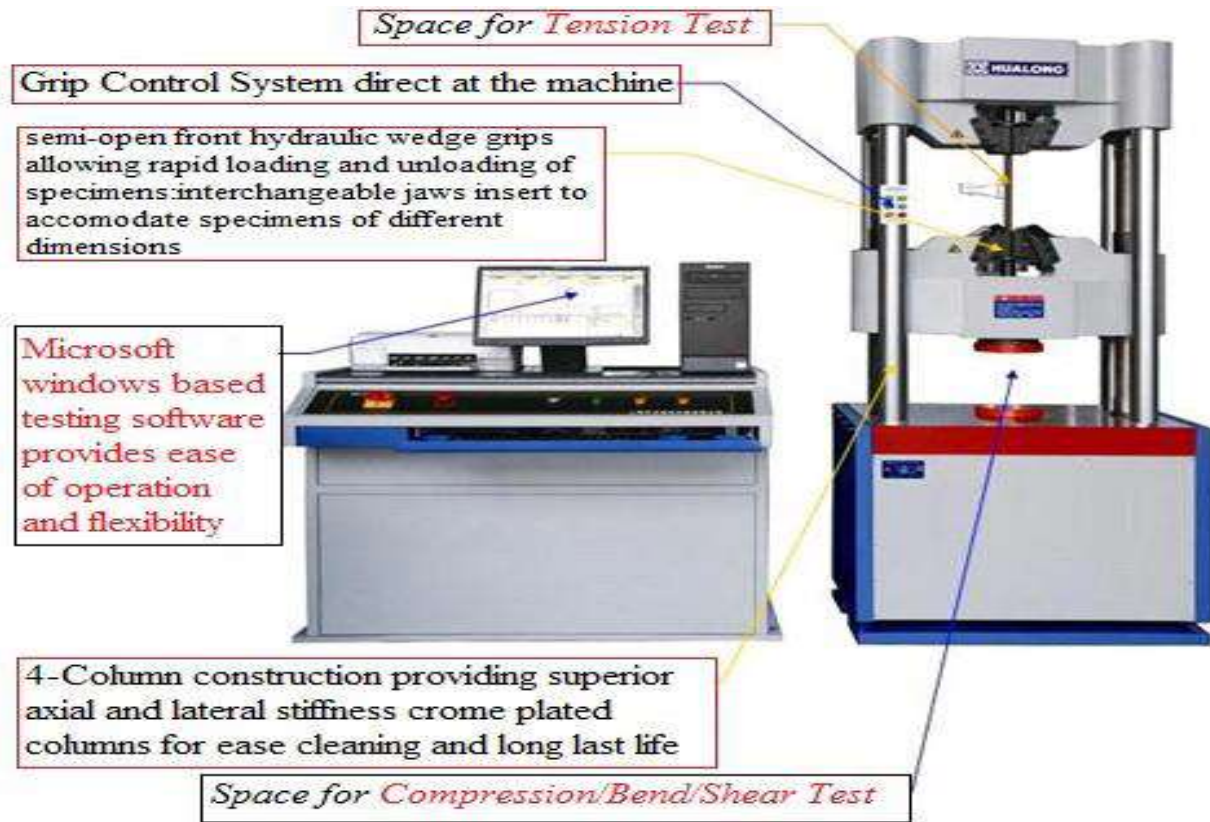


Figure 3.13. Universal testing machine testing system working sketch map [14].

3.3.3. Tensile Strength Test (ASTM D3039/D3039M)

The primary objective of this test was to assess the in-plane tensile properties of the palm and pineapple fiber composites. Three specimens were tested in the UTM machine for 15/85 percent of the sample. Each specimen was 25* 2.5* 250 mm in diameter. During the test, the specimens were placed in the UTM grips and the axial load is applied through both ends of the specimen. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; the cross-head speed used was 0.5 mm / min, and the gage length was 200 mm. Load and elongation were acquired by machine in real time and were provided at the end of each test.

CHAPTER 4

4. Results and Discussions

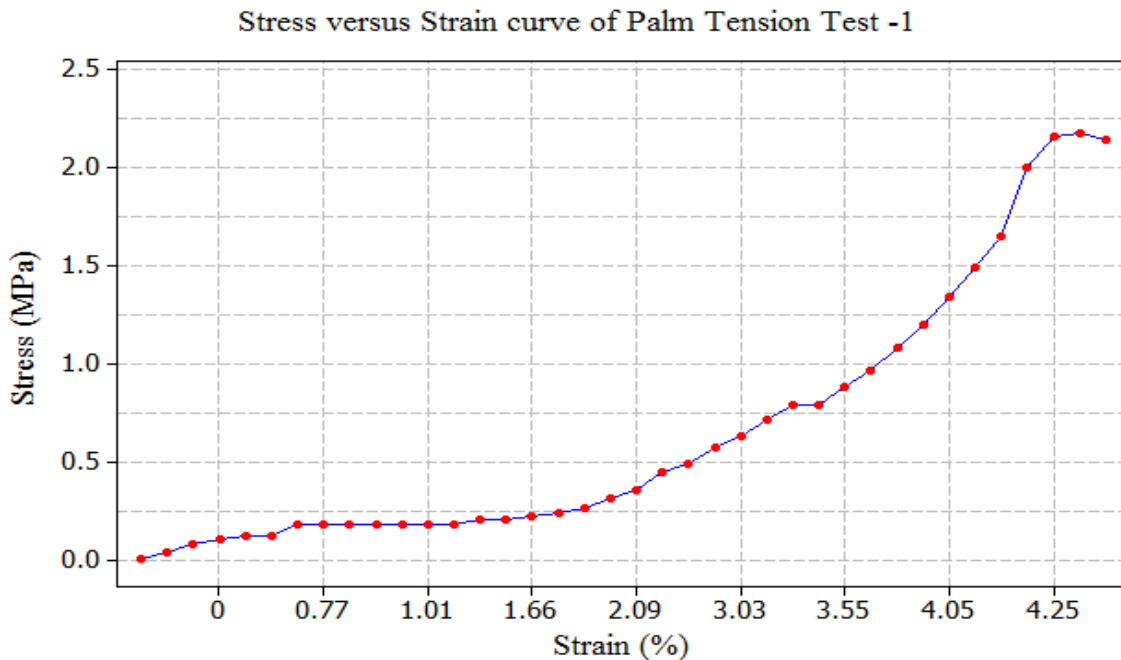
This chapter have two parts the first part is the result obtained by experimental work and the second was the discussion part for both types of fiber composites.

4.1. Mechanical Properties of Composites

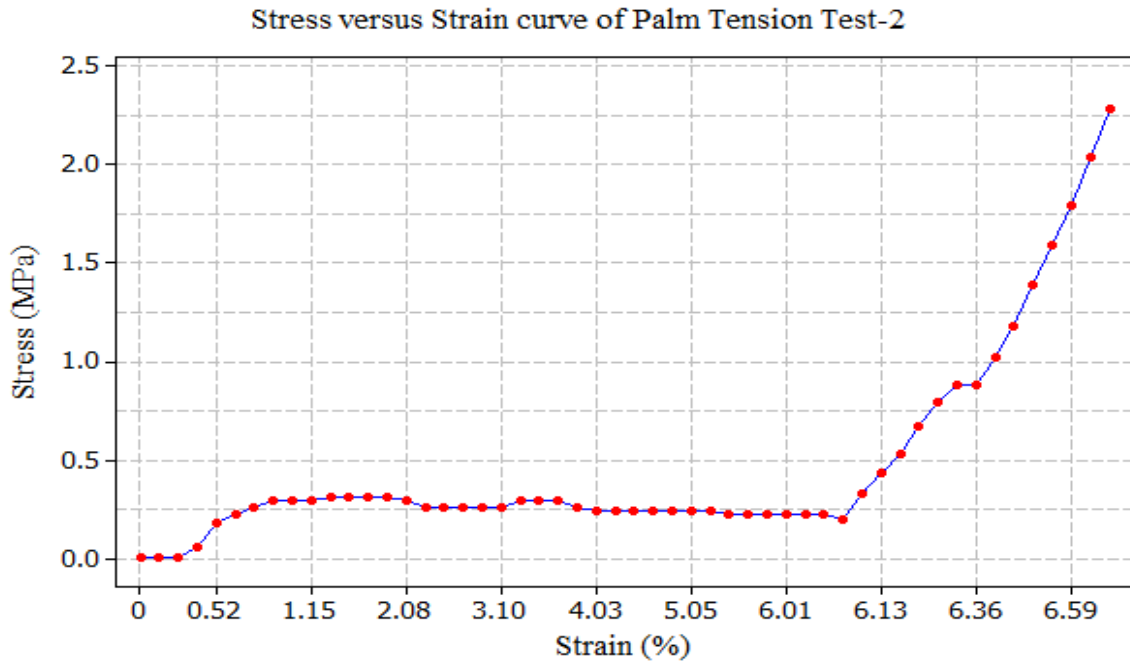
Mechanical properties of composites such as, tensile strength, maximum elongation has been investigated and also discussed. The mechanical properties of the composite are mainly depending on many factors such as fiber content and length.

4.1.1. Tensile strength of Palm Fiber

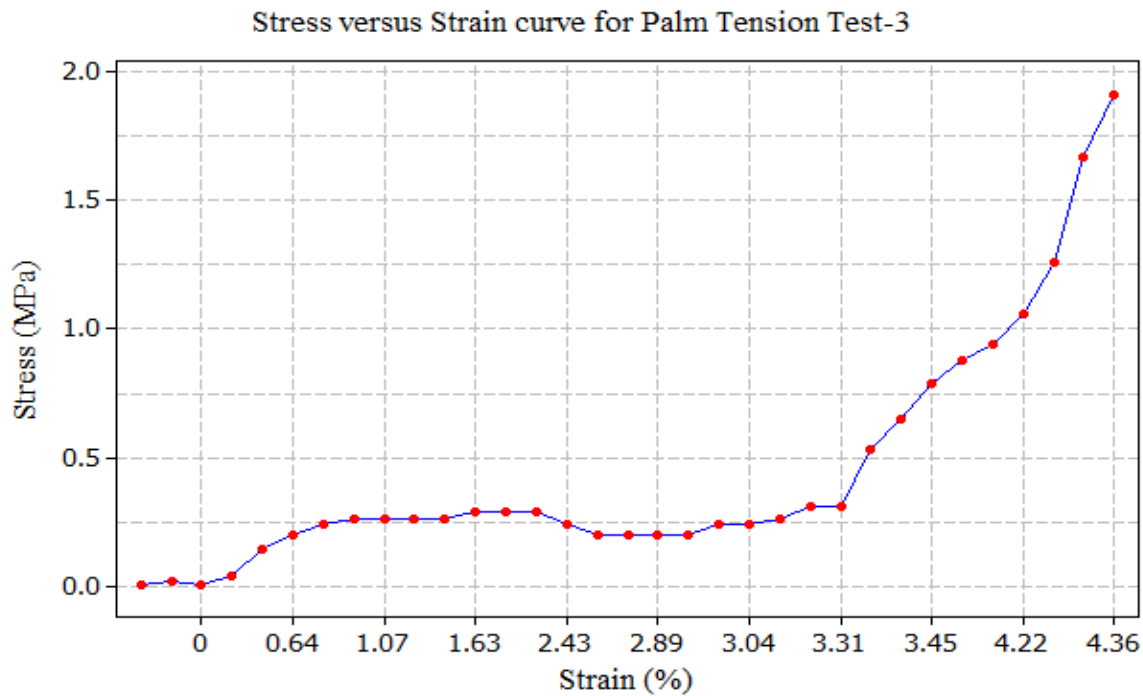
The tensile test is done as per universal machine which was shown in Fig 4.1, the maximum machine loading capacity was 50KN but for each sample it will not exceeds such limit and all acting loads are below such limits as shown in experiments, the specimen size was 250mm, 25mm width, 5mm thickness, and test result shows very good agreement with relevant literature.



A.



B.



C.

Figure 4.1. A, B, C, Stress-strain curve for sample #1, 2, 3 respectively

Figure 4.1A, shows that tension test result of palm leaf fiber epoxy composite stress versus strain curve of Test sample #1, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (2.14MPa) of the specimen, which means brittle nature of the material is shown.

Figure 4.1B, Shows that tension test result of palm leaf fiber epoxy composite stress versus strain curve of the Test sample #2, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (2.14MPa) of the specimen then failure will happen beyond this limit.

Figure 4.1C, Shows that tension test result of palm leaf fiber epoxy composite stress versus strain curve of test sample #3, the curve shows as stress and strain is directly proportional until the ultimate stress limit is obtained (1.1MPa) of the specimen then the specimen will failed to withstand the stress acting on the specimen.

To summarize and tensile report on stress versus strain on palm leaf fiber epoxy composite ash shown in Fig 4.2.

