Experimental Study on Mechanical Properties of Laminated Bamboo Strip/Alumina Particulate/ Epoxy Composite.

Jimma University
Jimma Institute of Technology
Faculty of Mechanical Engineering

A Thesis Submitted To The Graduate Studies Of Jimma University In Partial Fulfilment Of The Requirement For The Degree Of Master Of Science In Manufacturing System Engineering

By

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Approval Sheet

Experimental Study on Mechanical Properties of Laminated Bamboo Strip/Alumina Particulate/ Epoxy Composite.

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Declaration

I, **Aschalew Gebre**, declare that this thesis proposal entitled **"Experimental Study on Mechanical Properties of Laminated Bamboo Strip/Alumina Particulate/Epoxy Composite"** is my original work, and has not been presented by any other person in any form for an award of a degree or diploma at any other university or institution. It is submitted to the Faculty of Mechanical Engineering, Jimma Institute of Technology, in partial fulfillment of the requirement for the award of masters of sciences in manufacturing system engineering.

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List of acronyms

Al_2O_3	Aluminum oxide
ASTM	American Society for Testing Materials
BFRC	Bamboo fiber reinforced composite
BP	Bamboo plant
BRPC	Bamboo reinforced polymer composite
CCM	Component of composite materials
CM	Composite materials
DUCE	Defense university college of engineering
FSS	Flexural strength specimen
MC	Moisture Contents
NFRC	Natural fiber reinforced composite
NFRP	Natural fiber reinforced polymer
NFRPC	Natural fiber reinforced polyester composite
PRF	particle reinforced fiber
RM	Reinforcement materials
UTM	Universal testing machine
VHT	Vickers hardness test
WA	water absorption
WAT	water absorption test

Nomenclature

A_o	original cross sectional area
cc	cubic meter
E	modulus of elasticity
Gpa	gega pascal
h	thickness of plie
Hv	Vickers hardness
Kg	kilogram
KN	killo newton
Lit.	Liter
Mf	mass of fiber
Mpa	mega Pascal
P	load
t	Ply thickness
Vc	Volume of Composite
Vf	Fibers Volume fraction
Vf	Volume of fibers
Vm	Matrix Volume fraction
Vm	Volume of matrix
W_c	weight of composite
Wf	Fiber weight fraction
Wf	weight of Fiber
Wm	matrix weight fraction
Wm	weight of Matrix
Wp	weight of particulate
ρf	Density of Fiber
ρm	Density of Matrix
δf	Stress of fiber
ε	Strain

Abstract

Composites consist of natural fiber materials that offer attractive strength equivalent to conventional materials. However, the defect of bamboo is its hydrophilic character, severed with some properties which affect the performance of fibers. Synthetic fiber composite becomes expensive, non-biodegradable, and environmentally unfriendly, to address such issues and the necessity of composite in the automobile, aerospace, and construction industries. This paper is present an experimental studies on laminated bamboo strip fiber reinforced with alumina particulate to polymer composite. In recent years, Natural fiber composites have gained significant popularity as structural materials due to their stiffness and high strength with a low cost, as well as their light weight, short growing cycle, biodegradability, eco-friendliness, and high availability. For physical and mechanical characterizations, the specimen is prepared using the hand lay-up manufacturing processing techniques. Mild steel mold with dimensions of 320x260x50mm. The composite plate constitutes weight loading of bamboo/epoxy compositions is 25%:70%, 20%:70%, and 15%:70% with 5wt%, 10wt%, and 15%wt of Al_2O_3. Epoxy (LY556) and hardener (HY951) were used to mix in the ration 100:10 for curing bamboo composite with the reinforcement orientation on ($0^0/90^0 \& \pm 45^0$). The laminated composite ply stacking sequence on the $[0/90^0]_S$ and $[\pm 45^0]_S$. During this work, conduct mechanical property tests under ASTM standards, such as tensile, compression, flexural strength, hardness, and impact strength and water absorption. The greatest value for tensile strength is 86.7Mpa, flexural strength is 247.5Mpa, hardness is 207Hv and impact 6.984kJ/m of composite obtained at 5wt%, 15wt% and 10wt%alumina, respectively, and FTIR is intermolecular interaction between fibers and resin of materials. The goal of the study is to improve the mechanical properties of the bamboo composite that has been developed.

***Keywords**: Bamboo strip, Alumina particulate, Epoxy, bidirectional, reinforcements, matrix.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Composite materials are becomes the most popular engineering materials their demand and wide ranging applications have constantly grown, impregnating the market's inflexibility. Meanwhile, composites can reduce material weight and reduce the challenge of materials cost. The primary benefit of using composites is their cost-effectiveness and strength-to-weight ratio. As the cost of synthetic materials rises, researchers are increasingly turning to natural fibers as an alternative reinforcement in composites, which has piqued their curiosity [1]. The natural fibers are considered such as Flax, hemp, jute, coir, cotton, wool, bamboo, banana, sisal, and other natural fibers are examined. Natural Fiber Reinforced Polymer (NFRP) composites are rapidly gaining popularity in research and industry because they are widely available, inexpensive, renewable, and biodegradable, and they have comparably high mechanical qualities. Furthermore, natural fiber as reinforced composites has several advantages over synthetic fibers like carbon, glass, aramids, Kevlar, and boron fibers, such as lower processing costs, higher modulus to weight ratio, lower density, higher strength to weight ratio, and higher specific ratio, among others. They have been used in a variety of applications in recent years, including transportation, defense, civil engineering, marine, ship cargo, packaging, and consumer products [2]. Bamboo fiber has a higher tensile strength and modulus than natural fibers like jute, banana, sisal, and coir fibers [3].

Even though bamboo is a flexible natural fiber, it is not acknowledged as value addition in Ethiopia's economy. It is a naturally grown and plantation resource utilized for various building industries and furniture. Almost all bamboo products are produced traditionally and manually used for the local market because lack of advanced technology, knowledge, and skill undervalued the importance of bamboo. Bamboo is a fast-growing, renewable material with a simple production process, is expected to be a sustainable alternative for more traditional structural materials, such as concrete, steel, and timber (P.Vander et al, 2004). The significant importance for construction industry as an alternative to timber and scarce building material with promote large-scale bamboo farming and processing (Kassa, 2009).

The bamboo resources in rural livelihoods and national economy are the unrealized only type of bamboo used in rural bamboo-growing areas and nearby towns are selling bamboo culms and little value addition, for processing bamboo in the form of tables, chairs, beds, etc.[4] Bamboo product materials are a very important and essential resource in the Asian, African, and South American people rely on bamboo consisted for their housing and farming tools (Troya et al., 2014). The bamboo Culms with developed branches is a source of material for housing and construction, concrete reinforcement, scaffolding, bridges, furniture, plywood, paneling, flooring, roofing, etc. (Bareja, 2010 and Diver, 2001).

Over one billion people live in traditional bamboo houses in the world. These buildings are cheaper than wooden houses, light, strong, and earthquake resistant, unlike brick or cement constructions (Troya and Xu, 2014). In Ethiopia, Currently, highland bamboo is used for furniture (traditional processors and modern workshops), house construction, fencing, water storage/ water pipes, baskets, agricultural tools, beehives, household utensils, and various artifacts (FAO, 2005). In recent years, approximately more than 10 million Ethiopians are living in bamboo houses. Bamboo has many capabilities in realizing the food security mechanism of the country Ethiopia [5].

Bamboo is becomes increasingly important in the world because of a superior wood substitute cheap, efficient, and fast-growing, has a high potential for environmental protection, wide ecological adaptation, and the state of forest is shrinking globally [6]

Composite materials are composed of one or more fiber reinforcement and single polymer matrix materials of different constituents of chemical composition bonded together. It is useful for the aerospace, automotive, marine, biomedical, and construction industries. Composite materials are having excellent mechanical, Tribological, thermal, water absorption, and vibrational properties. Moreover, the use of composites to fabricate structures is one of the ways to reduce cost and weight In composite, fibers are the main source of strength while the matrix is used to adhesion the fibers together in form and transfers loads to the reinforcement. The fibers are carrying the loads along with their longitudinal directions. The common fibers used as reinforcing agents include beryllium carbide, carbon-graphite fibers, beryllium oxide, molybdenum, aluminum oxide, polyamide, glass fibers, natural fibers [7]

The matrix or binder maintains the position and orientation of the reinforcement. Significantly, the components of the composites retain their individual, physical and chemical properties. They together produce a combined quality of individual constituents but are incapable of producing alone [7].

The fiber-reinforced polymer composite materials are classification into four broad groups has been done as a result of the matrix that used. Thus are, carbon fiber reinforced polymer composites, polymer matrix composites, metal matrix composites, and ceramic matrix composites. Polymer matrices are made of thermoplastic or thermoset reinforced to glass, carbon, or boron. A metal matrix composite material consists of a matrix of metals or alloys reinforced with metal fibers. Ceramic matrix composite materials consist of ceramic matrices reinforced with ceramic fibers such as silicon carbide, alumina, or silicon nitride. They are mainly effective for high-temperature applications.

Polymeric is the most frequently used matrix material. In general, the mechanical and physical properties of polymer composites are inadequate for many structural applications. In specific, their stiffness and strength are low compared to metals and ceramic composites. Secondly, the processing of polymer matrix composites needs not involve high pressure and does not require high temperature. Also, the equipment essentials for manufacturing polymer matrix composite materials are simpler. For this reason, polymer composite materials developed rapidly and becomes popular for structural applications [8].

In addition, there are three types of polymer composite materials. These are Particle reinforced polymer (PRP), Fiber-reinforced polymer (FRP), and structural composites [9].

The primary phase of composite material is a matrix having a continuous characteristic. Matrices are a material used as a binder or hold a fiber in the desired place thereby transferring the external load to fiber reinforcement.

The common matrix such as epoxy, polyester, vinyl ester, polyurethane. Among these resin materials, epoxy has excellent adhesion and less shrinkage than the other matrix materials with high-cost Fiber. The composite material is composed of an epoxy matrix embedded with high strength of fibers such as carbon, glass, basalt, aramid, and natural fibers [10].

However, the utilization potential polymer matrix material used in many applications has been explored and superior mechanical properties have not been adequately well drawn for polymer composites [11]. Filler is encompassing a variety of materials have an important role in improving the performance of polymers and their composites. Particulate fillers are powdered substances, with particles often less than 100μm in size, which are added to polymers to reduce materials cost, to improve process ability, and/or to improve mechanical properties [11,12]

In addition, it increases properties like abrasion resistance, hardness and reduces shrinkage in fiber-reinforced polymer composites, a judicious selection of matrix and the reinforcing phase can lead to composites having the strength and modulus comparable to or even better than those of conventional metallic materials, their physical and mechanical properties can further be modified by the addition of a solid filler phase to the matrix body during the composite preparation [13]

1.2 Statement of the Problem

Our country has a great potential of bamboo plants that has been little economic value in contrast to other forest products because it is processed traditionally and manually for the local market. Due to lack of modern techniques and adaptation technology make undervalued. However, used as structural materials for varies applications but its contribution of bamboo to industrial sector of the country is very less as compared to other countries. Because lack of awareness, unavailability of experimental tools, and low manufacturing process capability, the performance, and applications of bamboo fibers and their composite materials are not investigated well.

Bamboo is a hygroscopic material because its compositions such as cellulose, hemicellulose, lignin and pectin's all are hydroxyl groups; these are allow to absorption water(hydrophilic). The cost of Synthetic fibers are rise and not biodegradable. Natural fiber reinforced composites can reduce the weight that is main concern. Therefore, lack of reports on developing bamboo reinforced polymer composites with improved mechanical properties.

1.3 Objectives

1.3.1 General Objective

Experimental study on mechanical properties of laminated bamboo strip/alumina particulate/epoxy composite.

1.3.2 Specific objectives

- Fabrication of a new class of epoxy-based preference oriented continuous bamboo strip with alumina composite.
- To study the physical, and mechanical properties of bamboo strip composites based on ASTM standards.
- To study the influence of process parameters such as fiber orientation, lamina arrangement, and weight or volume loading of alumina in the mechanical properties of composite.
- Characterization of laminated bamboo composite specimen on the FTIR analysis.

1.4 Significance of the study

The importance of naturally available bamboo fibers

- To increase the utilization of bamboo in Ethiopia for economic value-adding.
- To increase the demand for bamboo fiber composites instead of synthetic fibers because of the low density, abundant availability, low cost, and biodegradability
- Bamboo with alumina as an alternative in replacing synthetic materials such as Structural applications.
- Effective studies of bamboo fiber have been done the benefits will be
  i. The bamboo plants producer of local farmers in Ethiopia
  ii. Bamboo fiber composite manufacturing industries
  iii. The manufactured composite material can be used by construction industries, automobile industries, household products, industries, etc.
  iv. A researcher who is interested in carrying out bamboo fiber-reinforced composite

1.5 Motivation of the research

Polymer composites are very important materials in the aerospace, automotive, and construction industries. In recent years, the natural fiber becomes substantially increased to make composite materials due to its low cost, biodegradability, light weight, and eco- friendly this Bamboo is considerable natural fiber reinforcement that is abundantly available for making composite materials. It has stiffness and excellent strength, anti-corrosive properties which can replace synthetic fiber materials. Bamboo has been used for structural applications for many years in the world. Ethiopia has known the largest resource of bamboo existing in Africa. The product of bamboo-based materials should be improved for structural applications in Ethiopia and the economic potential of bamboo has not been explore and the role of bamboo resources in national economy is very little. Hence to add values to the bamboo plant, it is essential to develop the fiber extraction method, characterizing the prominent properties of fibers and convert the bamboo fiber into more valuable form of composite products which can be used in several industrial applications.

1.6 Scope of the study

The scope of the study includes the following.

- Fabrication of woven bamboo with alumina fiber reinforced epoxy composite.
- Experimentally studies on mechanical properties of bamboo composite material.
- Determining parameters like the weight of epoxy resin, the weight ratio of bamboo fiber, and alumina of composite materials.
- Makes laminated the bamboo composites material from lamina or ply
- Determine the fiber orientations and loading volume fraction.
- Make a different test on the specimen of composite materials using the universal testing machine (UTM).
- Measurement of water absorption test and density determination
- The fiber was extracted from manual extraction techniques.

1.7 Thesis Paper Organization

The thesis is organized into five chapters:

- **The first chapter:** is a brief description of composite materials related to their application and structural usage of composite, the thesis background, the statement of the problem, general and specific objectives, significance, application, motivation, and scope of the study.
- **Chapter two:** addresses a literature review, definition of composite, classification of composite, fiber orientation of composite, characterization of composite, the component of the composite, bamboo plants, bamboo fiber, and extraction process of fiber.
- **Chapter three:** deals with the experimental program which focused on describing the materials, machinery, and apparatus used for fabricating and also shows the testing equipment used to determine the mechanical strength, water absorption on the produced composites.
- **Chapter four:** addresses the results of mechanical characterizations, including tensile strength, flexural strength, compression strength, hardness strength, impact strength ,water absorption, density determination, and FTIR analysis.
- **Chapter five:** discusses the conclusion, recommendation, and future works.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

In recent years, the interest in natural fiber reinforced polymer composites increasing rapidly due to many advantages. These composites are more ecologically free and used in many engineering applications worldwide such as transportation (automobile, aerospace, and railway coaches), construction (ceiling, partition boards, etc.), consumer products, military applications, etc. The fiber-reinforced polymer composites can be either synthetic or natural fibers.

The fibers are obtained from natural resources like plants known as natural fibers. A great deal of work has already been made on the perspective of the natural fibers as reinforcements for composites. Advantages of natural fibers over synthetic fibers comprise low density, low cost, availability, recyclability, and bio-degradability [15].due to numerous advantages they are analogous to synthetic fibers used as reinforcements.

The natural fibers are consisting of cellulose, hemicellulose, lignin, waxes, and water-soluble substances. The properties of natural fibers are greatly influenced by their chemical compositions. The natural fibers are better as compared to glass fibers. Therefore, these higher specific properties are the main advantages of natural fiber as reinforcement in polymer composites on weight-sensitive applications. Natural fibers have become popular reinforcement material for fiber-reinforced polymer composite development. The reinforcement can replace the conventional fiber, such as glass, aramid, and carbon as alternative materials [16].

The main advantage of natural fibers includes low cost, fairly good mechanical properties, high specific strength, non-abrasive, & eco-friendly. Despite impressive specific mechanical properties, the main challenges associated with these reinforcements include severe moisture absorption, fire resistance, mechanical properties and durability, variability, and manufacturing processing of natural fiber-reinforced composite materials [17].

Many similar studies on natural fibers such as bamboo, hemp, kenaf, jute, and flax indicate that the mechanical and physical properties of fiber-reinforced composite materials depend on several fiber parameters such as fiber length, fiber weight loading, fiber aspect ratio, fiber orientation, and fiber-matrix adhesion and manufacturing process techniques [18]

There are a wide variety of different natural fibers that can be used as reinforcement or fillers.

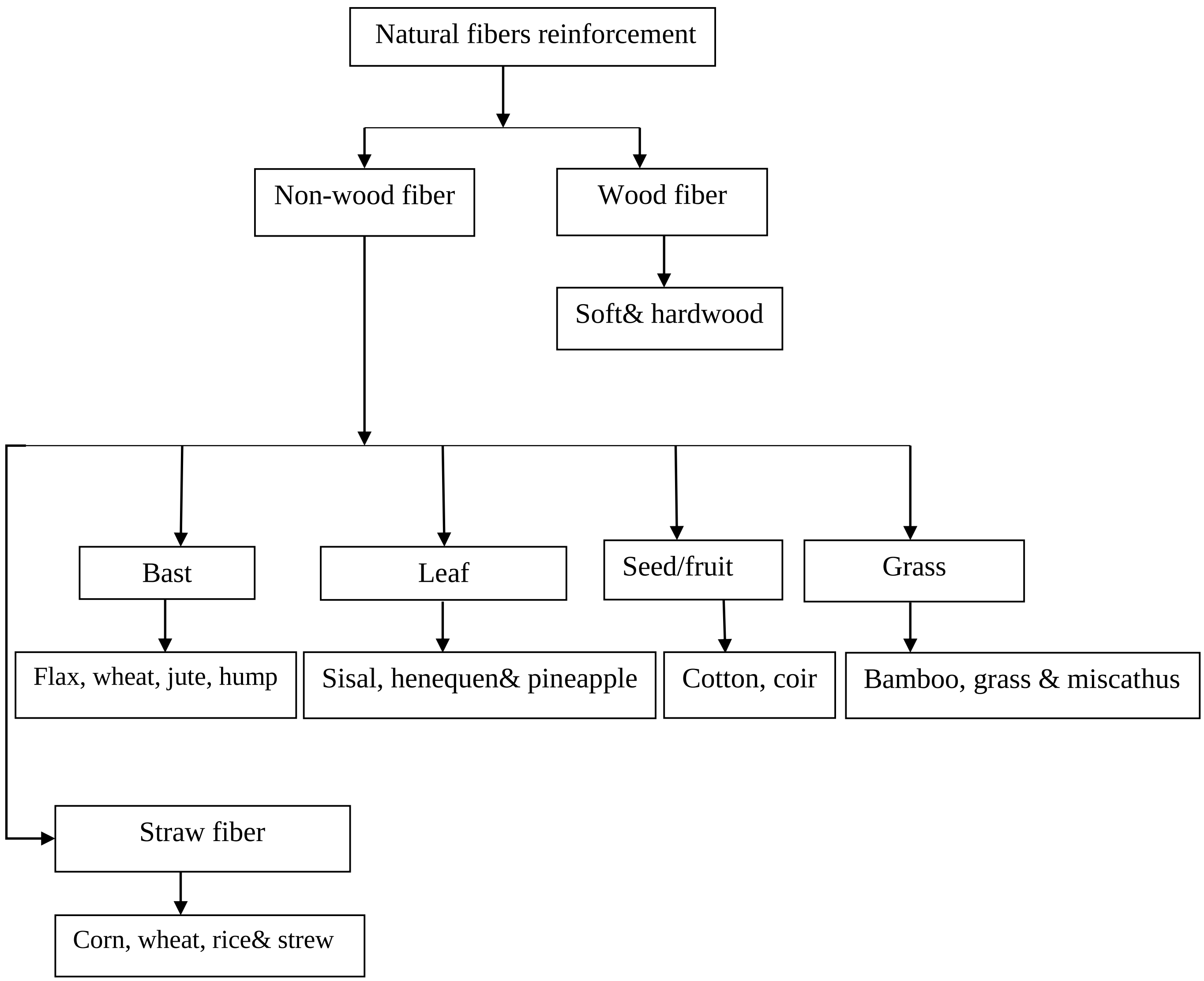


Figure 2.1 Classification of natural fibers used as reinforcement

2.2 composite materials

A composite material is the amalgamation of reinforcement and matrix materials components with different properties and different chemical compositions through compound processes. It is not only maintains the main characteristics of the original component but also shows new characters which are not possessed by any of the original components. The reinforcement phase principal load-carrying component that existed like fibers, flakes, or particles. Fibers are the common form of reinforcement, arranged as aligned continuous or randomly discontinuous or aligned discontinues during composite fabrications. The matrix is a continuous phase, used as a load transfer medium in the composites, and serves as a source of toughness.

The composition and internal structure of composite materials analysis include three basic physical phases. One is the continuous matrix phase, the other is reinforcement is scattered, another one is called the interface between the reinforcement phase and matrix phase. Further study on micro-structure level obtains near the interface become a complex structure which is different from both the matrix phase and the reinforcement phase.

The structure and morphology have an impact on the macroscopic performance of composites so near to the interface changes in structure and properties. Becomes the third phase of composites is interphase. Therefore, composite material is composed of matrix phase, reinforcement phase, and interphase. The structure and nature of these three phases, their configuration, and interaction, as well as the relative content, determine the performance of composite materials [19].

2.3 classification of composite materials

Based on different measurements to classify composite materials on the fiber arrangement and the types of matrix materials used in a composite can be considered.

2.3.1 Fiber orientation

The fiber orientation and arrangement within the composite is varying from one composite material to the other during the manufacturing process. The variations help the manufacturer to indicate materials have different properties. Based on fiber orientation and arrangement showed the figure 2.2 below [20]

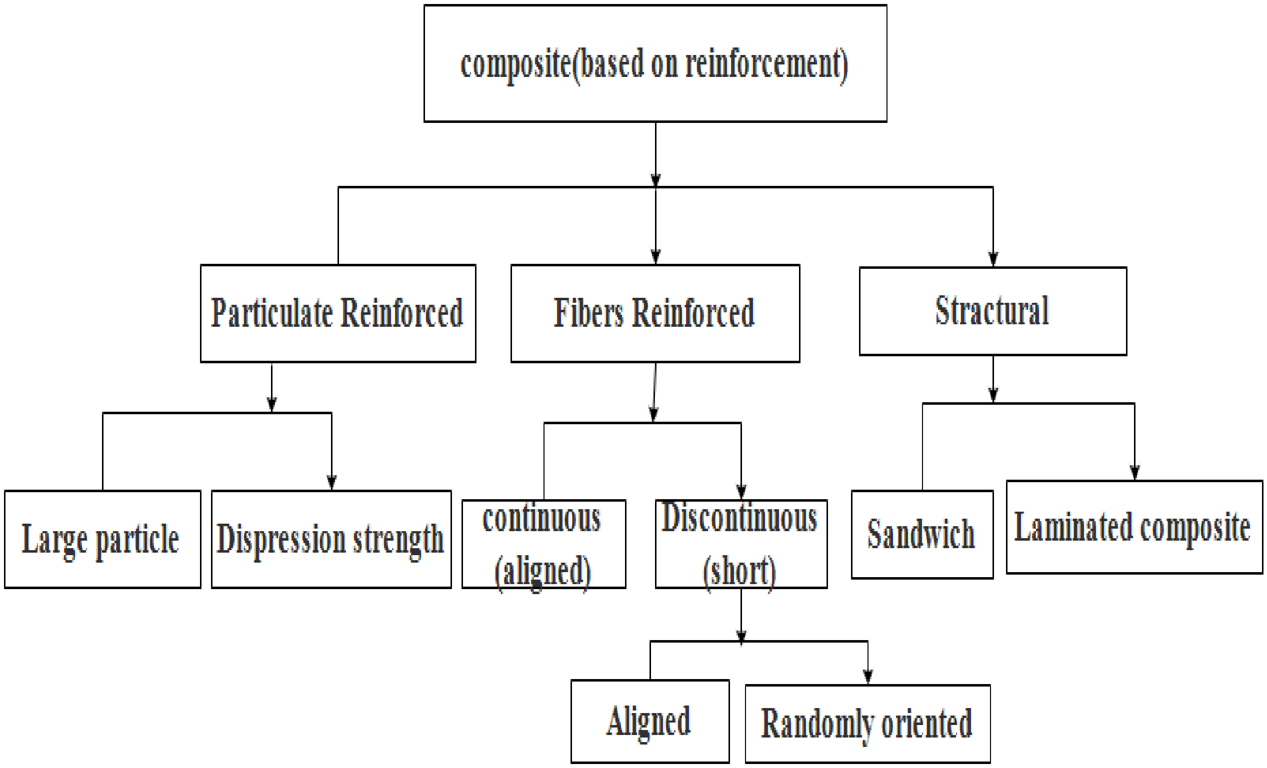


Figure 2.2 Composite materials classification based on fiber orientation

2.3.2 Particle-reinforced composite

The role of reinforcement in composite materials is primarily to increase the mechanical properties of the material such as strength and stiffness. Thus, particles used in the composite increase the modulus of the matrix, decrease the permeability of the matrix, and decrease the ductility of the matrix [20]. Particle reinforced composite is represented in figure 2.3 shown below.