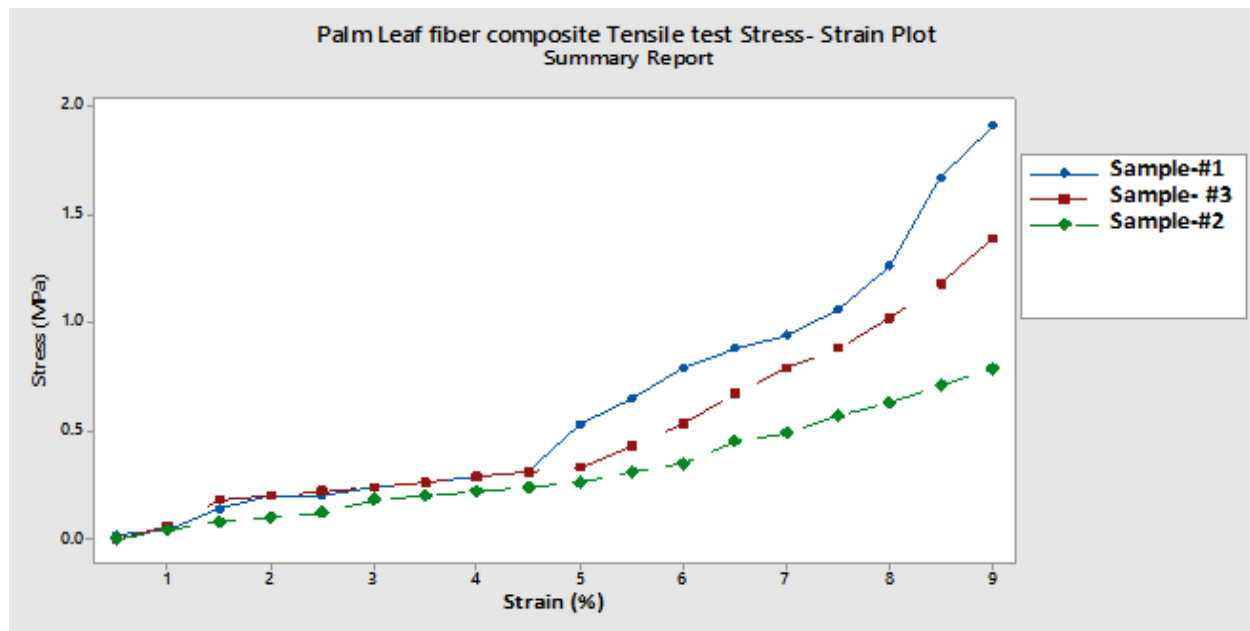


Figure 4.2. Summary of stress -strain curve of palm leaf fiber epoxy composite

Table 4.1. Tensile test result for stress –strain curve and tensile module

Specimen Number	Standard	Strain (%)	Tensile Stress (MPa)	Young's modulus (KPa)
ST-1	ASTM 3039	4.25	2.14	503
ST-2		6.59	2.14	325
ST-3		4.36	1.91	438
	Mean	5.07	2.097	414
	Standard Deviation(SD)	1.03	0.0975	0.2011

The mean (Eq. 4.1) and Standard Deviation (SD) of the estimated material properties are tabulated in Table 4.1. SD (Eq. 4.2) shows how much variation or dispersion from the average exists. A low

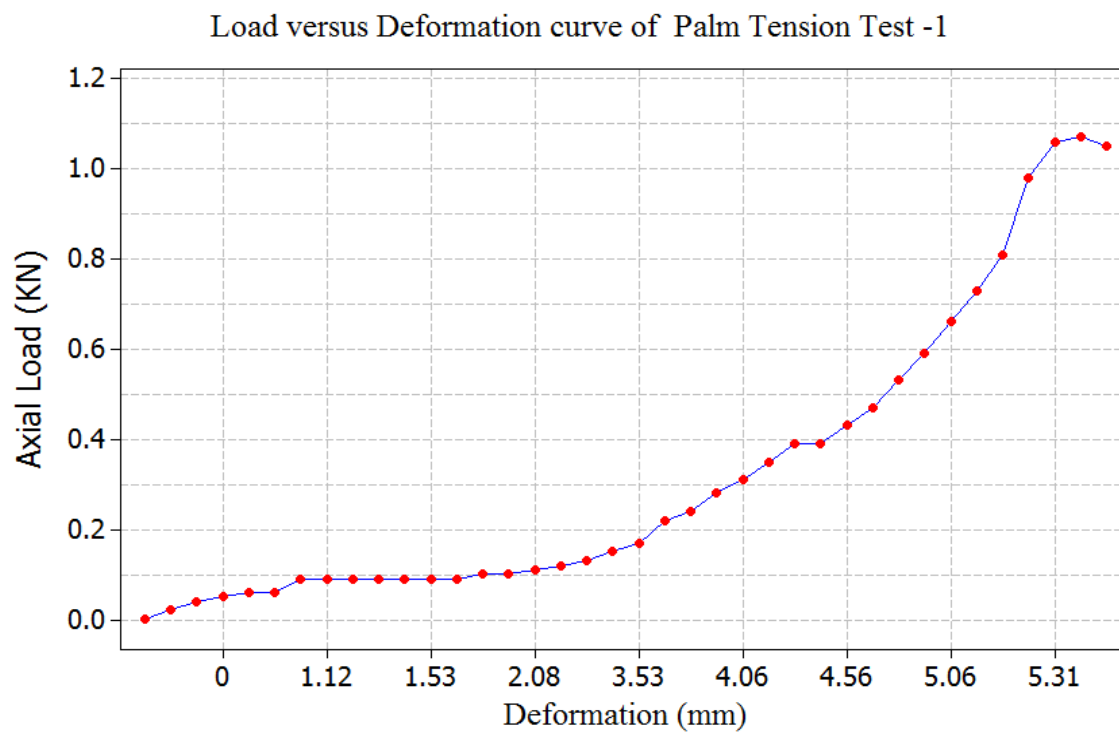
standard deviation indicates that the data points tend to be very close to the mean (also called expected value), a high standard deviation indicates that the data points are spread out over a large range of values.

Experiments were carried out on three specimens each prepared as per ASTM standards and their tensile strength, Young's modulus, Tensile strength, Strain were calculated. Tensile strength for ASTM D-3039 possesses a standard deviation of 0.0975, which mean that the observed tensile strength values disperse from the mean value at a smaller range. In case of Young's modulus for D3039 the standard deviation value is very small (0.2011), which indicates that the data points tend to be very close to the mean Young's modulus values.

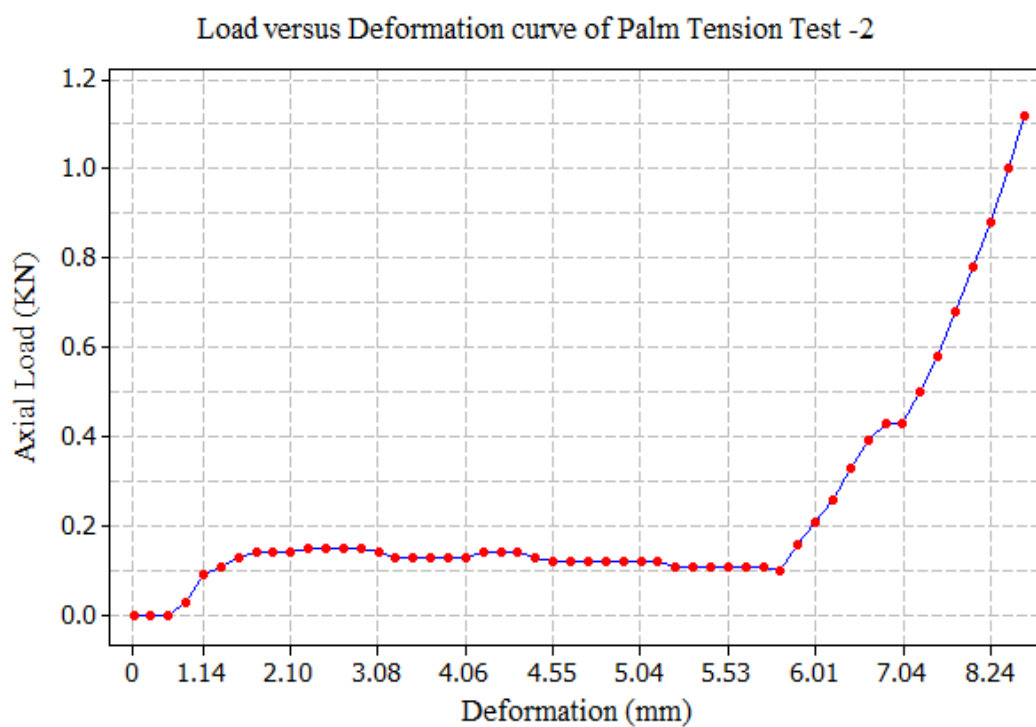
$$\text{Mean } (\mu) = \frac{\text{Sum of all values}}{\text{Total no of values}} \dots\dots\dots \text{Eq.4.1}$$

$$\text{Standard deviation } (\sigma) = \sqrt{\frac{\sum(x-\mu)^2}{N}} \dots\dots\dots \text{Eq.4.2}$$

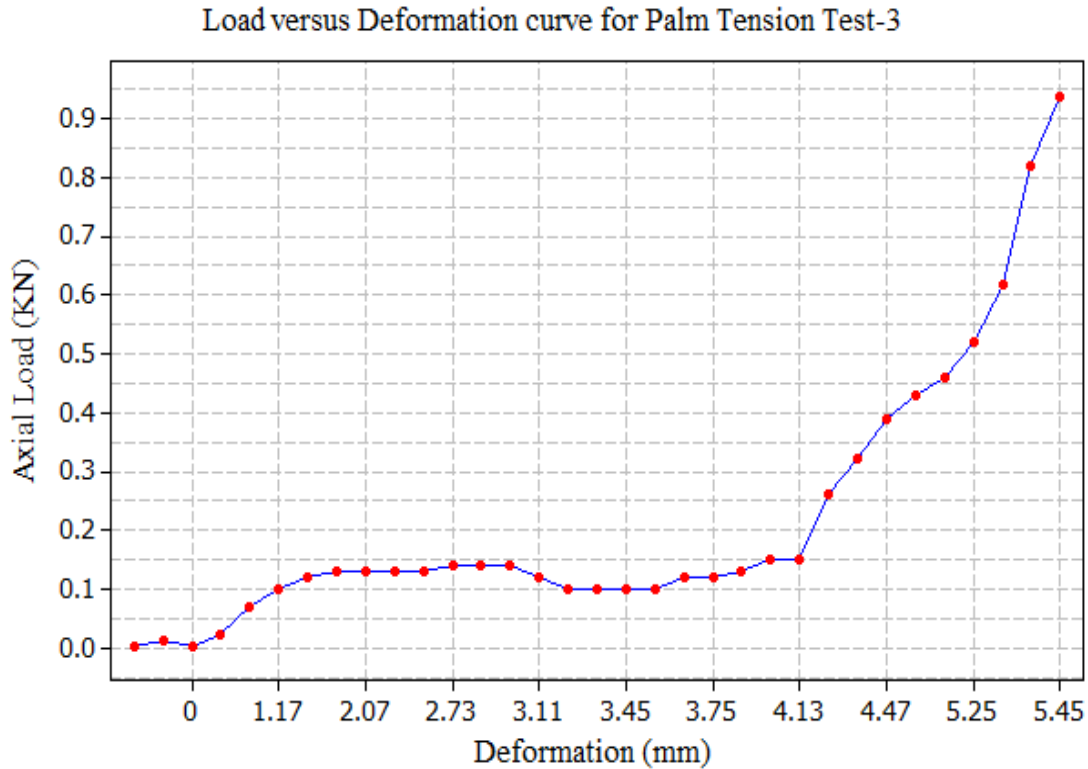
Whereas: - x=each values in the sample test, μ =mean value, N= Number of values



A.



B.



C.

Figure 4.3. A, B, C, Load -deformation curve for sample #1, 2, 3 respectively

Figure 4.3A, Shows that tension test result of palm leaf fiber epoxy composite load versus deformation curve of test sample #1, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (5.31mm) of the specimen, which means beyond such limit failure will happen on the material.

Figure 4.3B, Shows that tension test result of palm leaf fiber epoxy composite load versus deformation curve of test sample #2, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (8.24mm) of the specimen, which means the specimen failure will happen beyond this limit.

Figure 4.3C, Shows that tension test result of palm leaf fiber epoxy composite load versus deformation curve of test sample #3, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (5.45mm) of the specimen, which means the specimen failure will happen beyond this limit.

To summarize and tensile report on stress versus strain on palm leaf fiber epoxy composite as shown in Fig.4.4.