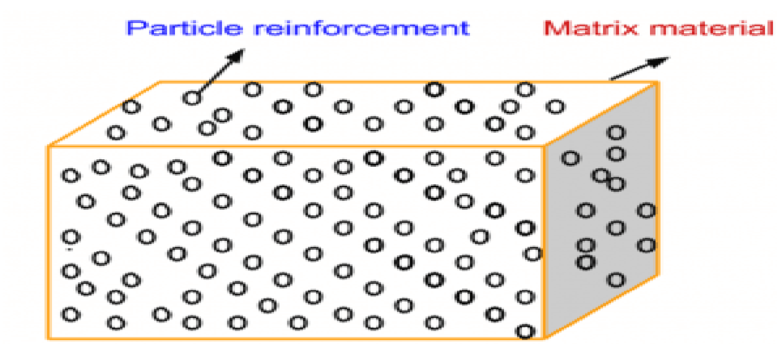
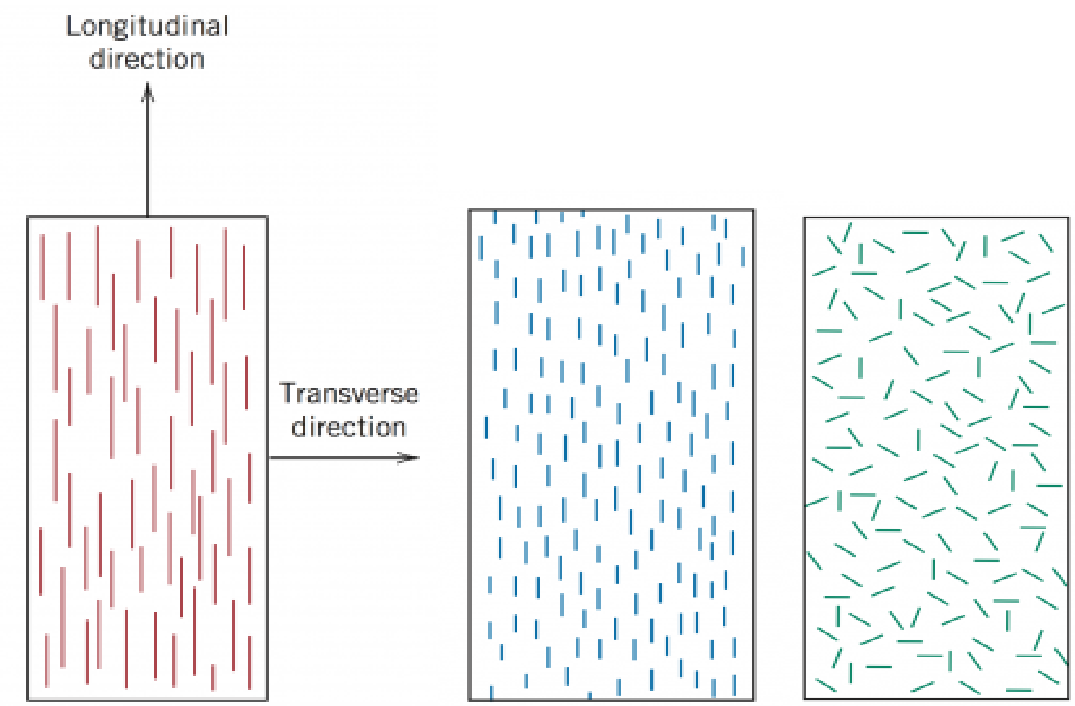


Figure 2.3 Particle reinforced composite [21]

2.3.3 Fiber Reinforced Composite

Fiber-reinforced composites are used to improve strength, fatigue resistance, and strength-to-weight ratio over the component of materials. Reinforcing fibers are essential to increase the modulus of the matrix material in the composite. The strong covalent bonds along the fiber length give them a very high modulus, arrangement, or orientation of the fibers, fiber concentration and distribution all have a significant influence on the strength and other properties of fiber-reinforced composites [20].



a) Continuous and aligned fiber b) Discontinuous and aligned fibers c) Discontinuous and randomly places fibers

Figure 2.4 Fiber reinforced composites (a-c) [20]

2.3.4 Structural composites

2.3.4.1 Laminate composite

Laminates are consisting of stacking sequence on the layers of the sheet which is called lamina or plies on different angles. The layers are often in the form of prepreg (fibers pre-impregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have been composed of different layers held together within the matrix. Laminate layers and the fiber orientation change from layer to layer regularly through the thickness of the laminate. These laminates can have unidirectional, angle ply, cross-ply, and symmetric laminates. The figure below shows how the laminate is formed from the lamina or ply [21].

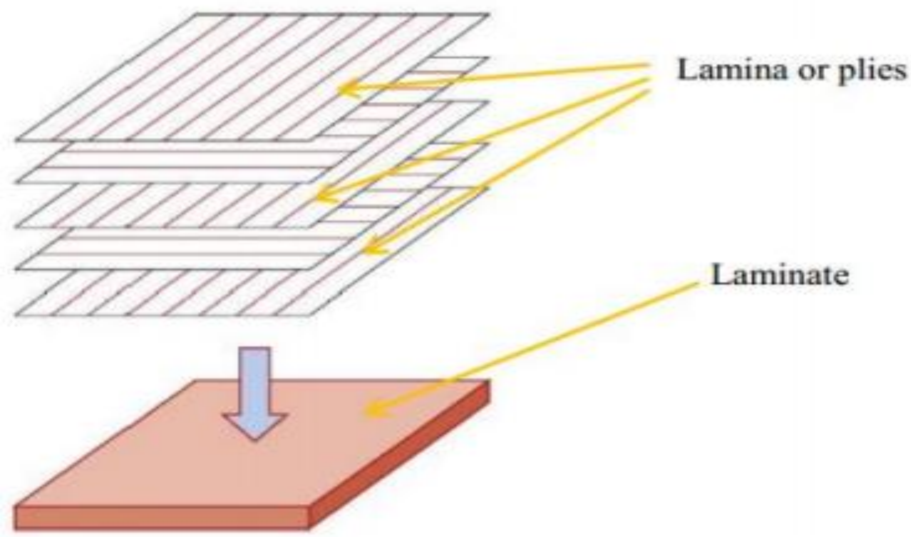
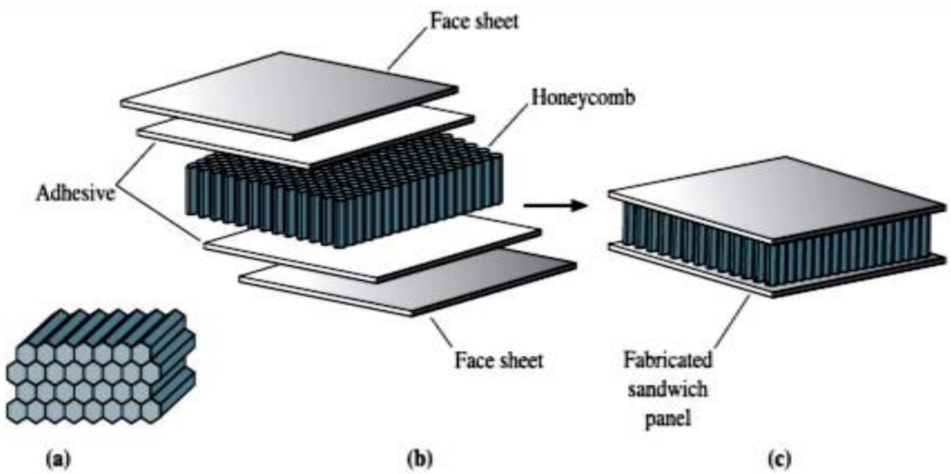


Figure 2.5 Composite laminated (21)

2.3.4.2 Sandwich panel composite

The Composite polymer matrix has low density, honeycomb core is reinforced with the face sheet by adhesive layers. The benefits of the Sandwich panels are small weight, large bending stiffness, and energy absorption [21, 22]



a) Hexagonal honeycomb core b) two sheets joined by adhesive layer c) can prepare light weight, stiff sandwich honeycomb structure.

Figure 2.6 Fabricated sandwich panel honeycomb core [22]

2.4 Matrix

The other classification of composites is on the types of matrix component of composite based on measurement, composite can be arranged on the chart shown below.

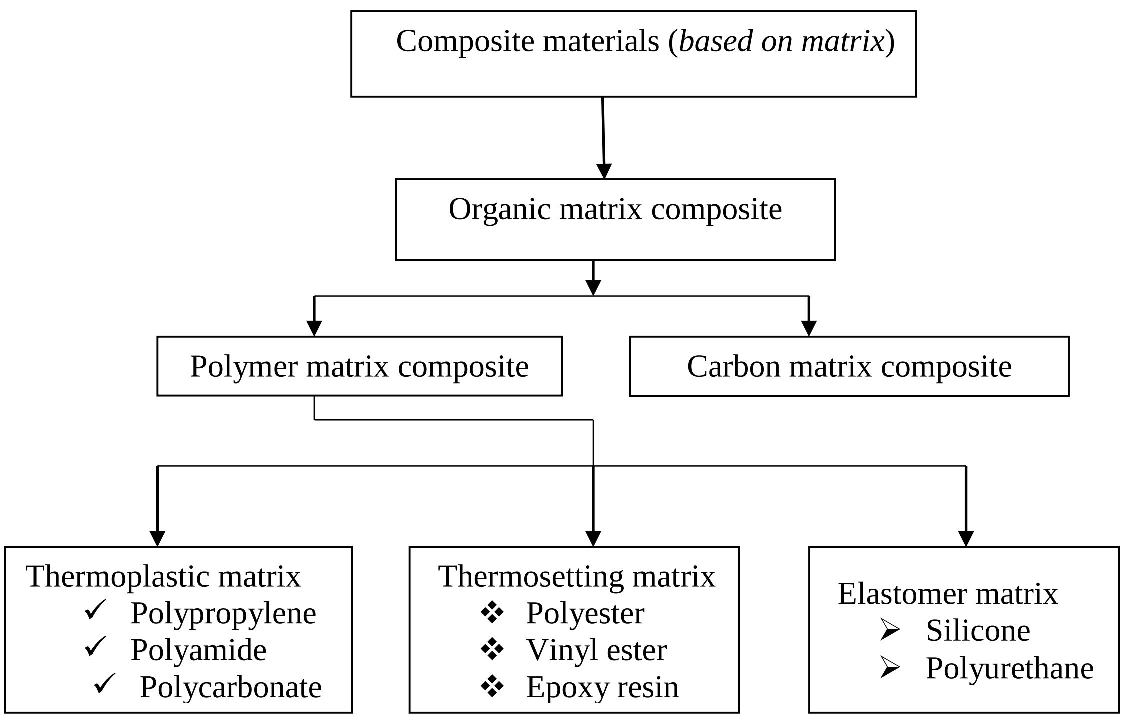


Figure 2.7 Flow chart of composite materials based on matrix [16, 23]

2.5 Characteristics of composite

Composite is embedded of discontinuous phases in a continuous phase. The discontinuous phase is often harder and stronger than the continuous phase is called load carried material whereas the continuous phase is known as the load transfer component. The behavior of composites is strongly dependent on the properties, distribution, and interaction of their constituent materials. The type of materials constitute, the geometry of the fibers (shape, size, and size distribution) affected the behavior of the composite.

The concentration distribution and orientation of the reinforcement also influence the properties of developed materials. The shape of the discontinuous phase can be spherical, cylindrical, or rectangular cross-section, the size and size distribution is controls the texture of the material and volume fraction determine the interfacial area, which plays an important role in determining the extent of interaction between the reinforcement and matrix. Concentration is often measured as volume or weight fraction to determine the contribution of a single constituent to the overall properties of the composites. Not only single parameter influence the properties of the composites, but also easily controllable manufacturing variables alter its properties [23]

3.32.6 Components of composite materials

2.6.1 Matrix materials

Matrix materials are different types like metals, ceramics, and polymers. Advantages of Polymer matrices compared to other types of the matrix are cost efficiency, easy availability, low density, lightweight, high strength to weight ratio, and environmentally friendly. Polymer matrices can be thermoplastic or thermoset. Thermoset matrices are formed due to an irreversible chemical transformation of the resin into an amorphous cross-linked polymer matrix. It has huge molecular structures and provides good electrical and thermal insulation. They have low viscosity, allow proper fiber wet out, better creep resistance, and excellent thermal stability. For this reason,

Thermoset matrices are epoxy, vinyl ester, polyester, and phenolic. Among these, epoxy is being extensively used for many advanced composites.[24]

2.6.1.1 Epoxy

Epoxy is a popular resin because of its many benefits, including its ability to join fibers, its lightweight, resistance to most alkalis and acids, stress crack resistance, stiffness and flexibility retention, low moisture absorption, non-staining, and ease of fabrication. Epoxy has been utilized for structural applications, industrial tooling applications, and is the most common polymer used in advanced composites due to its excellent adhesion, tensile strength, bonding strength, and fatigue resistance.

Besides, it has low shrinkage at curing and good chemical resistance, Ease of fabricating complex parts with less tooling cost, and excellent room temperature properties. Distributing the load between the fibers. Epoxy has various applications, including metal coatings, use in electronics/electrical components/LEDs, high tension electrical insulators, paintbrush manufacturing, fiber-reinforced plastic materials, and adhesives for structural. Due to several advantages over other thermoset polymers as mentioned above, the resin used for this study is epoxy (LY556)

2.6.2 Hardener (catalyst)

The hardener is a liquid substance that cures with the polymer matrix of composite materials. However, combined with suitable amounts of epoxy at room temperature. When epoxy and liquid hardeners are combined, a chemical reaction occurs, and the composite begins to harden or cure.

2.6.3 Reinforcement materials

Bamboo fiber is used as the reinforcement material of fabricating composites. In general, bamboo is existing around the world and is an abundant natural resource. Bamboo is an orthotropic material with high strength along and low strength transversal to its fibers.

The structure of bamboo constitute is the composite material in nature consisting of long and aligned cellulose fibers covered in a ligneous matrix. In this work, continuous bamboo fiber is used as the reinforcement of composites.

2.6.4 Particulate filler materials

Particulate fillers are the capability to improve the performance of polymers and their composites. Various types of fillers natural or synthetic both organic and inorganic used as reinforcement in polymeric composites. Among them, alumina (Al_2O_3), silicon carbide (Sic), silica (SiO2), Titanic (TiO2), etc. are widely used as conventional fillers. Many advantages consider different weight percentages of alumina (Al_2O_3) particulate is used as filler material for fabrication of bamboo fiber-reinforced composites in the present work.

Generally, Al_2O_3 commonly referred to as alumina is an inorganic material that serves as particulate filler material in various polymer matrices. Can available in several crystalline phases revert to the most stable hexagonal alpha phase at room or elevated temperatures. This is the phase of particular interest in structural applications. It is the most cost-effective and widely used material in the applications of engineering ceramics. Due to hardness, wear resistance, has excellent dielectric properties, high strength, and stiffness, resistance to strong acid and alkali attacks at elevated temperatures. For this reason and due to many advantages with a reasonable price, the fine grain technical grade of Al_2O_3 has a very wide range of engineering applications.

2.6.5 Bamboo plants

Bamboo is neither grass nor wood, but it has two of its characteristics. It belongs to the family of *Bambusoidae*. It has approximately up to 60–90 genera and 1100-1500 species of bamboo exist in the world. Bamboo grows mainly in tropical Africa, Asia, and Latin America [4, 25].

Bamboo has very strong in the longitudinal direction due to strong fiber bundles penetration and cylindrical shell of bamboo culm divided by transversal diaphragms at the nodes. Bamboo shells are orthotropic materials with high strength in the parallel direction and low strength in the perpendicular direction to the fibers. The thickness and strength of bamboo are decreasing from the base to the top of the bamboo culm [28, 30]. Ecological materials satisfy basic requirements like pollution prevention and cost minimization. The use of agricultural byproducts such as rice husk, coconut fibers, sisal, and bamboo fibers plays a great role in minimizing energy consumption, conserving non-renewable natural resources, reducing pollution, and maintaining a healthy environment, so Bamboo is the core material that fulfills these advantages [28].

Different researchers conduct various tests on the mechanical properties of different species of bamboo fibers as a function of age, moisture content, density, etc. The optimum strength value was obtained between 2.5 to 4 years of age bamboo [24, 29].

The Ethiopian has bamboo forest covering an area of about 1 million hectares, of which about 7% of the world total and 67% of African bamboo forest obtaining area. Ethiopia has Africa's biggest bamboo resources available and this plant can be harvested in sustainable cycles on 30%-40% of the mature culms every two years [29]. The total bamboo species is more than 1500 in the world and 43 species exist in Africa. The two indigenous bamboo species are the highland bamboo and lowland bamboo covers 15% and 85% respectively [29].

2.6.5.1 Highland Bamboo (Yushania Alpina, Arundinaria Alpina)

The highland Bamboo species is botanically known as Yushania Alpina, this bamboo species is the local name in Amharic is known as kerkeha [16]. The species grows naturally in 2200-4000 meters above sea level weather conditions. Distribution of Y. Alpina natural forests and manmade plantations in Ethiopia includes major places of the country namely Hagere-Selam, Injibara, Gojjam, Shewa, Kefa, Gamo-gofa, Sidamo, Bale, Jimma (Agaro, Gera), and Bore/Gujji [29, 34].

Figure 2.8 Diversity of bamboo species in Ethiopia [4]

Highland bamboo (Arundinaria Alpina) has the following properties [30];

- It grown at an altitude of 2300-4000m above mean sea level
- It needs 1500-2000mm rainfall and 10-20^{0}c temperature
- Its height and base diameters are 12-20m and 8-20cm respectively
- Hollow, monopodial, and evergreen
- It is single-stemmed types and culms are fully mature after 3 years of age
- It has a large diameter than other types and high strength.

2.6.5.2 Lowland Bamboo (Oxytenanthera Abyssinica)

Abyssinica natural forests are available in Gambella, Asossa, Dedessa, Pawe, West Wollega (Begi, Nejo, Gimbi, Guten, Didessa Valley, Kelem), north of Nekempte/Hinde, and the western part of the country on the major river valleys and bordering area of Sudan. Abyssinica is distributed throughout tropical Africa outside the humid forest zone [29]. Abyssinica grows with deciduous, savanna woodlands of western Ethiopia. These bamboo species have the following properties [34]

- It grows at an altitude of 500-1600 above sea level.
- It needs 20-27^{0}c temperature and 1150mm rainfall
- Lowland bamboo species even can grow on poor volcanic soils where the rainfall is only 600mm and the temperature is above 35$^o{}_C$.
- It attains an average height and base diameter of about 6-8m and 4-8cm respectively
- It is monotypic type culms species

In Ethiopia, the economic potential of bamboo has not been explored and the role of bamboo resources is not as well recognized in national economies. However, bamboo has been used in traditional ways in the countryside a little bit for the scaffolding, construction of houses, fuel feed houses, feed fodder, beehives, hats, mats, baskets, handicrafts, small furniture, and other numerous products [29]. Bamboo has many segmented culms with variety between different culms on stiffness, strength, and fracture toughness. The culm of a bamboo plant is a lignin-cellulose natural functionally graded composite material. Fibers are densely located around the outer cortex and on the top of the culm. As a result, when we examine bamboo timber from the inner to the outer and from the bottom culm to the top, the mechanical strength of the bamboo is augmented [31,32].Figure 2.9 shown below

Figure 2.8 Bamboo plants [14]

The strength of bamboo culm has consisted of many bamboo fibers aligned longitudinally along its length. Bamboo fibers form bundles, which are components of vascular bundles dispersed within the diameter of the culm. However, aging does not affect the percentage of fibers significantly [33]. The dry density of bamboo is typically about 500-800kg/m^3, although this can vary both along the length of the culm and as noted through the thickness of the wall.

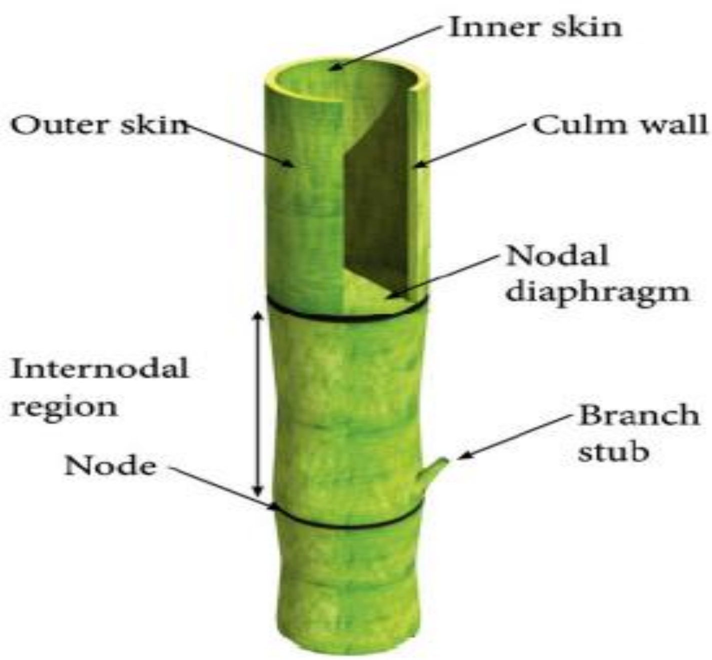


Figure 2.9 Structure of a bamboo culm [33]

2.6.6 Physical and mechanical properties of reinforcement

2.6.6.1 Properties of the bamboo plant

2.6.6.1.1 Specific gravity

It is a measure of the density of a substance in comparison with the density of water. The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on anatomical structure [8]. The outer part of the bamboo culm has higher specific gravity than the inner part. Specific gravity increases along the culm from the bottom to the top [45]

2.6.6.1.2 Moisture content

Bamboo is the tendency to absorb moisture due to the presence of constitute materials cellulose and lignin in hydrophilic behavior. Bamboo varies from the bottom to the top portion vertically and from the outer layer to the inner layers horizontally. Green bamboo may have high moisture content than the innermost layers and the peripheral layers.

2.6.6.1.3 Age of bamboo

Fiber length and fiber diameter increase with increases of the age of bamboo and the strength of bamboo increases with an increment of age. The optimum strength value occurs between 2.5 and 4 years and decreases at later ages [16].

2.6.6.4 Nature of fibers

Bamboo fibers are long and tapered at their ends. They contribute 60-70% of the weight of total culm tissue. Fiber length showed considerable variation within species. Fibers in bamboos are arranged in bundles and sheaths around the vessels. The epidermal wall consists of an outer and inner layer of which the latter is highly lignified [8].

2.6.6.5 Chemical properties

The Chemical composition of bamboo culms is cellulose, hemicellulose, and lignin with minor constituents consisting of resins, tannins, waxes, and inorganic salts. Composition varies according to species, condition of growth, age of the bamboo plant, and part of the culm. Bamboo has 60.8% cellulose and considerably about 32% of lignin [38, 29]. Bamboo fibers are often brittle compared to other natural fibers due to being covered with lignin.

Therefore, the process should be adopted to extract the bamboo fibers for reinforcement of composite materials [26, 35]. The chemical constituents of bamboo are shown in table 2.1.

Table 2.1 Composition of few commonly used natural fibers [26]

Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (Wt%)	Pectin (wt%)	Moisture (wt%)	Waxes
Sisal	66-78	10-14	10-14	10	10-22	2
Flax	71	18.6-20.6	2.3	2.2	8-12	1.7
Bamboo	60.8	0.5	32	-	-	-
Cotton	85-90	5.7	-	0-1	7.85-8.5	0.6
Hemp	70-74	17.9-20.4	3.7-5.7	0.9	6.2-12	2
Banana	63-64	19	5	-	10-12	-
Kenaf	45-47	21.5	8-13	3.5	-	-

2.6.6.7 Extraction process of bamboo fiber

The process should be taken as to extract the bamboo fibers for reinforcement of composite materials. Bamboo fibers can be extracted in different ways some of them are discussed below

2.6.6.7.1 Chemical processing

It is hydrolysis alkalization. The crushed bamboo is cooked with the help of Sodium hydroxide (NaOH) into the regenerated cellulose fiber. Hydrolysis has been done through carbon disulfide combined with multi-phase bleaching. Due to the high consumption of energy, health problems, and pollution aspects; chemical processing is not environmentally friendly, since it is preferred by many manufacturers as it is a less time-consuming process [38].

2.6.6.7.2 Mechanical processing

The extraction method has different processes such as heat steaming or a steam explosion retting, crushing, rolling in a mill, and grinding. All the above methods have been used to extract bamboo fiber for the application of fiber-reinforced composite materials in several industrial applications. The main benefit of mechanical extraction of bamboo fiber over the chemical extraction processes is not enhanced environmental faces [31]. Thereafter cutting nodes, the most inner portions and an outer thin layer of the exoderm of the highland bamboo plants have been detached, to extract fibers from bamboo culm firstly and then the hollows portions have been used for processing. The remaining parts have a slice in the longitudinal direction to the thin strips with 60-70cm in length and 2-3 mm in thickness by the slicer machine [38].