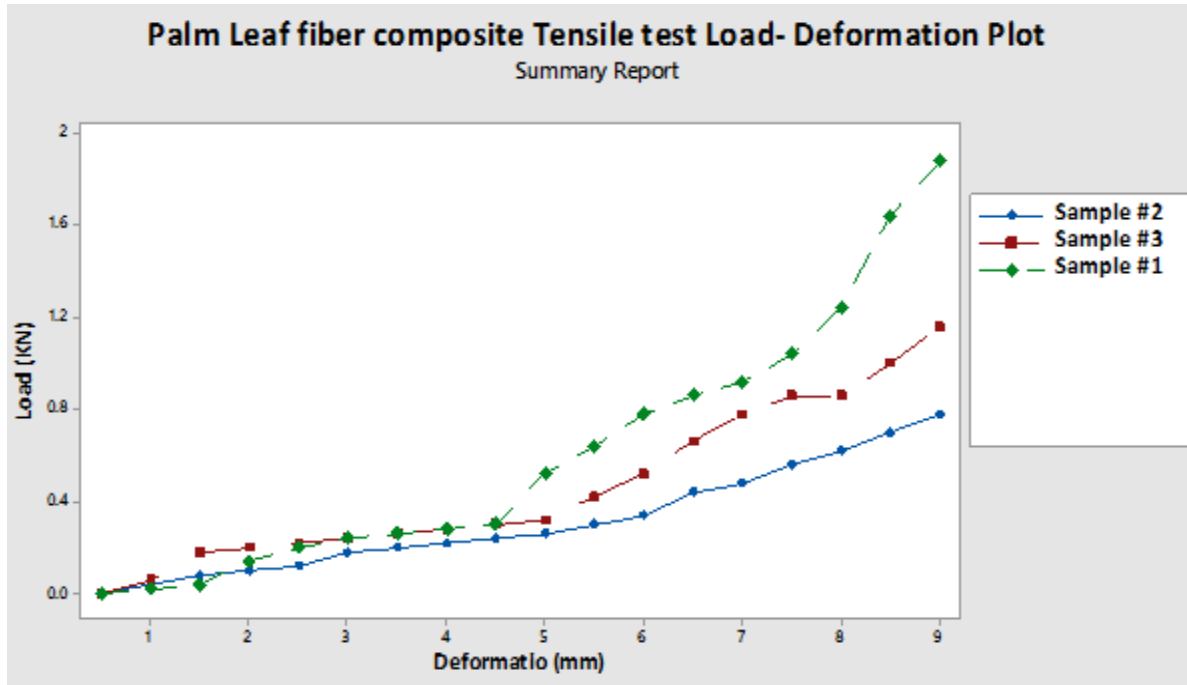


Figure 4.4. Summary of load -deformation curve of palm leaf fiber epoxy composite

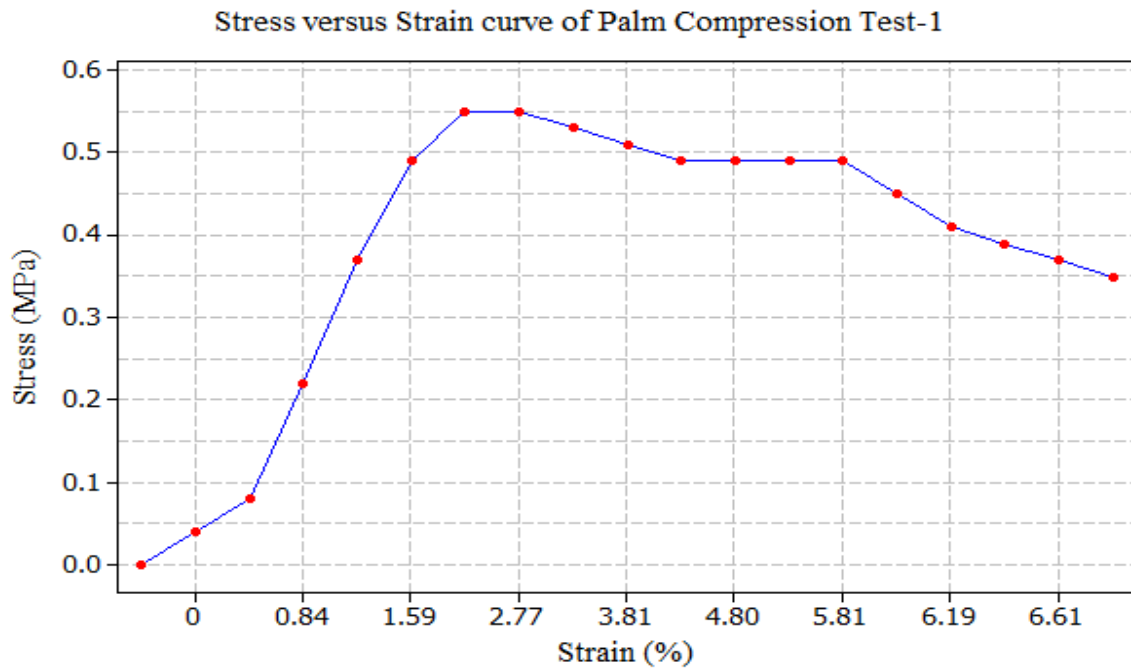
Experiments were carried out on three specimens each prepared as per ASTM standards and their deformation, maximum load, were calculated. Maximum deformation at given load for ASTM D-3039 possesses a standard deviation of 1.35, which mean that the observed deformation values disperse from the mean value at a medium range. In case of maximum load for D3039 the standard deviation value is very small (0.0742), which indicates that the data points tend to be very close to the mean load values.

Table 4.2. Palm Leaf fiber epoxy composite tensile test result for Load– deformation curve.

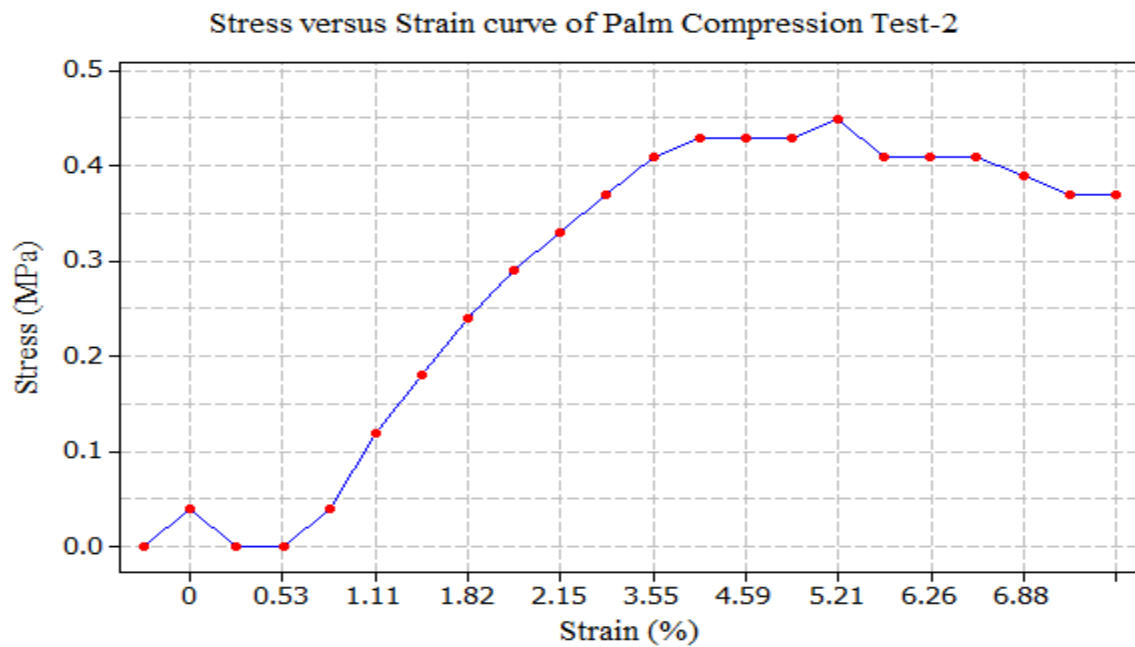
Specimen Number	Standard	Deformation (mm)	Max load (KN)
ST-1	ASTM 3039	5.31	1.05
ST-2		8.24	1.12
ST-3		5.45	0.94
	Mean	6.39	1.04
	Standard Deviation(SD)	1.35	0.0742

4.1.2. Compression Strength of Palm Fiber

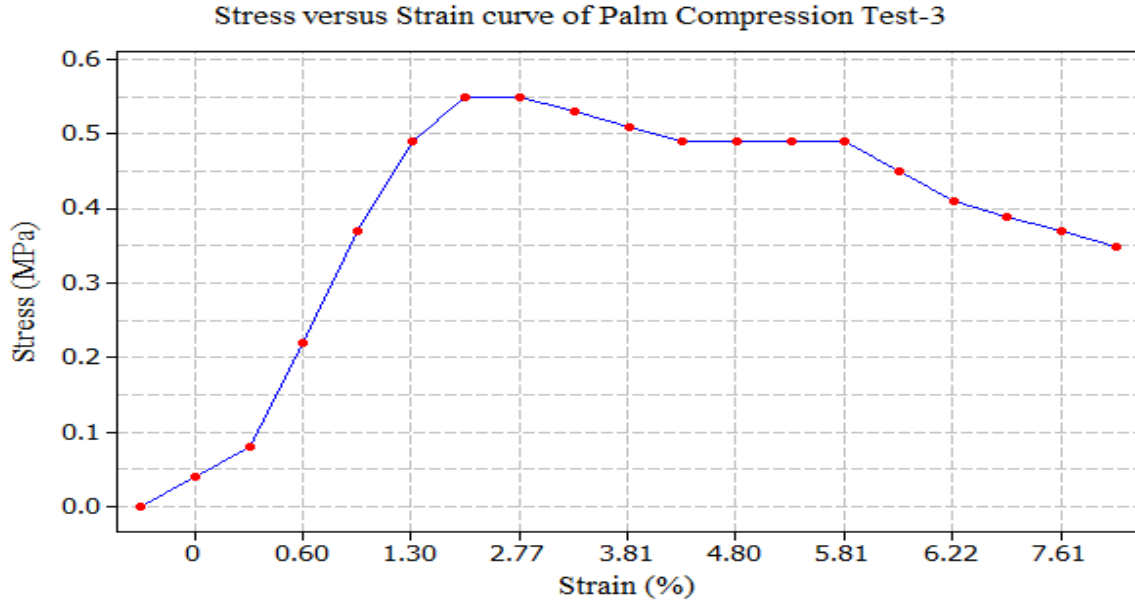
Compression test is done to characterize the compression strength of the Palm leaf fiber epoxy composite for three test samples prepared as per ASTM standard.



A.



B.



C.

Figure 4.5. A, B, C, Stress-strain curve for sample #1, 2, 3 respectively

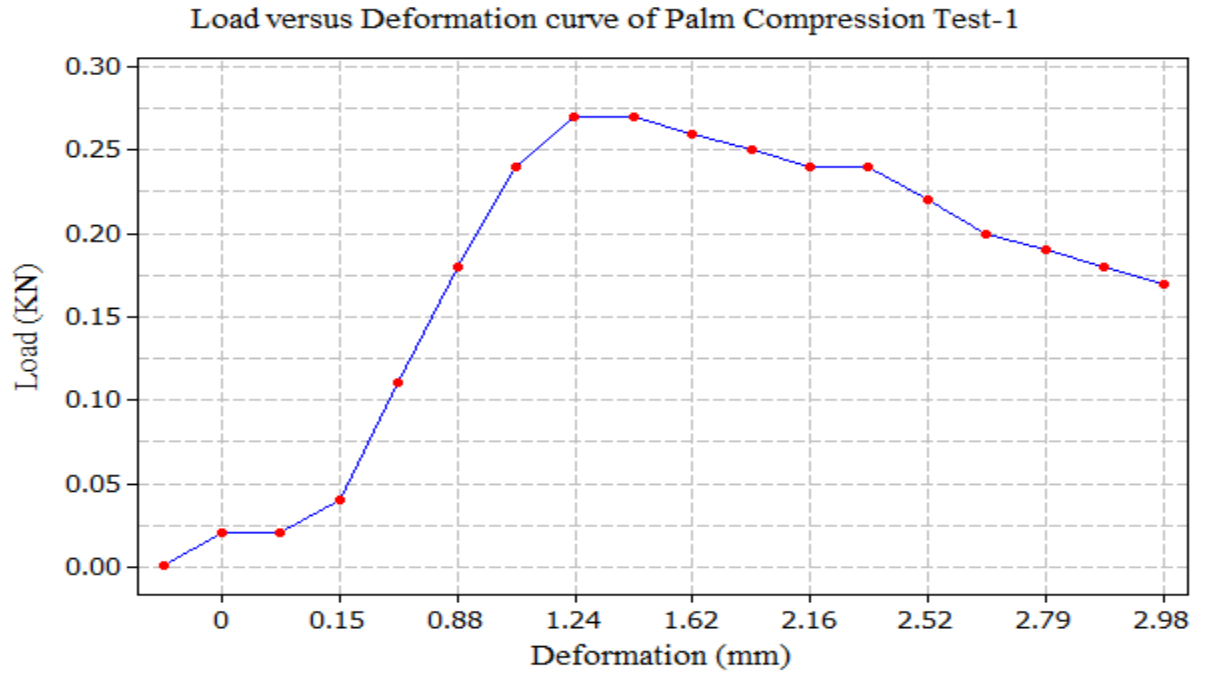
Figure 4.5A, shows that compression stress versus strain plot of palm leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 53KPa.

Figure 4.5B, shows that compression stress versus strain plot of palm leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 55KPa. But due to some voids developed during specimen fabrication the specimen may fail below expected stress limit.

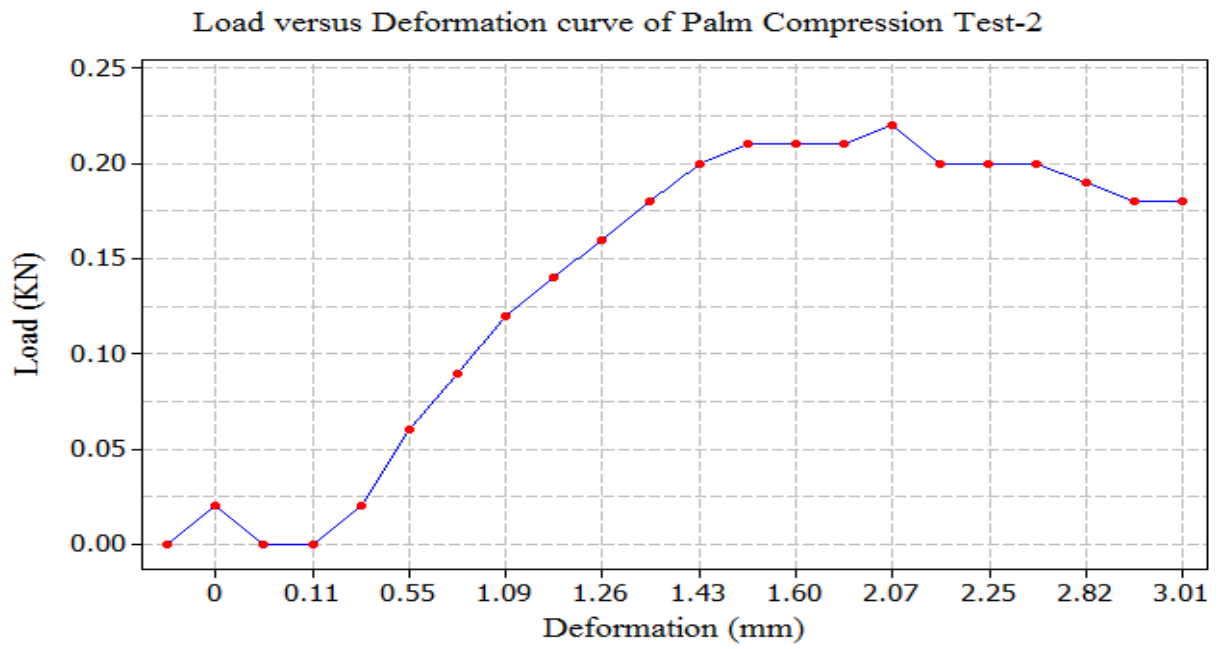
Figure 4.5C, shows that compression stress versus strain plot of palm leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 46KPa.

Table 4.3. Palm Leaf fiber compression test result for stress –strain curve and tensile module

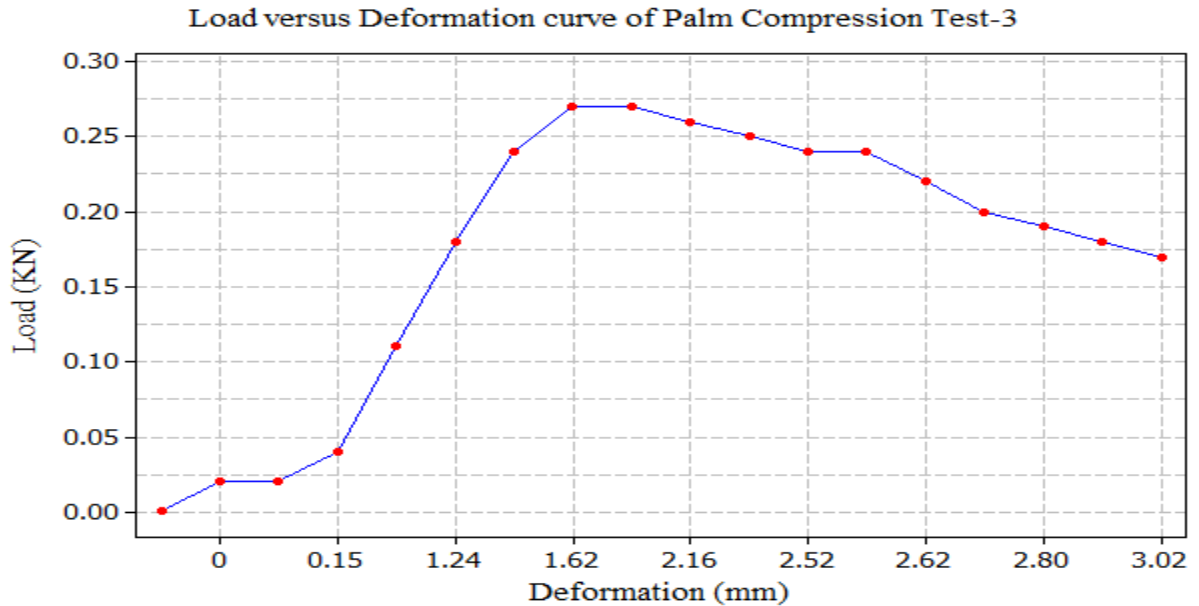
Number	Standard	Strain (%)	Stress (KPa)	Elastic Modulus (KPa)
ST-1	ASTM 3039	6.61	350	53
ST-2		6.68	370	55
ST-3		7.61	350	46
	Mean	6.97	356	51
	SD	0.46	0.003	0.0004



A.



B.



C.

Figure 4.6. A, B, C, Load -deformation curve for sample #1, 2, 3 respectively

Figure 4.6A, shows that compression load versus deformation plot of palm leaf fiber reinforced composite in universal compression testing machine, load versus deformation will continue until the material gets its ultimate load of 170N.

Figure 4.6B, shows that compression load versus deformation plot of palm leaf fiber reinforced composite in universal compression testing machine, load versus deformation will continue until the material gets its ultimate load of 180N. But due to some voids developed during specimen fabrication the specimen may fail below expected load limit.

Figure 4.6C, shows that compression load versus deformation plot of palm leaf fiber reinforced composite in universal compression testing machine, load versus deformation will continue until the material gets its ultimate load of 170N.

The summary of load versus deformation plot shows the mean and standard deviation values of palm leaf fiber.

Table 4.4. Palm Leaf fiber composite compression test result for Load– deformation curve

Specimen Number	Standard	Deformation(mm)	Load(N)
ST-1	ASTM 3039	2.98	170
ST-2		3.01	180
ST-3		3.02	170
	Mean	3.003	173
	SD	0.017	0.0048

4.1.3. Bending Strength of Palm Fiber

As shown in Fig 4.7 Universal testing machine which is three point bending test have maximum acting load for composite is 50KN, which have standard size of specimen to be tested is length 250mm, width 25mm and thickness 5mm, was tested and very good result is obtained.

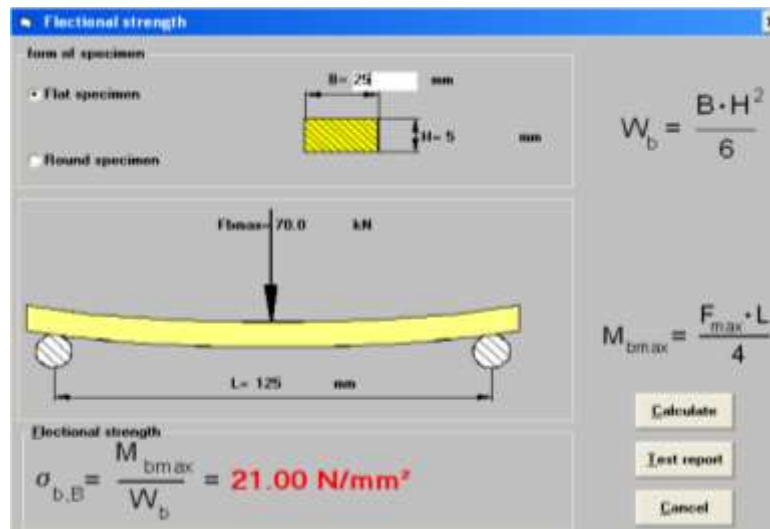


Figure 4.7. Bending strength of sample #1, same for other two test samples.

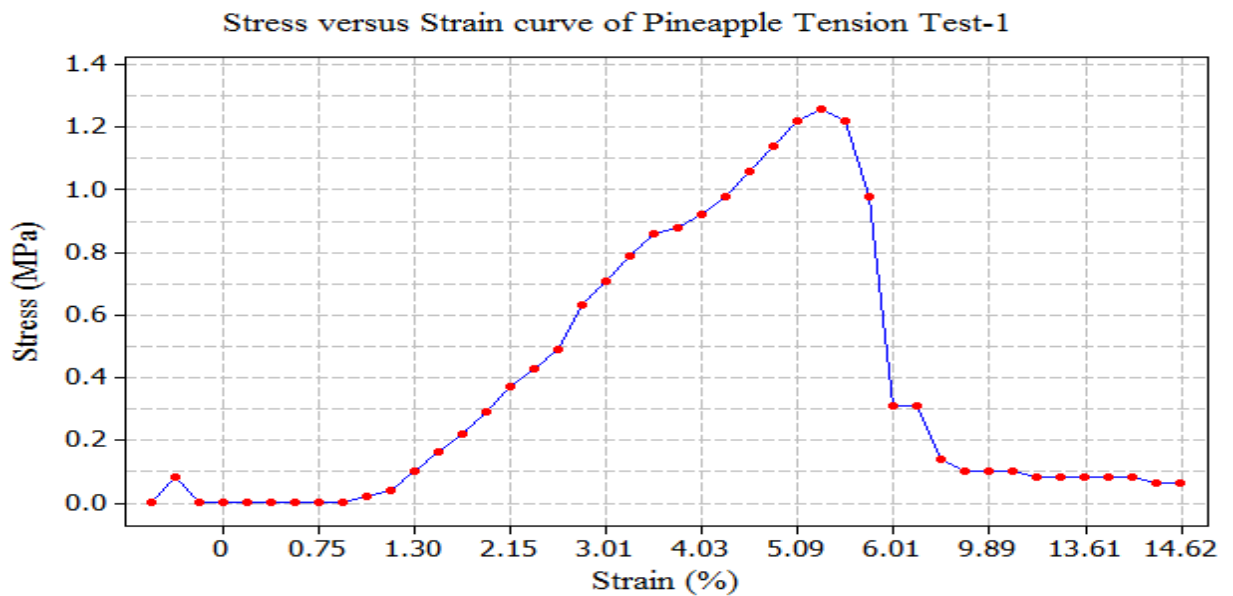
Table 4.5. Summary of Palm Leaf fiber bending test result of samples

Specimen Number	Standard	Bending Stress (N/mm ²)	Max Load (N)
ST-1	ASTM 3039	21	70
ST-2		6	20
ST-3		21	70
Mean		13	53.3
Standard Deviation		6.164	23.57

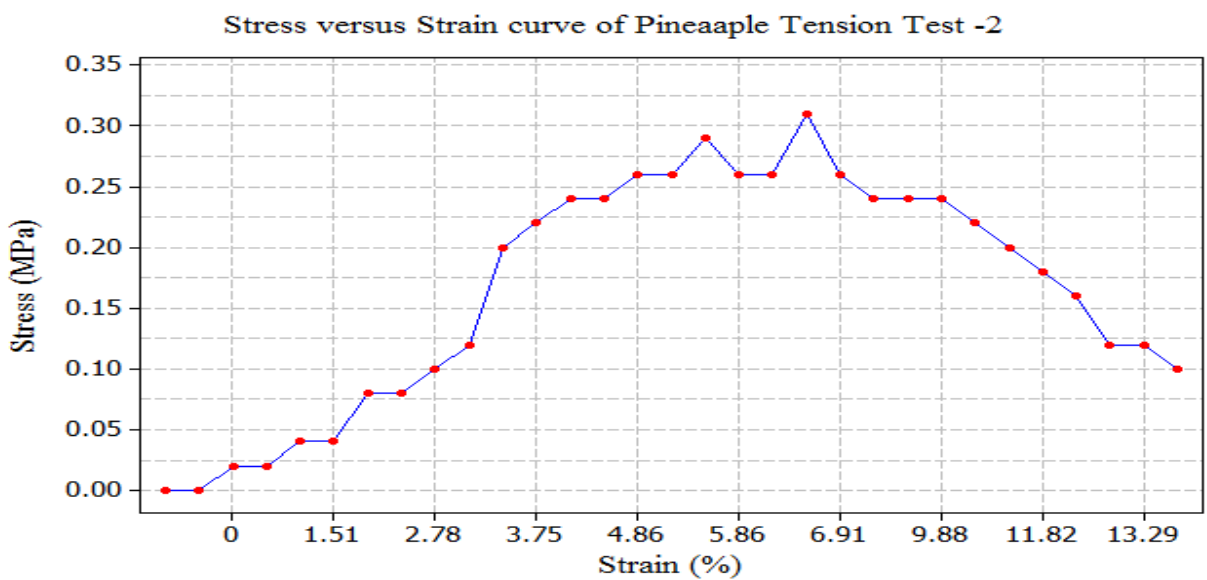
Three bending tests are done to know the bending strength of palm leaf fiber epoxy composite as shown in Table 4.5. the response of the test sample is as shown in Fig 4.7.