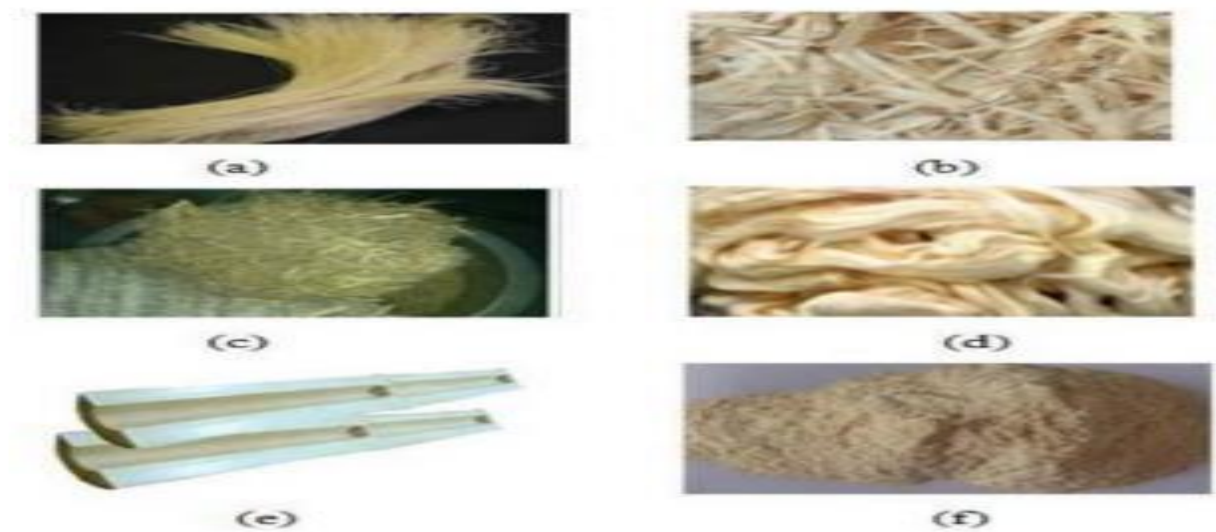
2.6.6.7.3 Manual processing

Raw bamboo was first sliced into bamboo culms with 30-32cm in length by hand tools. The bamboo culms are cleaved into the strip with length, width, and thickness of 300x5x0.75mm.

For the current work, bamboo fibers have been extracted manually since it was reported in (Murali MRK, & Mohana, 2007) that the manually extracted fibers exhibit improved fiber density properties compared to chemically extracted fibers. Therefore, in this work bamboo fiber was extracted using a manual extraction technique for the following reasons.

- No need for advanced equipment, such as roller, mechanical dryer, boiler, autoclave, etc.
- The high aspect ratio of fiber (length-to-diameter ratio)
- Low energy consumption and
- Easy control of fiber property

Bamboo fibers are different types that can be used as reinforcements in composites. However, the fibers determine the methods of composite fabrication. Bamboo can be used as reinforcement material in the composite for various forms, such as bamboo powder, bamboo strips, bamboo fibers, bamboo fabrics, or bamboo woven mat, long and short bamboo fibers have been used by the researcher in different studies mentioned below[21, 22].



A)long fibers b)flake c) short fibers d) sliver e)strip f) powder

Figure 2.10 Types of bamboo fibers for composite reinforcement [21]

The tensile test is carried out in order to determine the amount of force needed to pull out material or specimen to what extent it will stretch before rupture. The failure to exhibit identical tensile properties can be attributed to the condition under which fibers are left in the environment for retting (dew or water retting), damage caused by processing fibers by hand or machine, types of fibers (long or short fibers), adhesion between fibers in the bundles and fiber orientation [36]. The fiber length and the manufacturing method have a great influence on the tensile properties of the fibers. a longer fiber has lower tensile properties as compared to a shorter fiber [31, 17].

Applications of bamboo fiber and its composites are roof construction, car dashboard & doors, rope, making sheet, paintbrush, upholstered furniture, geo-textile, bamboo cycle, computer hardware, bamboo decorative elements, house construction [32].

The bamboo fiber has a comparable property with that of glass fiber. Moreover the mechanical properties of bamboo fiber is comparable to the mechanical properties of the best among natural fibers [37].

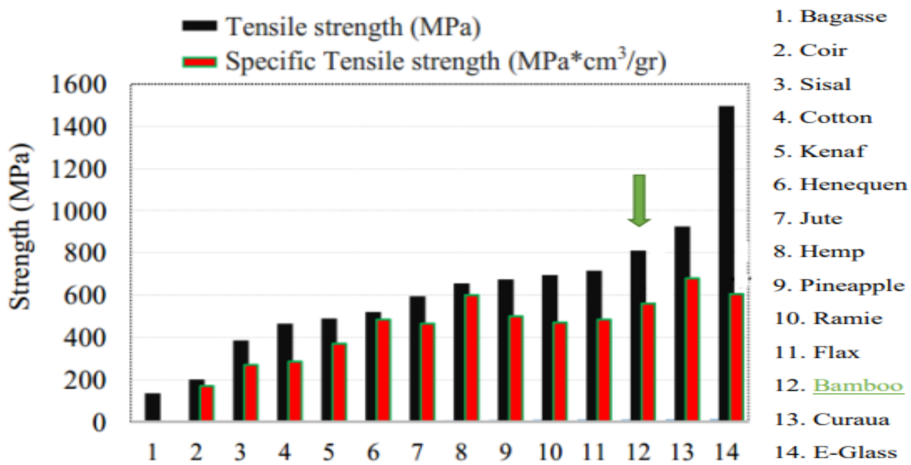


Figure 2.11 Comparisons of natural fibers strength and specific strength [37]

2.8. Summary of previous work

Researchers have been focused on natural fibers composites. as a result of, increasing demand for environmentally friendly materials & the desire to reduce the cost of traditional materials, natural fibers reinforced composites have been developed.

S.Sathish et al [10]. the research carried out Experimental Investigation on Volume loading of Mechanical and Physical Properties of bamboo and flake Fibers Reinforced Hybrid Epoxy Composites. The results depicted that the tensile, impact, flexural, and ILSS are maximum for 40:0 (flax: bamboo) hybrid composites. The void content minimum at 20:20 (flax: bamboo) composites due to tightly packed flax fiber and more compatibility towards the epoxy resin.

S.Kolli et al[11]. the studies on Mechanical properties of bamboo fabric with alumina as a filler material in the polyester composite. The mechanical properties of the composites such as tensile strength, flexural strength properties are greatly influenced by the fiber composition. From graph-1 In Tensile test composites have shown a gradual increase in tensile strength to 15% and the tensile strength has been reduced when it comes to 20%. From graph-2 in flexural test, the composite with Alumina 15% has maximum Transverse strength and 0% to 15% it has increased gradually but when it comes to the 20% the transverse strength has gradually reduced.

The result shown that tensile strength is 31.9215N/mm2 at the addition of 15% alumina and flexural strength is 144.49N/mm^2

Hussian et, al [38]. investigated mechanical properties of Tensile and Flexural strength of short bamboo fiber reinforced polyester composites filled with alumina powder. Adding three different percentages of alumina particulates 5wt%, 10wt%, and 15wt% of alumina are used keeping bamboo fiber at a fixed percentage (i.e. 45wt %). The maximum value of tensile strength is 15.601Mpa.

K.K.Alane et al[12]. Study indicated the Mechanical properties of Al/Mg/Si matrix composites reinforced with alumina and bamboo leaf ash. The mechanical Al-Mg-Si alloy matrix composites containing 0:10, 2:8, 3:7, and 4:6 wt. % bamboo leaf ash (BLA) and alumina as reinforcements have been investigated. The results show that the hardness of the hybrid composites decreases slightly with an increase in BLA content with a maximum reduction of less than 9% observed on Tensile strength reductions of 4.7, 9.32, and 14.3 % were obtained for the composites containing 2, 3, and 4 wt % BLA, respectively. On the other side, specific strengths of hybrid composites 2.24, 5.58, and 8.73 % lower were observed for the 2, 3, and 4 wt% BLA, respectively.

Vivek Kumar et,al[57]. Researched on High-Performance Moldable Bamboo Fiber Epoxy Composites. For the development of the composites, woven bamboo mats were used where the bamboo was stripped into narrow strips, about 4.25mm wide and about 0.5 mm in thickness. The composites contain between 30-40wt% fibers, although up to 60 wt. % fiber can be used. Fillers such as carbon black and fly ash can also be added to these composites. The composites exhibit tensile strengths of 140MPa, flexural strengths of 160 MPa, and notched Charpy Impact strengths of 60 kJ/m^2. These composites were molded into auto body parts (dashboard, doors, and panels) and are under test with an auto-rickshaw manufacturer.

Chandrasekhar et al[40]**.** the studies conducted on tensile, flexural, and impact tests to investigate the effect of fiber orientations in bamboo/polyester laminates. The orientations were tested at 30°, 45°, 60°, and 90°. The laminated bamboo/polyester was produced by hand lay-up technique. The investigation was concluded that the maximum flexural and impact strengths were achieved at 60°of bamboo fiber orientation and the tensile strength was maximum in 30° of bamboo fiber orientation.

Shinji Ochi et, al [17] studies the tensile properties of bamboo fiber reinforced biodegradable plastics, Steam explosion method was used to extract bamboo fibers. High strength emulsion-type biodegradable resin is used as matrix and bamboo fiber bundles as the reinforcement. The unidirectional fiber-reinforced composites were fabricated by hot pressing and bamboo fiber bundles with a fiber content of 70% showed a high tensile strength of 265Mpa

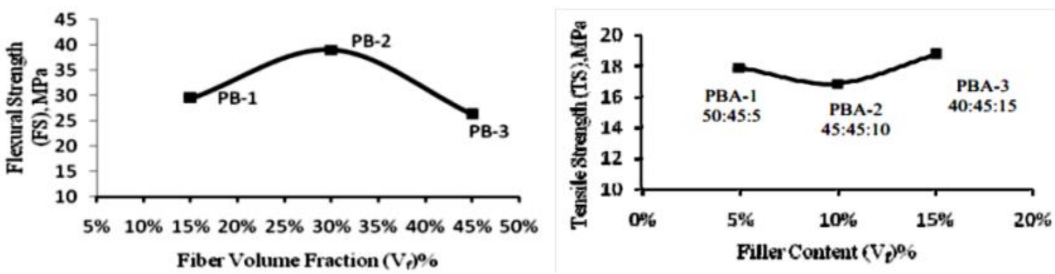
Sreenivasulu S, et.al[32].. The Studies of mechanical properties of short bamboo fiber reinforced polyester composites with alumina filler. The hand lay-up technique was employed to fabricate composites. Tensile strength of the composite material with filler increases with the increase in filler content keeping 45% of bamboo fiber constant and flexural strength of the composite material with filler increase with the increase in filler content up to 30% and keeping 45% of bamboo fiber constant. Many researchers have added synthetic fiber with natural fiber reinforced polymer composite and they found the positive result of hybridization in terms of an increase in mechanical properties of single natural fiber reinforced polymer composite.

Hemalata Jena et, al[39]. studies hybrid composite using bamboo-epoxy and cenosphere as a filler material for the preparation of the composite. The bamboo fiber is treated in alkali to improve its surface properties. The conventional compression molding technique is used to prepare different composite specimens. 20 different numbers of composites specimens are prepared with varying numbers of laminate and filler content. Increased in lamina from 3 to 7, the impact strength is increased, and increasing the lamina to 9, the strength is decreased. 7 layer composites with 1.5wt% of cenosphere have a maximum impact strength of 18.132KJ/m^2.

Honey Banga et, al [40] conducted the effect of bamboo fiber at different weight percentages 19, 29 reinforcement into the polyester. The tests are conducted on universal testing machines, Rockwell hardness testing machines, and impact testing machines. Composites fabrication was done by the compression molding machine. Result depicted that 30wt% of bamboo fiber mixed polyester give optimum mechanical properties such as tensile, flexural, and impact properties and increased water absorption of the materials.

S.A.H.Roslan et.al [8]**.** Conducts a Review based on characterization studies on several types of bamboo reinforced composites such as laminated bamboo fiber-reinforced composite, randomly oriented bamboo reinforced composite, hybrid fiber-reinforced composite, bamboo fiber reinforced bio-composite, and bamboo fiber sandwiched structure composite. It can be shown that the laminated bamboo composite in general gives higher mechanical properties compared to other structural forms of bamboo composite.

Syed Altaf Hussain et al[42]. Investigated the Mechanical properties of short bamboo fiber reinforced polyester with alumina particulate filled composites. Evaluation of mechanical properties like Tensile strength and Flexural strength of short BFRPC filled with alumina particulates. Specimens were prepared by hand lay-up technique and cut as per ASTM standards to perform the test. The experimental result indicated that the mechanical properties of the composite material were highly influenced by the fiber volume fraction. In addition to (Al_2O_3) alumina particulate at various proportions as filler material the mechanical properties i.e. tensile strength and flexural strength are distinctly improved.

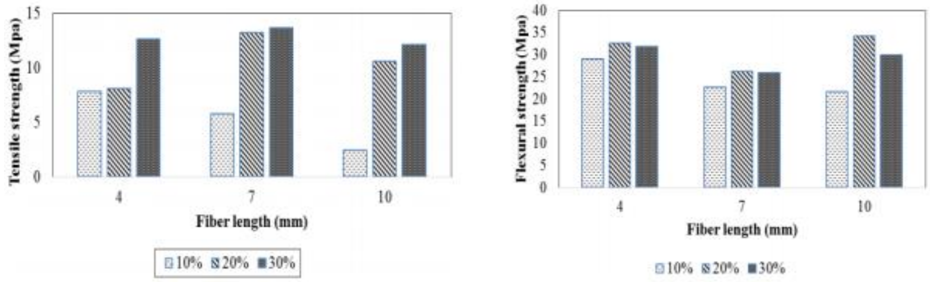


a) Flexural strength b) Tensile strength

Figure 2.12 Variation of mechanical properties with respect to the filler contents

S.Samanta et al[35]. investigated the mechanical characterization of Natural Fiber Reinforced Composites (NFRC) consisting of polyester resin reinforced with jute fiber and bamboo fiber. Fabrication of the composite specimens was used Hand lay-up manufacturing technique. The effect of fiber orientation (0 /90,15 /-75,30 /-60, and 45 /-45) was analyzed and shows that the fiber orientation of 0 /90 provides higher strength and stiffness than other fiber orientations used in this work. The natural fiber-reinforced composite can be used in place of light load application is important and the economics of natural fiber composite materials is more beneficial as compared to E-glass fiber composites.

Sub hash Kumar Gupta et, al[46]. the study on the mechanical behavior of bamboo fiber-based polymer composites. It has been investigated the mechanical behavior of short bamboo fiber-reinforced composites with different lengths and contents reinforced in epoxy for fabricating composite materials. The effect of fiber length and content on the mechanical behavior of the composite was studied under this work. The study has shown that mechanical properties of bamboo reinforced epoxy composites as tensile strength, flexural strength with varying composites.



a) Tensile strength **b) Flexural strength**

Figure 2.13 Effect of fiber parameters on the mechanical properties composite [46]

Fekadu Tarekegne et al[27]. conducted a study of Ethiopia's high land bamboo-composite for structural materials. The main objective of the study was to introduce the industrial application of bamboo to bamboo sectors of the country investigate the performance of bamboo fiber composite. The experimental analysis was carried out using a short bamboo fiber reinforced polyester composite (bamboo fiber content of 25wt%) to evaluate its mechanical properties. The fiber was extracted from a two-year-old highland bamboo, obtaining tensile strength 187.73Mpa and flexural strength is 190,32Mpa, compression strength is 114.13Mpa and young's modulus is 3852Mpa. The results depicted that the researcher's conclusion was analyzed BFREC material has attractive mechanical properties which can replace the current structural materials. The research was commissioned by Fortune Enterprise P.L.C collaborated with GTZ on a public-private partnership project (PPP). The PPP has the objective of establishing a sustainable production of high-value composite bamboo materials and promoting industrial production.

Kishore Debnath et, al[47]. conducted on the studies a study on mechanical behavior and damage assessment of short bamboo fiber-based polymer composites. Using hand layup fabrication processing techniques the result show that tensile strength 15.14Mpa, Flexural strength is 26.1Mpa, and impact strength is 1.3764J.

Srinivasan BN et,al [44]. the research shows the Development of SiC Filled Bamboo/Epoxy Composites and their Mechanical Properties Evaluation. Unfilled, 5%,10%,15% on the laminated composite fabrication on the hand layup process. The result indicates on the tensile strength is 70Mpa, Flexural strength is 128.28Mpa and compression strength is 33.23Mpa but better mechanical properties obtain in unfilled composite.

Sandhyarani Biswas et, al[49]. conduct the study of the Effect of Ceramic Fillers on Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites. Hand layup methods are used by the addition of 10% and 20% alumina the result shows that tensile strength is 159.73.flexural strength is 151.10 and impact strength is 0.331J.highest strength obtained in 10% ceramic is added on the composite.

Kannan Rassiah et, al [50] the studies shown on Mechanical properties of laminated bamboo strips from Gigantochloa Scortechinii/polyester composites. Using hand layup techniques the result showed the best tensile stress, tensile modulus, flexural modulus, and Charpy impact strength, with values of 48.767MPa, 3897.210 Mpa, 5208.650 Mpa, and 4.2 J/ $mm^{2.}$

2.9 Limitation of the studies

Major constraints while this work was done

i. Unavailability of experimental testing setup
ii. difficult to get preferable resin
iii. Financial matter

2.10 Litarature gap

However, much work has been done on a wide variety of natural fibers for polymer composites, very little has been reported on the reinforcing potential of continuous bamboo fiber in spite of its several advantages over others.

The mechanical characteristics of either fiber reinforced composites or particle filled composites have been the subject of a lot of studies. However, the notion that combining particles and fibers in a polymer could produce a synergistic effect in terms of better performance has yet to be thoroughly addressed.

Based on the above and most of the recent valuable studies are giving emphasis on mono-fiber composite, bio composite, hybrid composite, sandwich composite, and laminated composite materials but Very few studies are done in laminated fiber composite material. That has been developed with fiber laminated. Laminated fiber reinforced composite is a new opportunity to develop composite material with enhanced mechanical performance over other composites. Therefore, Developing laminated composite with the attention of locally available, cheap, and abundantly available, eco-friendly natural fibers, for this reason. Bamboo fiber and Al_2O_3 as fiber reinforcement and epoxy as matrices will be used.

CHAPTER THREE

This chapter deals with materials and methods for the preparation of composites that are used in different chemical substances, equipment, and machines for testing and characterizing composite materials.

3. Materials

The composite is composed of bamboo, alumina, and epoxy, the bamboo is called natural glass fiber because of its high strength and stiffness used for reinforcement of composite materials also have low density and light weight, alumina is used as filler materials due to its ability to resist wear and thermal condition also increase the performance of the polymer and the composite, epoxy is used to adhesion of the fiber and matrix, it is transfer load from matrix to fiber. Then the bamboo composite material is used for different structures that are better than conventional materials.

The composite manufacturing by using hand lay-up techniques, sample preparation, and testing procedure elaborated here. Bamboo strip fiber is extracted from bamboo culm obtained in the south region in Gurage, epoxy, and hardener purchased from world fiber glass and water proofing engineering Company Addis Ababa, shola, Ethiopia.

Table 3.1 Composite materials

No	Items	quantity	unit
1	Bamboo strip woven	18	roll
2	Alumina particulate	1000	gm.
3	Epoxy	5	kg
4	Hardener	0.5	Lit
5	Wax(mold releaser)	1	kg

Table 3.2 Tools utilized

No	Items	Quantity	unit
1	Mild steel Mold	2(320x260x50)	mm
2	Roller	1	kg
3	Mixing graduate beaker	9(150&1000)	ml
4	Steel rule and mater scale	2	cm
5	Test machine	5	-
6	Weight measuring machine	1	gm.
7	Cutter/band saw machine	1	-
8	Oven dry machine	1	^{o}c
9	Alen key	1	-
10	Vernier caliper	1	mm
11	Squeezing	1	kg
12	Brush	2	-
13	Hand gloves	10	-

3.1 Methodology

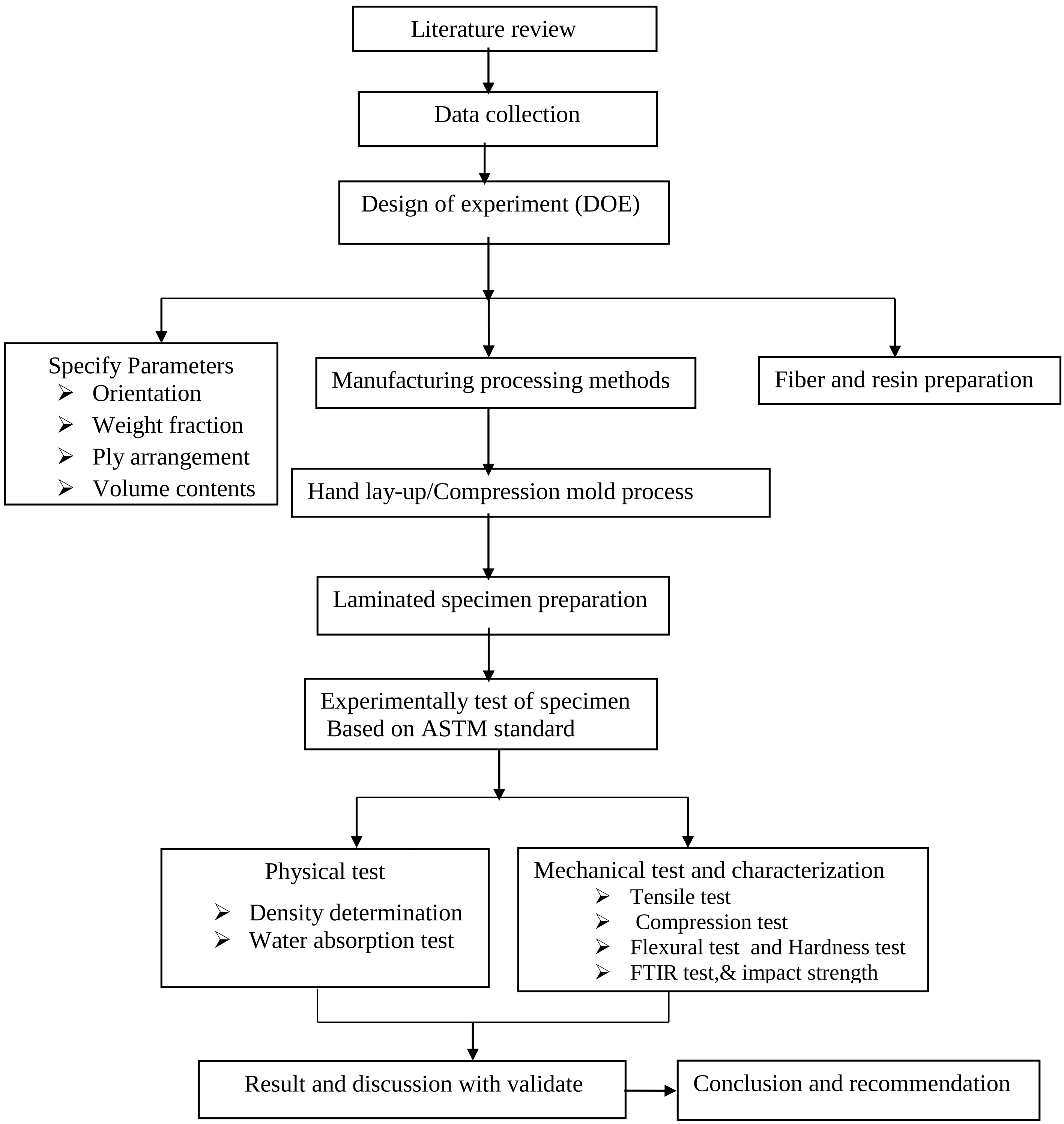


Figure 3.1 Schematic flow diagram of Research design

1.2 Experimental Design

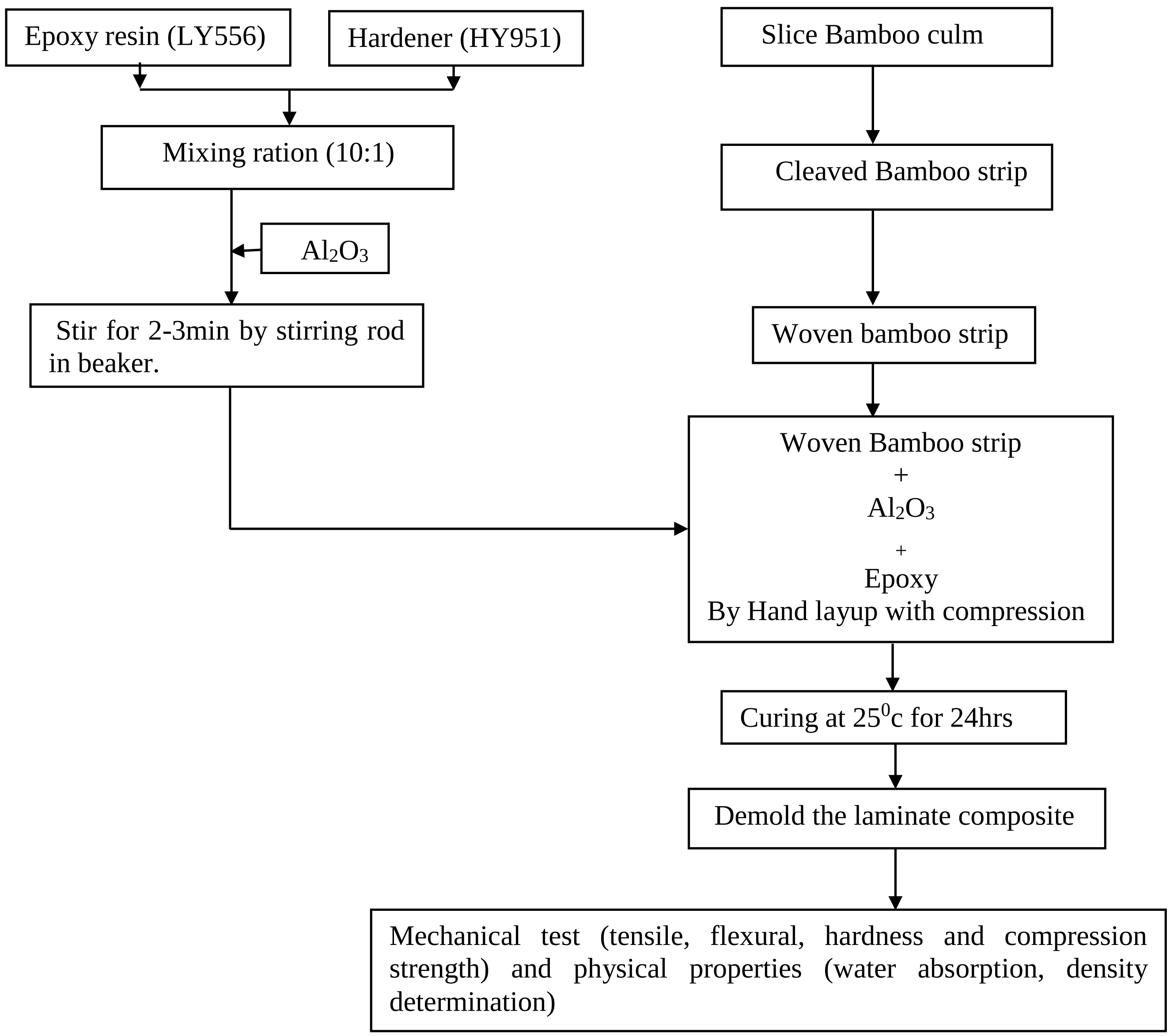


Figure 3.2 Flow chart of fabrication of Bamboo strip/Al_2O_3/Epoxy Composite

3.3 Specimen preparation procedure

step1. The mold place on the bottom should be cleaned.

step2. The mold is first polished by releasing agent (wax).

step3. Epoxy is poured in the bottom mold as base material.

step4. Woven reinforcement added in the top of epoxy resin laid by hand.

step5. Epoxy brush over the woven mat use compression roller to remove air bubbles.