4.1.4. Tensile strength of Pineapple Fiber

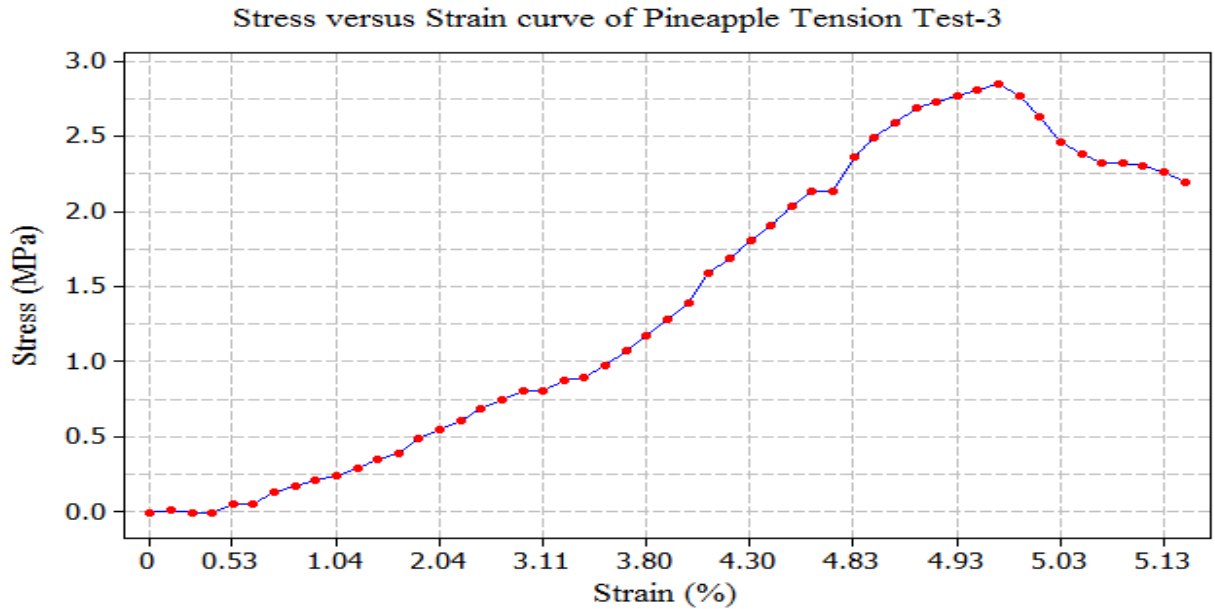
The tensile test is done as per universal machine, the load applied for such case was 50KN, and the specimen size was 125mm, 25mm width, 5mm thickness, and Test result shows very good agreement with relevant literature.



A.



B.



C.

Figure 4.8. A, B, C, Stress-strain curve for sample #1, 2, 3 respectively

Figure 4.8A, Shows that tension test result of pineapple leaf fiber epoxy composite stress versus strain curve of test sample #1, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (80KPa) of the specimen, which means brittle nature of the material.

Figure 4.8B, Shows that tension test result of pineapple leaf fiber epoxy composite stress versus strain curve of the test sample #2, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (100KPa) of the specimen then failure will happen beyond this limit.

Figure 4.8C, Shows that tension test result of pineapple leaf fiber epoxy composite stress versus strain curve of test sample #3, the curve shows as stress and strain is directly proportional until the ultimate stress limit is obtained (220KPa) of the specimen then the specimen will failed to withstand the stress acting on the specimen.

To summarize and tensile report on stress versus strain on of pineapple leaf fiber epoxy composite ash shown in Fig. 4.9.

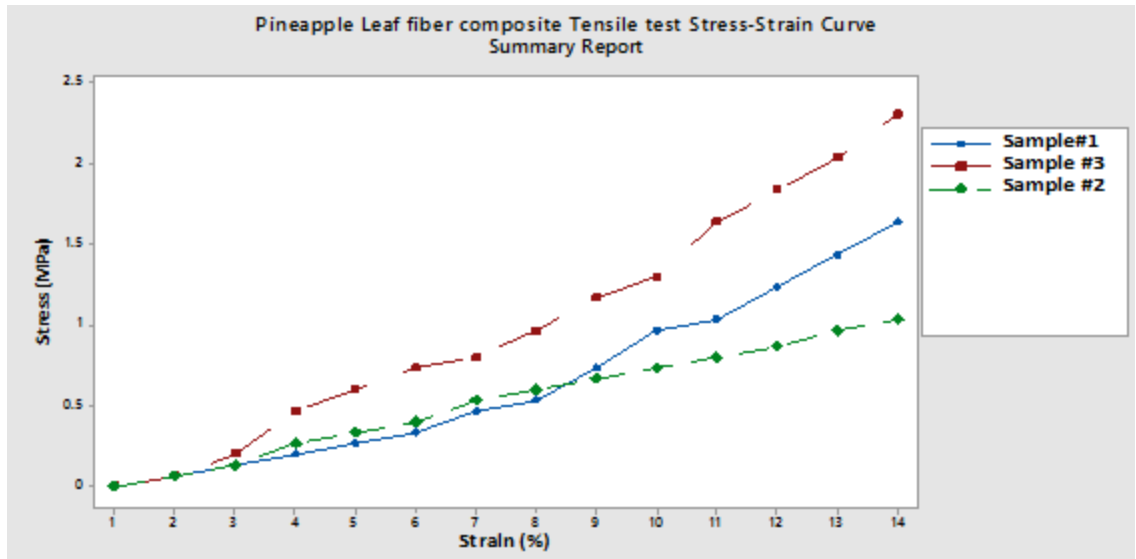
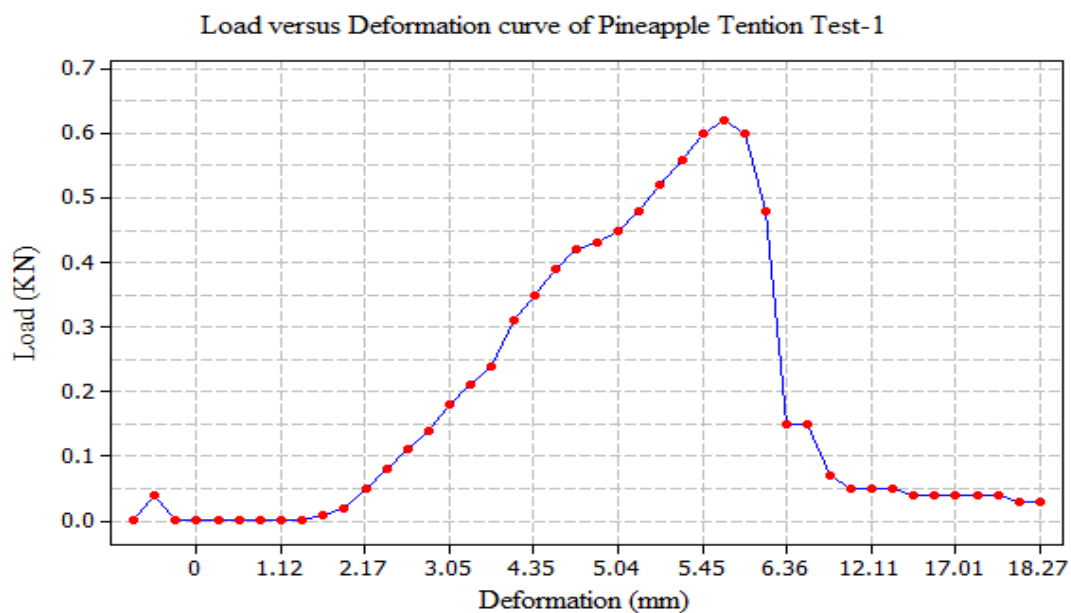


Figure 4.9. Summary of stress -strain curve of Pineapple Leaf fiber epoxy composite

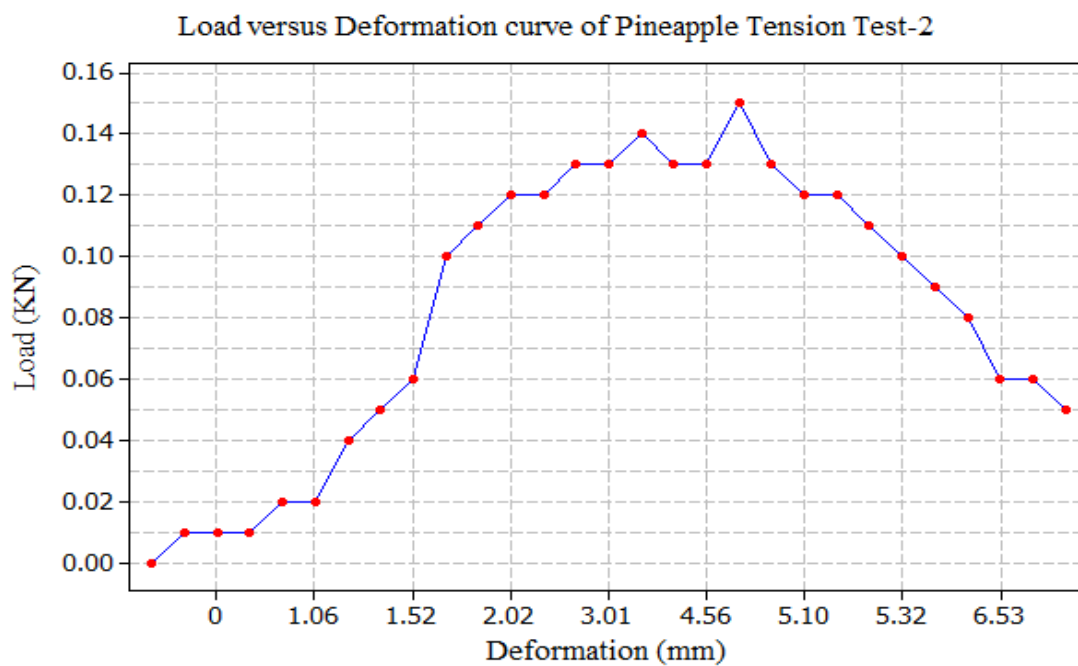
Table 4.6. Pineapple Leaf fiber tensile test result for stress –strain curve and tensile module

Specimen Number	Standard	Strain (%)	Tensile Stress (KPa)	Young's modulus (KPa)
ST-1	ASTM 3039	14.62	80	438
ST-2		13.29	100	503
ST-3		5.13	220	438
	Mean	11.013	133.4	459
	Standard Deviation(SD)	4.195	0.99	0.0306

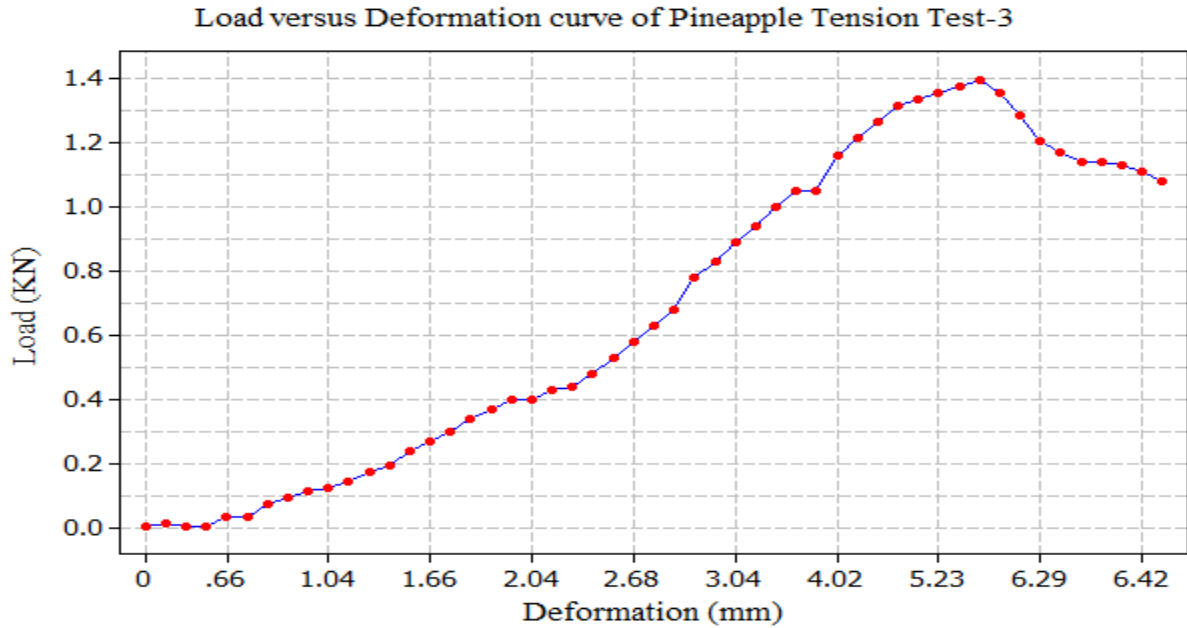
Experiments were carried out on three specimens each prepared as per ASTM standards and their tensile strength, Young's modulus, Tensile strength, Strain were calculated. Tensile strength for ASTM D-3039 possesses a standard deviation of 0.99, which mean that the observed in Table 4.6 tensile strength values disperse from the mean value at a smaller range. In case of Young's modulus for D3039 the standard deviation value is very small (0.0306), which indicates that the data points tend to be very close to the mean Young's modulus values.