Step6.the same procedure is repeated until to get the required laminated thickness.

step7. Cover the top mold on the lamina of composite specimen material.

step8. Compressed by applying a load of 15 bar pressure on the sample.

step9. Specimen curing for 24hr at room temperature until hard.

Step10. Removal from the mold then prepared as per ASTM standards.

Step11. Finally the specimen used for each mechanical test.

3.4 Bamboo fiber reinforcement composite preparation

3.4.1 Bamboo Strip Preparation

The highland bamboo (Yeshinia alpines) was collected from a local source, this bamboo species are very large on average length about 12-20m, its diameter 8-20cm and the thickness is 4mm respectively. Increasing the age also increases the strength but the size and shape of bamboo are different based on age. This bamboo has many culms throughout the entire length. The bamboo culm is cut by knife on the node and split each strip on the required length, width, and thickness from its internodes. The selection of this type of bamboo is superior strength, availability, and lightweight. The strip is used as a bidirectional woven mate.

a) Slice Bamboo culm

b) cleaved bamboo strip

Figure 3.3 Bamboo strip preparation

3.5 Fiber orientation

Fibers are arranged in preferred or randomly during the preparation of the composite materials for the development and advancement of composite fiber-reinforced on manufacturing materials. The fiber is aligned on unidirectional and bidirectional oriented by different angles. For now bidirectional two plain-woven in $0/90^0$ and $\pm 45^0$ on the same mold shown in the figure below 3.4.

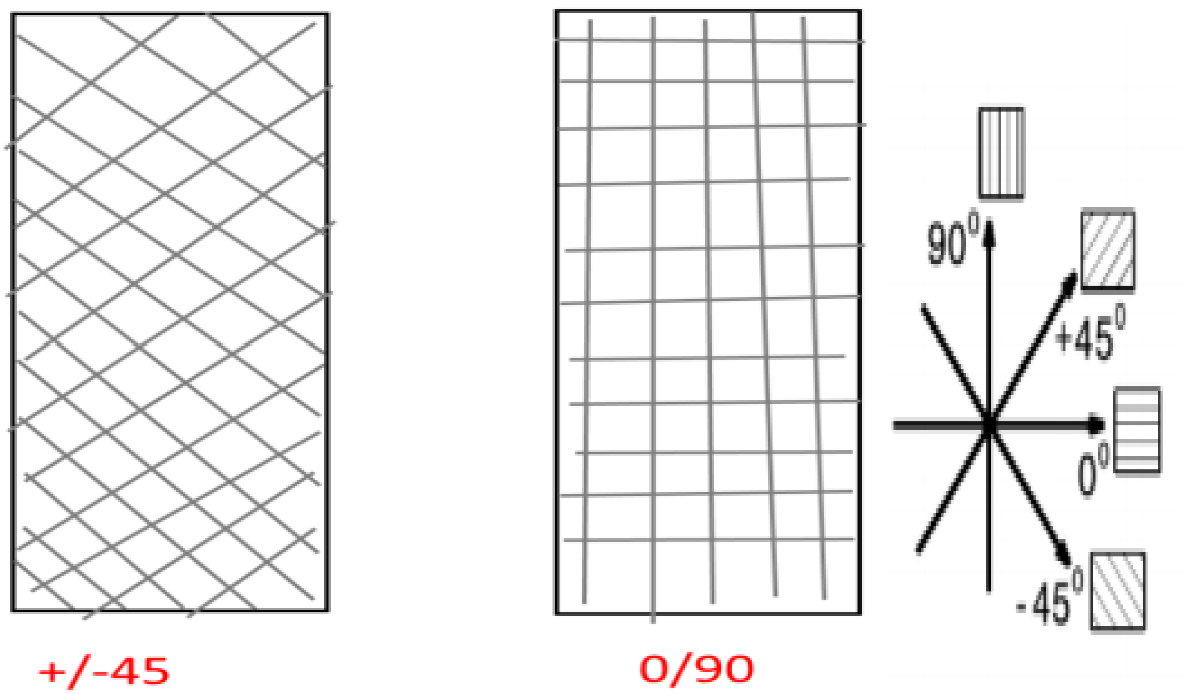


Figure 3.4 Orientation of woven bamboo composites

3.6 Fiber and matrix volume content of the composite

In the design, fabrication, and analysis of composite materials, the first and critical work is the determination of constitute percentages such as fiber and matrix (resin) fraction presence in laminate ply Composite. To determine the content of the fiber and the polymer matrix. It is decided to have two basic different approaches. The first one was done by its weight ratio and the second by its volume ratio and the density of composite can be obtained by the rule of mixture methods.

The components are microstructural elements of the composite laminate in which the composite's strength and properties are determined and limited by these values. Fiber and Matrix Contents Measured and Calculated Results are summarized in Table 3.3 In generals, the result obtained from the equations shown below are necessary.

- Composite laminate preparation
- To use ASTM standards. To determine the size of laminates that meets the ASTM requirements before laminate fabrication, these values are very useful.
- The improvement of fabricated laminate for the future by varying these values.
- The values were obtained from a design manual in collaboration with composite laminate mechanics.

To decide this, we have to evaluate the following:

Volume of the composite= lxwxt=3200x260x5mm^3=416,000mm^3=416cm^3

Mass of composite=volume of composite x density of composite

i. Fiber and matrix weight fraction (W_f ,Wm,Wp)

$$\text{Fiber weight fraction} = \frac{\text{weight of fiber}}{\text{Total weight}}$$

$$\text{Matrix weight fraction} = \frac{\text{weight of matrix}}{\text{Total weight}}$$

$$Wf = \frac{Wf}{Wf+Wp+Wp} \qquad 3.1$$

$$Wc = Wf+Wm+Wp \qquad 3.2$$

$$Wm = Wf+Wm+Wp \qquad 3.3$$

$$Wf+Wm+WP = 1 \qquad 3.4$$

ii. Fiber and matrix volume fraction (Vf,Vm,V_p)

$$V_f = \frac{W_f}{\rho f} \quad Vm = \frac{Wm}{\rho m} \qquad 3.5$$

$$Vc = Vf+Vm+Vp \qquad 3.6$$

iii. $$\text{Fiber volume fraction} = \frac{\text{volume fiber}}{\text{Total volume}}$$

$$vf = \frac{vf}{vf+vm+vp} = \frac{vf}{vc} \qquad 3.7$$

Iv. Matrix volume fraction= $\frac{\text{volume of matrix}}{\text{Volume total}}$

$$Vf = \frac{vf}{vf + vm + vp} = \frac{vf}{vc} \qquad 3.8$$

$$Vc = Vf + Vm + Vp \qquad 3.9$$

$$Vf = \frac{Wf\ x\ pf}{Wfxpm + Wmpf} \qquad 3.10$$

$$Vf + Vm + Vp = 1 \qquad 3.11$$

$$vm = \frac{wmx\rho f}{wfx\rho m + wm\rho f} \qquad 3.12$$

v. Mass of ply density (ρ)

$$\rho c = \frac{\text{total weight}}{\text{Total volume}}$$

$$\rho c = \frac{\text{weight of fiber}}{\text{Total volume}}$$

$$\rho c = \frac{\text{weight matrix}}{\text{Total volume}}$$

$$\rho c = \frac{1}{\frac{wf}{\rho f} + \frac{wm}{\rho m} + \frac{wp}{\rho p}} \qquad 3.13$$

vi. Ply thickness, t

The thickness of layer simply the number of grams of mass of fiber per unit area

$$\text{Total volume} = A\ x\ t$$

$$t = \frac{\text{total volume}}{\text{Area}}$$

$$t = \frac{wf}{vfx\rho f} \qquad 3.14$$

$$t = wf\left(\frac{1}{\rho m} + \frac{1}{\frac{\rho m(1-wf)}{wf}}\right) \qquad 3.15$$

Where:

wf: weight of Fiber (g)

Wm: weight of Matrix (g)

w_c: weight of composite (g)

ρf: Density of Fiber (g/cc)

ρm: Density of Matrix (g/cc)

t : Ply thickness (mm)

wf : Fiber weight fraction

wm : matrix weight fraction

vf : Volume of fibers, (cm3)

vm : Volume of matrix, (cm3)

vc : Volume of Composite (cm3)

vf : Fibers Volume fraction

Vm : Matrix Volume fraction

Wp : weight of particulate

Table 3.3 Details of Fiber and Matrix Contents of Composite

Primary data		**Calculated Results**	
Parameters	**Value**	**Parameters**	**Value**
Bamboo fiber weight	122.8g	Bamboo fiber volume	104cc
Alumina particulate weight	82.4g	Alumina particulate volume	20.8cc
Bamboo fiber density	1.181g/cc	Total fiber volume	125.2cc
Composite weight	528.2g	Matrix volume	291.2cc
Matrix weight	323.23g	Total fiber weight	205g
Matrix density	1.110g/cc	Alumina weight ration	15.5%
Total composite volume	416cc	Matrix weight ration	61.2%
Composite Density	1.26g/cc	Total fiber volume ratio	38.8%
fiber weight ration	23.2%	Total matrix volume ration	70%
Alumina density	3.95g/cc	Total fiber weight ration	30.1%
Epoxy Weight	293.8g	Alumina volume fraction	5%
Hardener weight	29.4g	Bamboo ply thickness	0.15cc

3.7 Preparation of Resin

3.7.1 Hardener (catalyst)

Is used for cured the epoxy resin which causes a chemical reaction to take place without changing its composition. The catalyst initiates the chemical reaction of the epoxy and monomer ingredient from liquid to a solid-state. Hardener can be either a reactant or a catalyst in the chemical reaction that occurs during the mixing process. Without hardener in the epoxy cannot perform mechanical and chemical composition for the intended purpose.

3.7.2 Epoxy resin

Epoxy is a thermosetting polymer chemical substance used for various purposes on composite materials such as transfer of load, excellent adhesion for reinforcement, and ignoring shrinkage.

Table 3.4 Mechanical and physical properties of epoxy.

Tensile strength	68.5	Mpa
Tensile modulus	4.3	Gpa
Viscosity at room T^0	10000-1200	Mpa
Density	1.15-1.20	g/cm^3
Flash point	200	^0c
Storage temperature	2-40	^0c

The resin purchasing from world glass Fiber Company in Addis Ababa, shola sub-city, Ethiopia Resin of which mixing of epoxy (Hy556) and hardener (Hy951) in the ratio100:10 by weight to prepare the composite. When mixing epoxy and hardener in the graduated beaker. The material is not affected by the exothermic reaction. Using the string stick and stir the mixture 2-3minutes for uniform mixing.

a) Hardener(Hy951) b) Epoxy(Ly556) c) mixing resin

Figure 3.5 Epoxy and hardener resin mixed

3.8 Alumina particulate

Aluminum oxide (Al_2O_3) referred to as Alumina is inorganic material used as filler in various polymer matrices for improving the polymer strength. Alumina can exist in several crystalline phases the most stable hexagonal alpha phase at elevated temperatures. This phase has particular interest for structural applications. Alumina is a widely used material in the family of engineering ceramics because of hard, wear-resistant, has excellent dielectric properties, is resistant to strong acid and alkali attack at elevated temperatures, has high strength and stiffness, and is cost-effective.