A.



B.



C.

Figure 4.10. A, B, C, Load -deformation curve for sample #1, 2, 3 respectively

Figure 4.10A, Shows that tension test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #1, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (18.27mm) of the specimen, which means beyond such limit failure will happen on the material.

Figure 4.10B, Shows that tension test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #2, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (6.53mm) of the specimen, which means the specimen failure will happen beyond this limit.

Figure 4.10C, Shows that tension test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #3, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (6.42mm) of the specimen, which means the specimen failure will happen beyond this limit.

To summarize and tensile report on stress versus strain on pineapple leaf fiber epoxy composite as shown in Fig.4.11.

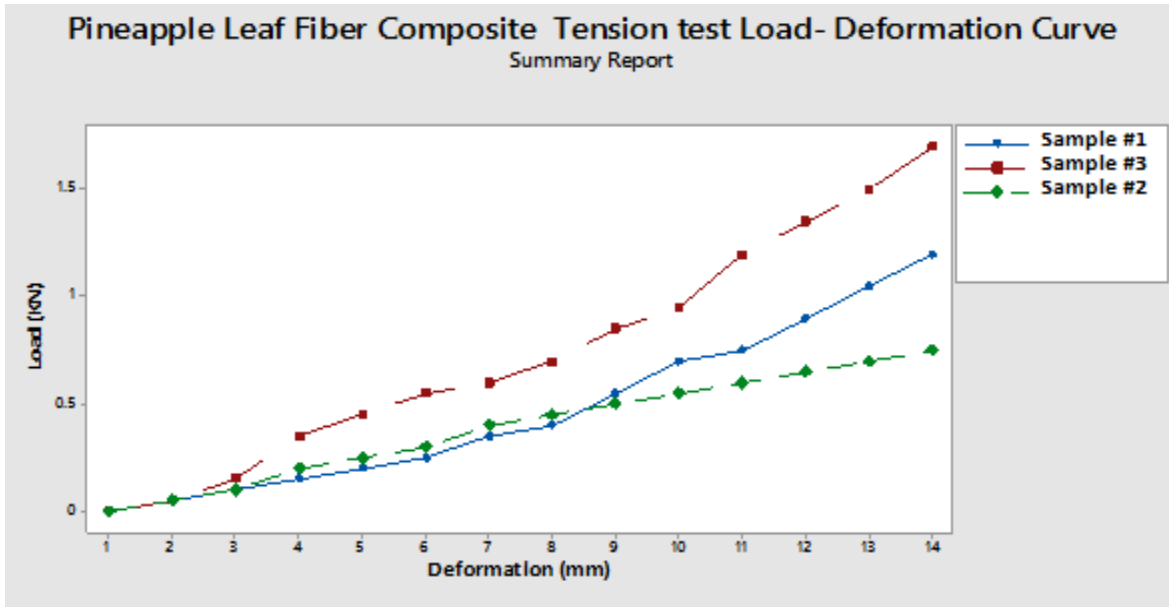


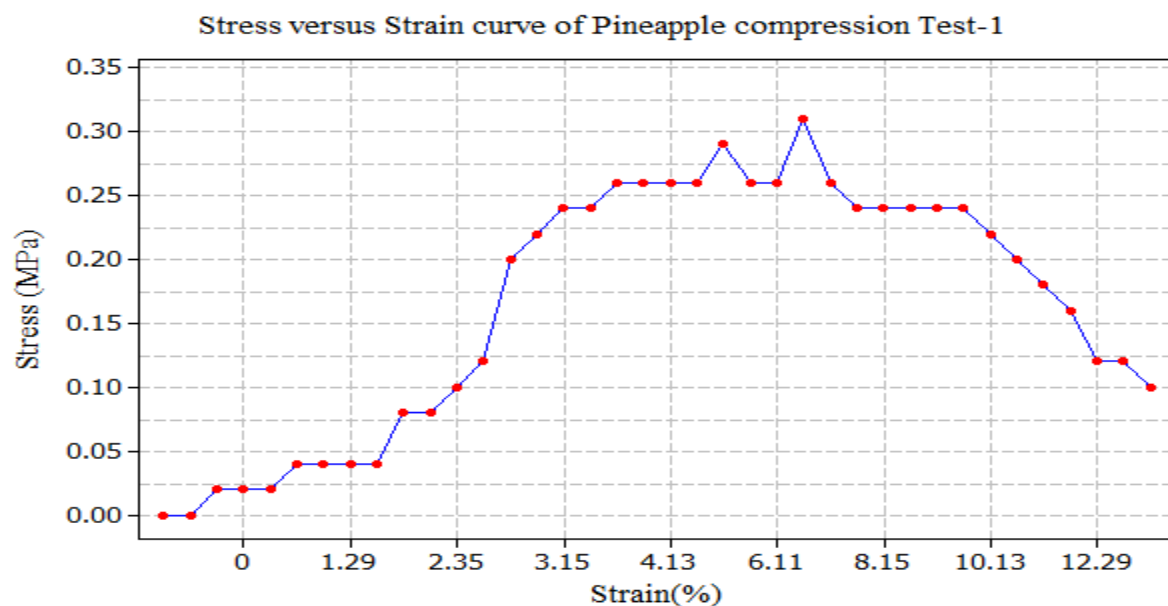
Figure 4.11. Summary of load -deformation curve of Pineapple leaf fiber epoxy composite

Table 4.7. Pineapple Leaf fiber tensile test result for Load -deformation curve

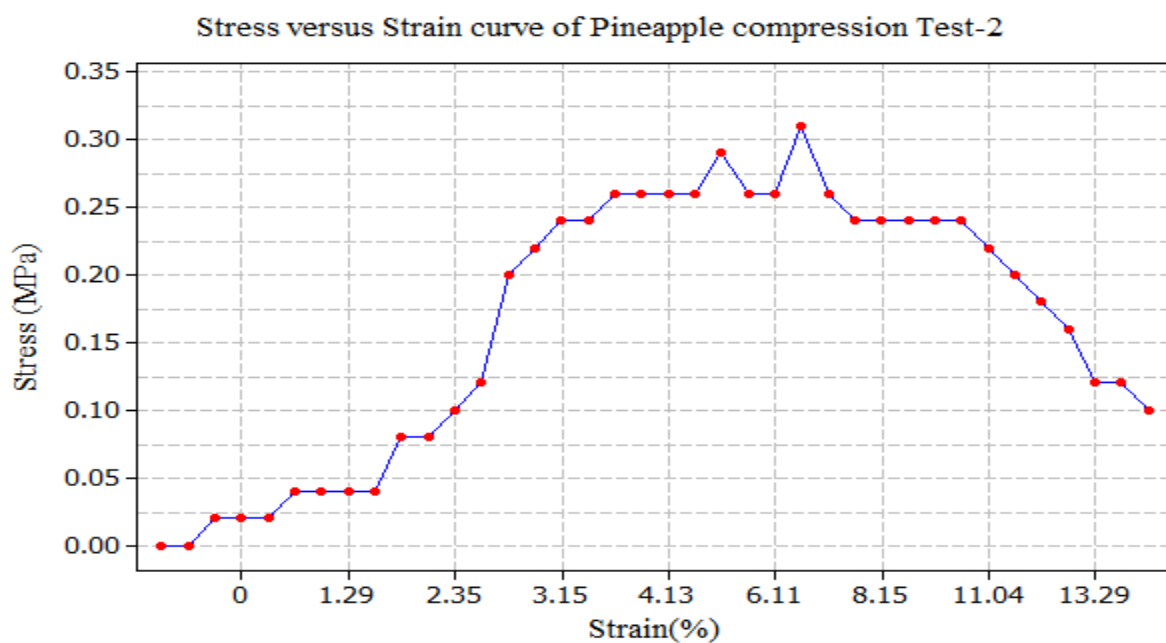
Specimen No	Standard	Deformation(mm)	Axial Load (N)
ST-1	ASTM 3039	18.27	40
ST-2		6.53	50
ST-3		6.42	108
	Mean	10.41	66
	Standard Deviation	5.56	0.488

4.1.5. Compression Strength of Pineapple Fiber

Compression test is done to characterize the compression strength of the pineapple leaf fiber epoxy composite for three test samples prepared as per ASTM standard.



A.



B.

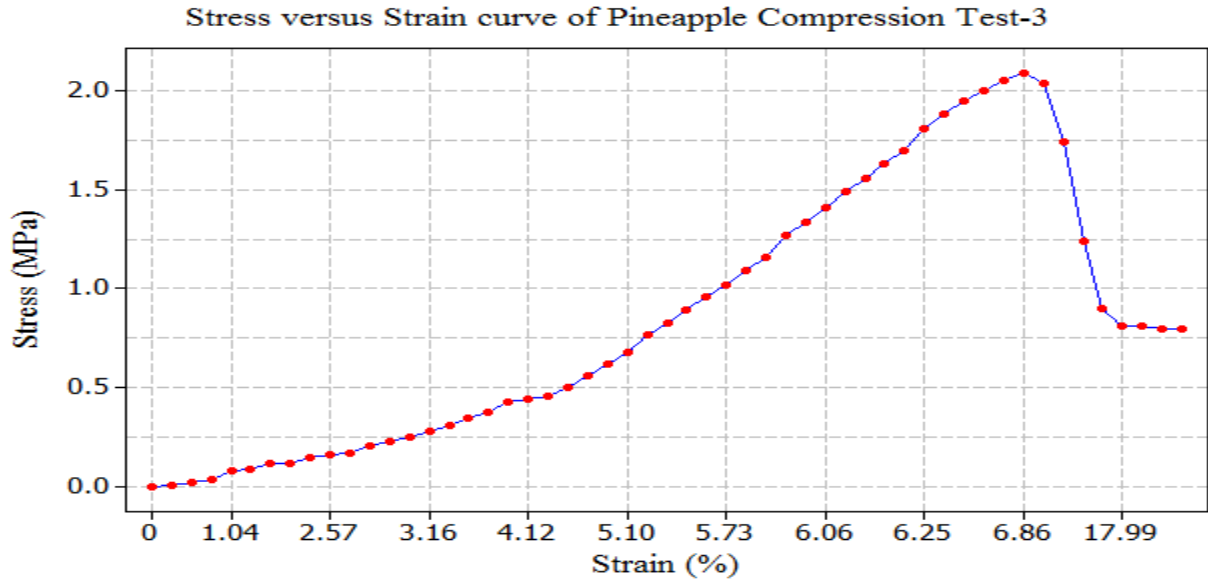


Figure 4.12. A, B, C, Stress-strain curve for sample #1, 2, 3 respectively

Figure 4.12A, shows that compression stress versus strain plot of pineapple leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 100KPa.

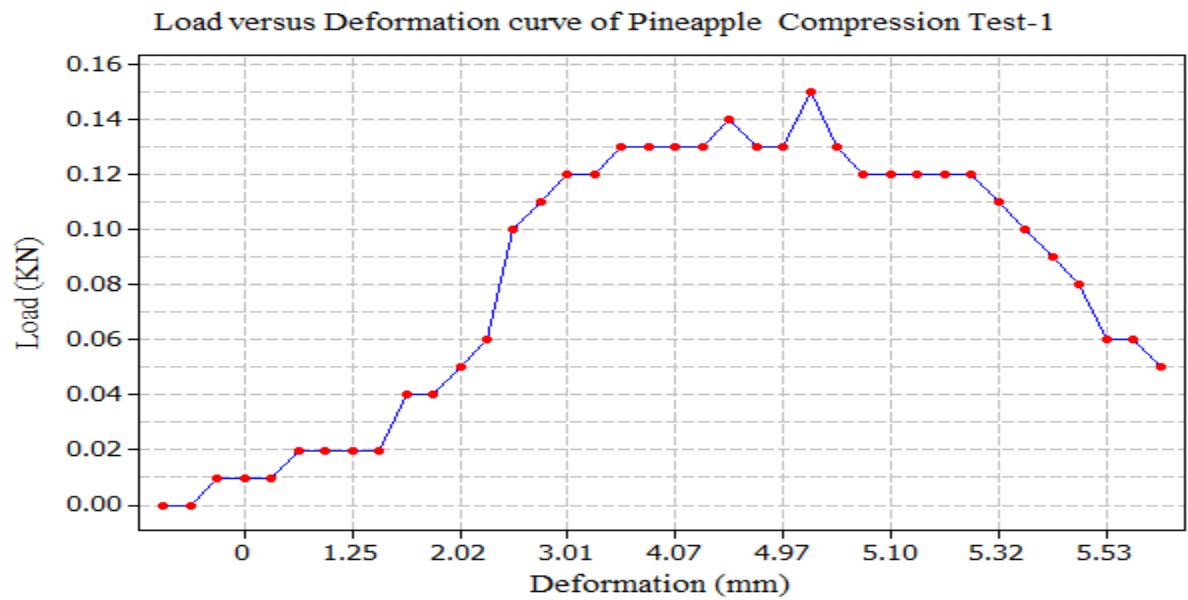
Figure 4.12B, shows that compression stress versus strain plot of pineapple leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 100KPa. But due to some voids developed during specimen fabrication the specimen may fail below expected stress limit.

Figure 4.12C, shows that compression stress versus strain plot of pineapple leaf fiber reinforced composite subjected to compression load in universal compression testing machine, stress versus strain will continue until the material gets its ultimate stress of 10KPa.

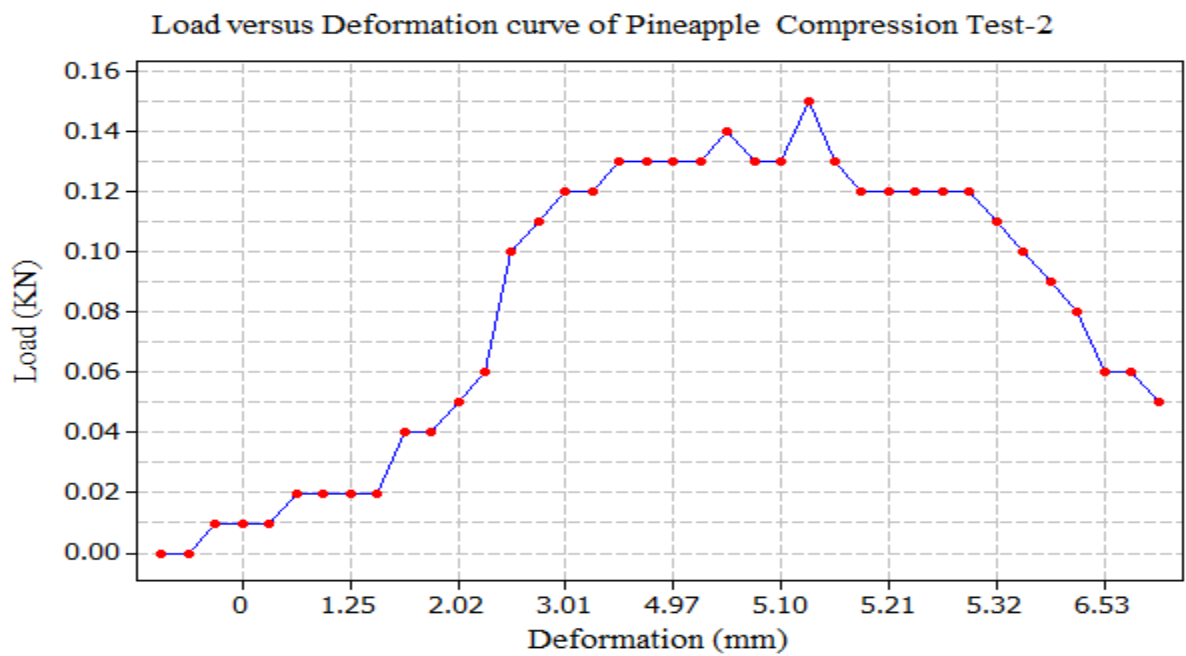
Table 4.8. Pineapple Leaf fiber compression test result for stress –strain curve and tensile module

Specimen Number	Standard	Strain (%)	Compression Stress (KPa)	Young's Modulus (KPa)
ST-1	ASTM 3039	12.29	100	8.14
ST-2		13.29	100	7.52
ST-3		17.99	10	5.56
	Mean	14.52	70	4.81
	SD	2.484	0.0424	0.0060

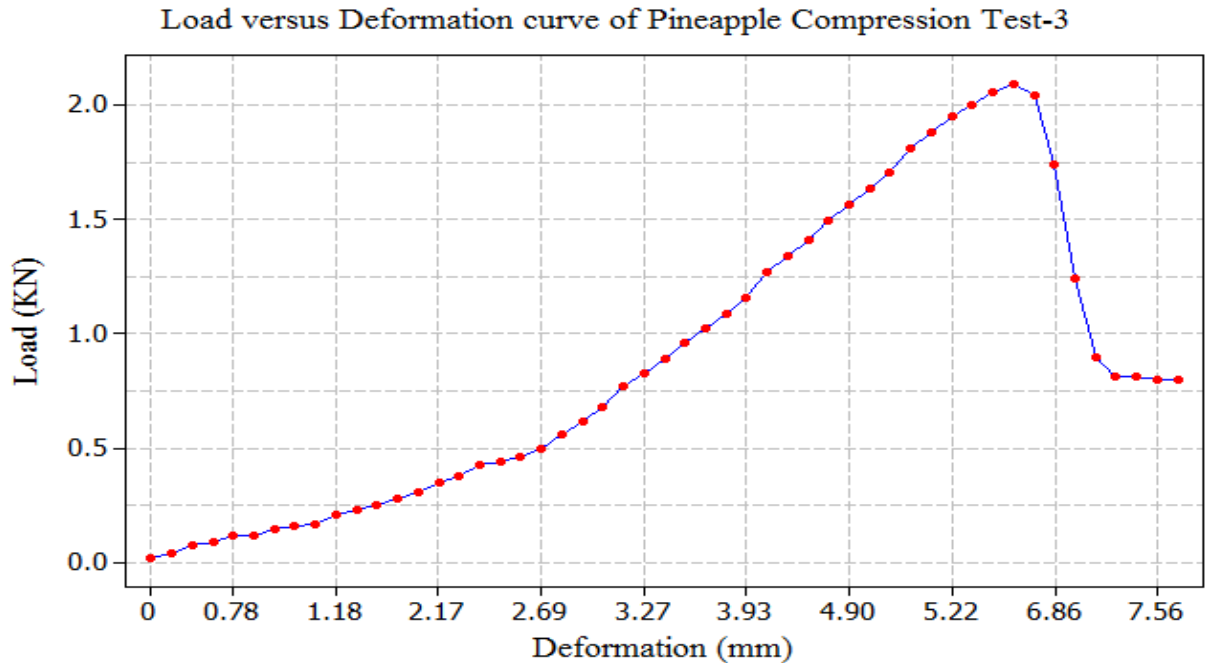
The summary Table 4.8 shows that the result read from the test specimens under UTM, mean and standard deviation of tested specimen stress versus strain plot. The values are recorded while each test are done.



A.



B.



C.

Figure 4.13. A, B, C, Load-Deformation curve for sample #1, 2, 3 respectively

Figure 4.13A, Shows that compression test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #1, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (5.53mm) of the specimen, which means beyond such limit failure will happen on the material.

Figure 4.13B, Shows that compression test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #2, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (6.53mm) of the specimen, which means the specimen failure will happen beyond this limit.

Figure 4.13C, Shows that compression test result of pineapple leaf fiber epoxy composite load versus deformation curve of test sample #3, the curve clearly shows as load increases the corresponding deformation increases until the maximum deformation (7.56mm) of the specimen, which means the specimen failure will happen beyond this limit.

The acting load reading is automatically controlled by the computer attached with machine so that the load with goes until the specimen will unable to resist it so that the maximum load the specimen with stand is 50N which was less than the UTM can works up to 50KN for composite materials. Hence, the reading will varies as per the strength of composite specimen see Table 4.9.below.

Table 4.9. Pineapple Leaf fiber compression test result for Load- deformation curve

Specimen No	Standard	Deformation(mm)	Load (N)
ST-1	ASTM 3039	5.53	50
ST-2		6.53	50
ST-3		7.56	30
	Mean	6.54	43.3
	Standard Deviation	0.8287	0.1196

4.1.6. Bending Strength of Pineapple Fiber

As shown in Fig 4.14 which is three point bending test have maximum acting load for composite is 50KN, which have standard size of specimen to be tested is length 250mm, width 25mm and thickness 5mm, was tested and but the maximum bending load the speciemn can with stand is 140N, which is not exceded the limit of the UTM can act for composites in general.

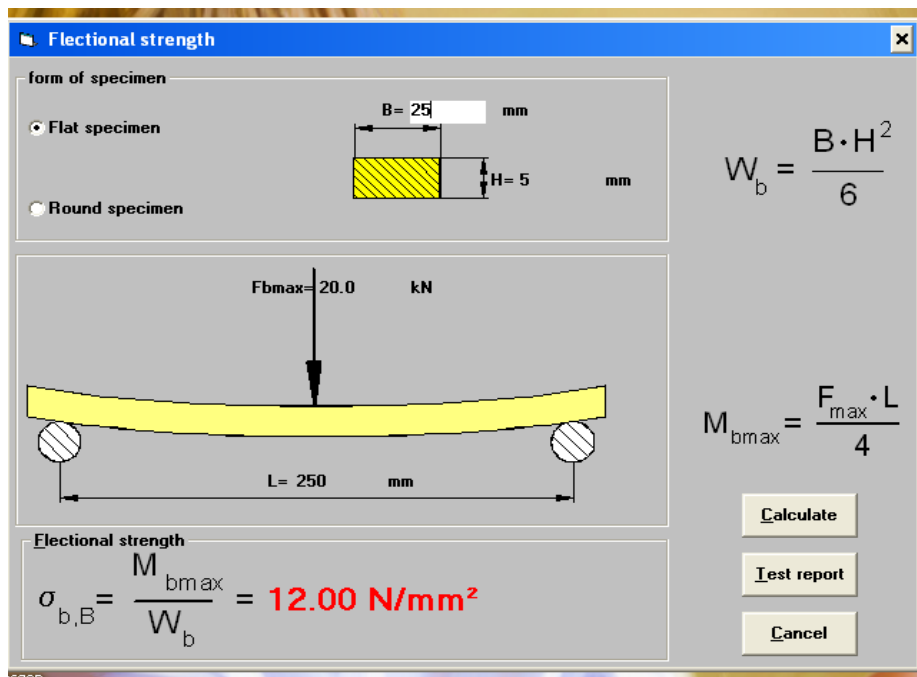


Figure 4.14. Bending strength of sample #3, same for other two test samples

The bending stress in MPa and loads in Newton's are summarized in Table 4.10, shows all results are read from the computer attached with UTM while each tests are done and which are below the

standard in which the UTM machine can work for composite materials this is recommended values for the test specimens.

Table 4.10. Summary of Pineapple Leaf fiber bending test result of samples

Specimen Number	Standard	Bending Stress (N/mm ²)	Max Load (N)
ST-1	ASTM 3039	18	60
ST-2		42	140
ST-3		12	20
	Mean	24	73.3
	Standard Deviation	12.96	49.89

4.2. Comparison of Mechanical Properties

As shown in figure 4.15 and 4.16, comparison of the experimental result obtained through this research is compared with relevant literatures so that as figure show the properties obtained for palm and pineapple leaf fiber epoxy composite were comparable properties with other natural and synthetic fiber epoxy composites.

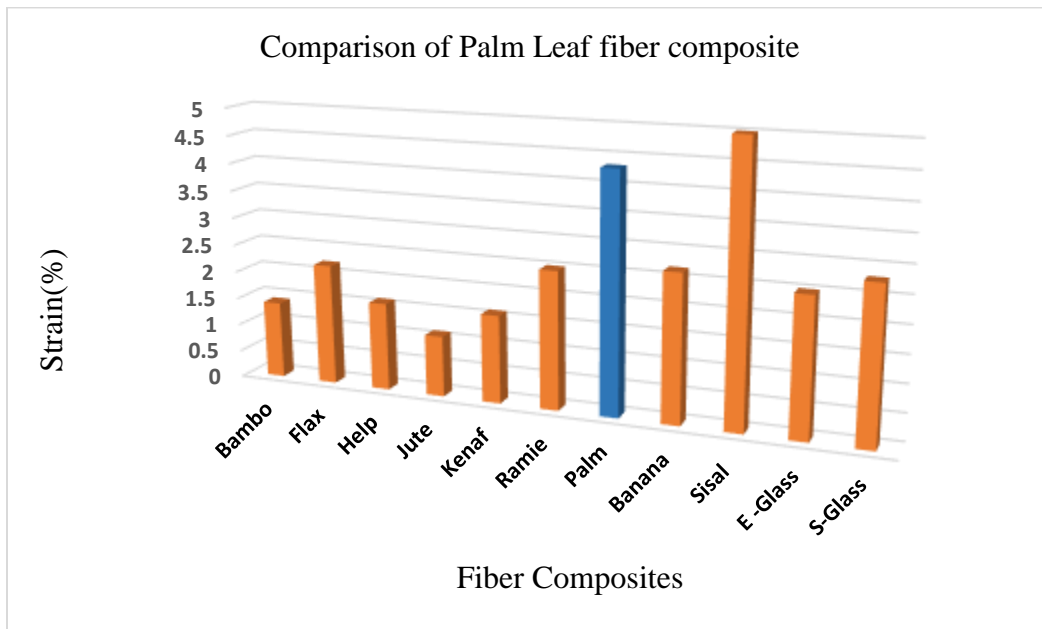


Figure 4.15. Comparison of palm leaf fiber epoxy composite with existing literatures [21, 23].

As shown in Figure 4.15 one of the basic mechanical property of Palm leaf fiber epoxy composite is strain, it have comparable values with relevant literatures even it have better strain values as compared to natural fibers.

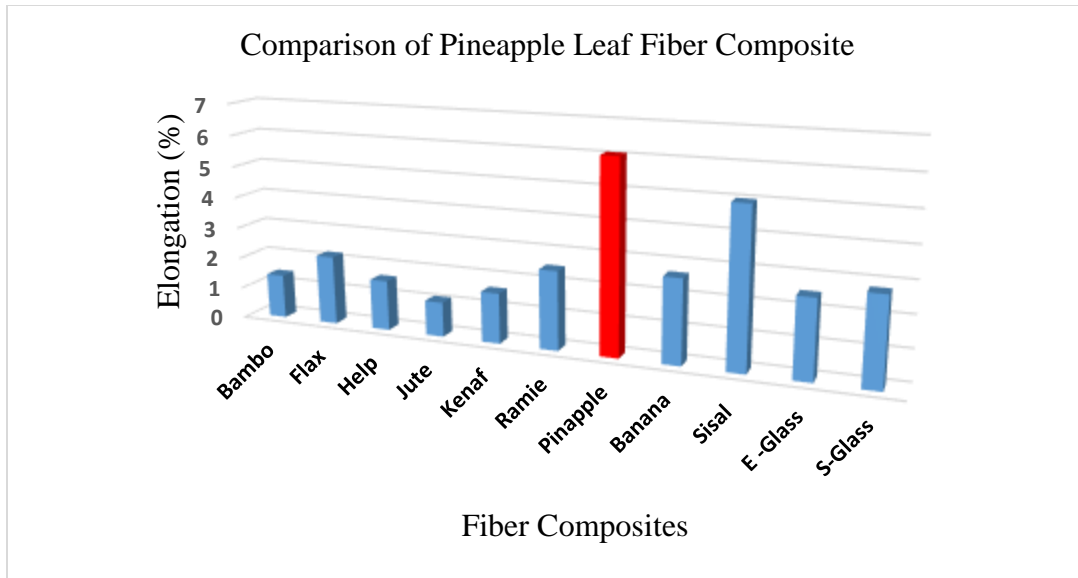


Figure 4.16. Comparison of pineapple leaf fiber epoxy composite with existing literatures [21, 23].

Figure 4.15 & 16, shows that pineapple fiber epoxy composite have comparable with relevant literatures discussed on [21, 23] of the study, hence elongation of both palm and pineapple leaf fiber epoxy composite have comparable elongation and strain with existing relevant literatures hence it is better to use in light mechanical applications like packaging of foods instead of using synthetic fiber for such applications.

CHAPTER 5

5. Conclusions, Recommendations and Future Works

5.1. Conclusions

This experimental investigation to characterize the mechanical behavior of palm and pineapple leaf fiber epoxy composites indicates the fiber have comparable strengths to substitute the glass fiber epoxy composites which have strong environmental influence and cost. Hence this finding can show as how to focus in new source of fiber and making better environment for 2050. there for the points are the pillar finding of the research work:-

- Palm leaf fiber epoxy composite have better strength as compared to pineapple leaf fiber epoxy composite and both new source of leaf fiber composites have comparable strength with E Glass and other fiber source.
- Stress of material is (356-2097KPa) & (70-790KPa) for palm and pineapple leaf fiber epoxy composite respectively. Fiber extracted from Palm leaf have more strength as compared to pineapple leaf fiber.
- Tensile modulus of the material is (51-414KPa) & (4.81-459KPa) for palm and pineapple leaf fiber epoxy composite respectively. This result was obtained by either by dividing tensile stress with strain of the given test or from the slope of stress versus strain curve, hence it is observed that Young's modulus of pineapple leaf fiber is bigger as compared to palm leaf fiber due to it pineapple leaf fiber have large strain.
- Strain of the material developed is (5.07-6.97%) & (11.01-14.52%) for palm and pineapple leaf fiber epoxy composite respectively.
- Bending strength of the material is 13MPa and 24MPa for palm and pineapple leaf fiber epoxy composite respectively.

5.2. Recommendations and Future Works

This thesis work mainly addressed the extraction, fabrication and mechanical Property characterization of palm and pineapple leaf fiber composite for light mechanical application. But there are different related research areas which are highly important to improve the Mechanical property of palm and pineapple leaf fiber composite material. Here the following topics are suggested for further studies, such as:

- Characterization of the fibers as a form of mat type and fine powder type.
- Investigate the contribution of fiber direction, orientation and volume ratio for the benefit of higher mechanical properties.
- Characterization of fibers can also be done using different fabrication techniques.
- Further we can make use of advanced or bio-matrix materials (high density polyurethane or PEEK).
- The physical, chemical, crystalline, and thermal stability analyses were not discussed
- Finding of different palm and pineapple leaf fiber extraction and treatment processes for the better palm and pineapple leaf fiber surface texture.
- Testing like fatigue test, shear test, impact test, moisture content test and thermal test.

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APPENDIX 1. Palm and Pineapple Leaf Fiber Chemical Treatment & Fabrication Steps



1. Resin/Epoxy



2. Na OH & Distilled Water



3. Mass Measuring Device



4. Painting Wax on Al Foil



5. Arranging Fibers in Al Foil



6. Fill Fibers with Resin and Hardener



7. Covering preparing for Curing



8. Ready to Cure



9. Inserting in to mold for compression



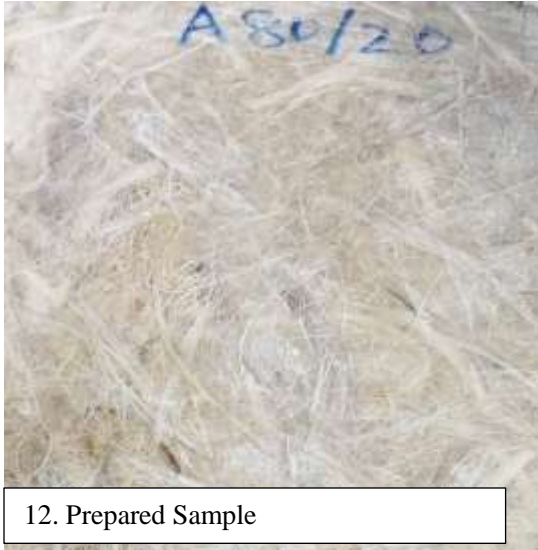
10. Compression takes 2-3 hrs.



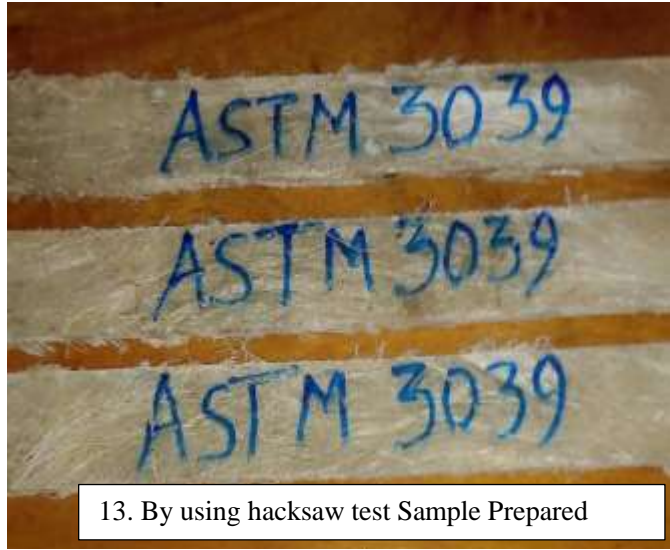
Compression on going



11. after compression with its Al foil



12. Prepared Sample



13. By using hacksaw test Sample Prepared

APPENDIX 2. Composition Analysis of Palm and Pineapple Leaf Fibers

➤ **Weight Fraction and volume Fraction of the Fiber and the Matrix Content of the Composite**

The volume of the composite was defined by the length, width and depth of the mold prepared for the molding of the composite material, and the total volume of the composite is also the sum of the volume of the palm and pineapple fiber and epoxy resin.

$$V_C = L * W * D \dots \dots \dots (1)$$

$$V_C = V_f + V_E \dots \dots \dots (2)$$

V_E is volume of epoxy resin, L is length of the mold, W is width of the mold and D is depth is the mold.

The density of the composite was calculated by means of a method which allows for the application of the rule of law of the mixture and was first obtained by adding the volume of the epoxy resin and the palm and pineapple fibers for each fiber-matrix ratio. After the calculation of the density of the composite material, the total mass of the composite material is calculated.

Density of composite

$$\rho_C = m_C / V_C \dots \dots \dots (3)$$

Where: m_C is mass of composite V_C is volume of composite

We can define the volume of the composite from the above density equation:

$$m_C / \rho_C = m_f / \rho_f + m_E / \rho_E \dots \dots \dots (4)$$

Where: m_f is mass of palm and pineapple fiber, m_E is mass of Epoxy, ρ_f is density of pineapple and palm fiber = 1.52 gm/cm³ & 1.33 gm/cm³ and ρ_E is density of Epoxy = 1.2 gm/cm³

➤ **Mass composition of the composite is percent mass composition of the fiber plus percent mass composition of Epoxy.**

$$m_C = x\% * m_f + y\% * m_E \dots \dots \dots (5)$$

Where: x% is mass fraction of palm and pineapple fiber and y% is mass fraction of Epoxy resin and $x+y=1$.

➤ **Calculation to find the mass composition of the composite material for test sample**

Preparation:

*volume of the die or composite, $V_C = L * W * D \dots \dots \dots (6)$*

$$V_C = 200 * 300 * 5 = 300000\text{mm}^3 = 300\text{cm}^3$$

Appendix 3. Experimental Test data's for both Tension, compression and Bending Test

Test-1 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PALM
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max. Test force:	20.0 N
Flectional strength	12.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	250 mm
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-2 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PALM
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max.Test force:	70.0 N
Flectional strength	21.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	125 mm
Date:	13.11.2019
Name of tester:	Marta
Signature:	_____

Test-3 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PALM
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max. Test force:	20.0 N
Flectional strength	6.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	125 mm
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-1 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PINAPPLE
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max. test force:	60.0 N
Flectional strength	18.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	125 mm
Date:	12 11 2019
Name of tester:	Marta
Signature:	_____

Test-2 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PINAPPLE
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max. test force:	140.0 N
flectional strength	42.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	125 mm
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-3 Report

Kind of test:	Bending test DIN 50110
Material of specimen:	PINAPPLE
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
Max. test force:	40.0 N
Flectional strength	12.00 N/mm ²
Ductile yield	_____
Description of the fracture area:	_____
Distance between supports:	125 mm
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-1 Report

Kind of test:	Tensile test DIN 50106
Material of specimen:	PINEAPPLE
Dimensions of specimen:	Tension specimen B25 x 125 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength Re U/ Re L:	_____
Yield stress R _p :	_____
Tensile Strength R _m :	11.20 N/mm ²
Elongation at fracture A:	_____
Contraction at fracture Z:	_____
Date:	11.11.2019
Name of tester:	Marta
Signature:	_____

Test-2 Report

Kind of test:	Tensile test DIN 50106
Material of specimen:	PINEAPPLE
Dimensions of specimen:	Tension specimen B25 x 125 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength Re U/ Re L:	_____
Yield stress Rp:	_____
Tensile Strength Rm:	4.96 N/mm ²
Elongation at fracture A:	_____
Contraction at fracture Z:	_____
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test- 1 Report

Kind of test:	Tensile test DIN 50106
Material of specimen:	PALM
Dimensions of specimen:	Tension specimen B25 x 125 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	_____
Yield stress Rp:	_____
Tensile Strength Rm:	7.52 N/mm ²
Elongation at fracture A:	_____
Contraction at fracture Z:	_____
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-2 Report

Kind of test:	Tensile test DIN 50106
Material of specimen:	PALM
Dimensions of specimen:	Tension specimen B25 x 125 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	_____
Yield stress Rp:	_____
Tensile Strength Rm:	8.56 N/mm ²
Elongation at fracture A:	_____
Contraction at fracture Z:	_____
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____

Test-3 Report

Kind of test:	Tensile test DIN 50106
Material of specimen:	PALM
Dimensions of specimen:	Tension specimen B25 x 125 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	_____
Yield stress Rp:	_____
Tensile Strength Rm:	7.52 N/mm ²
Elongation at fracture A:	_____
Contraction at fracture Z:	_____
Date:	12.11.2019
Name of tester:	Marta
Signature:	_____