Figure 3.6 Alumina filler of composite

The outer and middle bamboo layers were sliced into the strip and put in the dry oven (Memmert basic universal oven-UFB 400-500) was used at room temperature for 24hr to dry the bamboo strip fiber before the woven fabric has done.

a) extracted strip b) strip dry in the oven

Figure 3.7 Bamboo strips extraction

a)Bamboo strips b) bamboo weave plain mat c) Measuring the weight of plain-woven reinforcement

Figure 3.8 a) bamboo strip and b) bamboo weaved mat c) Measuring the weight of plain-woven reinforcement

3.9 Mold releaser

Wax releaser is used for coating the mold to prevent the epoxy didn't stick with the mold during laminates. Although, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this work is paste wax. The releaser is brushed on the mold in each laminate are prepared.

Figure 3.9 Wax releaser

3.10 Combination of composite materials

Bamboo reinforced epoxy composite consist of different weight loading and orientation of materials shown in the table below.

Table 3.5 Composition of materials for laminated composite sample preparation

S.no	Orientation fiber	Bamboo strip (wt %)	Filler (wt %)	Epoxy resin (wt %)	Ration of samples	No of laminated layer, composite
BC_1	$[0/90]^0$	25	5	70	25:5:70	3
		20	10	70	20:10:70	3
		15	15	70	15:15:70	3
BC_2	$[\pm45]^0$	25	5	70	25:5:70	3
		20	10	70	20:10:70	3
		15	15	70	15:15:70	3

3.4 Composite laminate design

The properties of laminated composite generally depend on

- The manufacturing process/method of laminate composite
- The content of fiber and polymer matrix of the composite
- Arrangement of the fiber reinforcement of composite

3.4.1 Laminated Composite Manufacturing Methods

The former manufacturing method for fiber-reinforced composite structural parts used a hand lay-up technique. Although hand layup is a reliable manufacturing process, it is very slow and labor-intensive in nature. In recent years, particularly due to the interest that emerged in the automotive industry, the development of manufacturing processes that can support mass production rates is Compression molding, pultrusion, and filament winding. For this thesis, the manufacturing method will be the hand lay-up method.

3.4.1.1 Hand lay-up

is an open compression molding process suitable for making a wide variety of composites products from very small to very large. The proper amount of epoxy resin mixture and layers of preferred bamboo fibers, such that starting and ending with layers of resin. The quantity of accelerator and catalyst added to resin at room temperature for curing was 10% by volume of resin each.

Fiber deformation and movement should be minimized to yield good quality preferred fiber composites. Therefore, at the time of curing a compression pressure of 15kg was applied on the mold, and the air gaps formed between the fibers during the processing were gently squeezed out by hydraulic press to force the air to exist in between the fibers and resin and kept an hour to get perfect samples then pressed hard and the excess resin is removed and dried. [44]

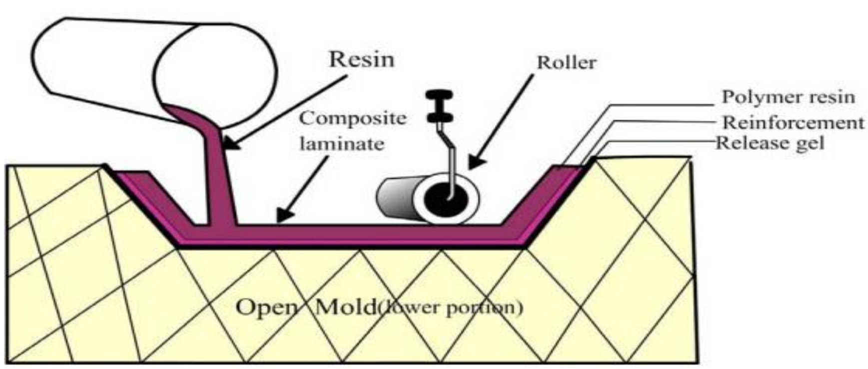


Figure 3.10 Hand lay-up techniques [44]

The principal merit of the open contact molding method:

- Highly used for several years
- The principle is easy
- Low-cost equipment, cure the resins at room temperature
- Widely obtain materials type
- Fiber contents and long fibers usage are higher than that of spray lay-up.
- Open mold processes are an effective method of manufacturing composites such as spray-up (chopping) and hand lay-up used to produce boats, RV components, truck cabs and fenders, spas, tubs, showers, and other fiberglass composite products.
- Composite materials are an essential technique for prototype and short production runs.

3.4.2 Hydraulic press

In the compression molding process, the whole assembly is placed in a press that can apply pressure, this hydraulic press can have the capacity of 50tone but now pressed about 15bar pressure for curing or adhering the bond of the lamina on the laminate bamboo composite stays for about 24 hrs. For the strong bonding between the matrix and reinforcement also lamina to lamina sticking.

Figure 3.11 Hydrualic press

3.4.3 Fabrication process of developed composite materials

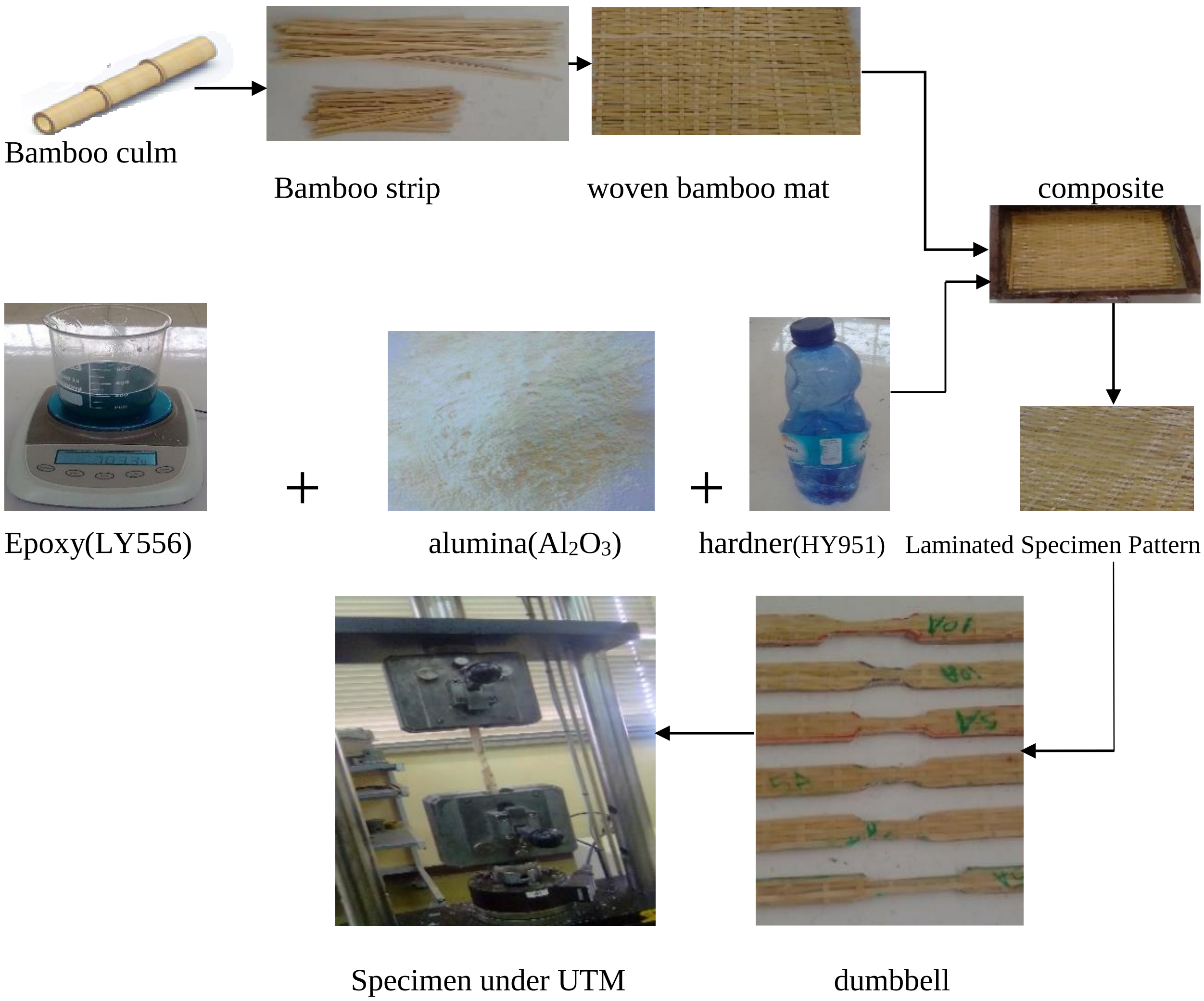


Figure 3.12 Fabrication process of composite

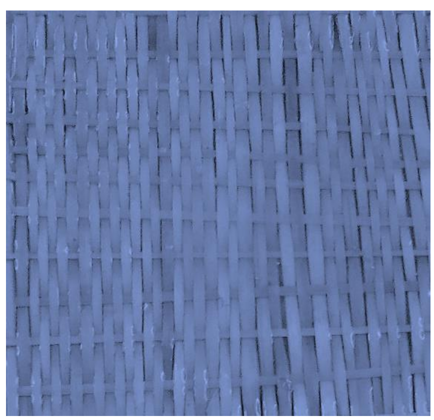
The Raw highland bamboo was first sliced into bamboo culms with 300-320mm in length by hand tools. The bamboo culms are cleaved into the strip with the length, width, and thickness is $300x5x0.75mm^3$ on its internodes. The strip woven is used as reinforcement in the specimen fabric and epoxy is serve as adhesion of the reinforced mat and 5wt%, 10wt% &15wt% Al_2O_3 particulate used to give reinforced agent with the ratio (10:1) to the epoxy and the composite, the hardener is provide curing hence laminated the composite and demold the pattern from the mold then prepared ASTM procedure for different test.

3.4.4 Mold of new composite

The mold is made of mild steel and it is rectangular in shape the dimension is 320x260x50mm the mold consist of the flat base plate, four rectangular frames and connected by eight bolt and it contains a cover frame as shown in Figure 3.13 The base plate is the very thick plate which is placed the bottom. The functions of the cover plate are to compress the pattern and to avoid the debris from entering into the composite parts during curing.



a) Mild steel mold b) cover fram of mold c) roller


d) Laminated composite sample in mold e) Laminated bamboo epoxy composite mat f) ASTM, the standard of tensile specimen

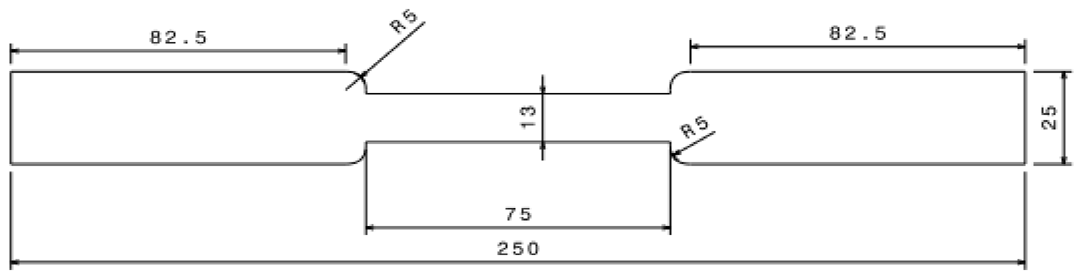
Figure 3.13 a)mild steel mold b) laminated bamboo composite plate

3.4,5 Band saw cutter machine

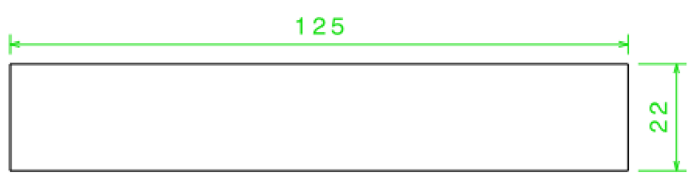
The band saw a cutter is a machine that was used to cut each laminated based on ASTM standards for various experimental tests. the cutter has a speed of 915m/minute. The specimen for this research test required a total of 30 mats from each sample plate has three replicas of bamboo composite.

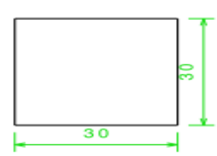
3.4.6 Dimension of the sample

The dimension was prepared according to the American Society of Testing Materials (ASTM) standards for the specimens of bamboo fiber reinforced epoxy composite test and each value is shown in figure 3.14 below.

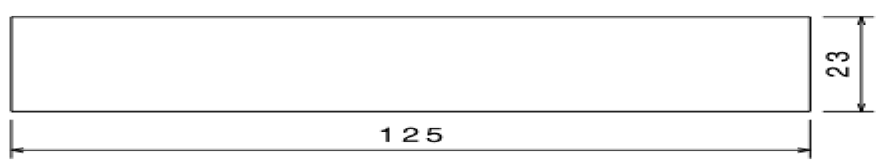


a) Tensile specimens





b) Flexural specimen c) hardness sample



d) Compression specimen

Figure 3.14 Dimension of each specimen

Table 3.6 Experimental setup

No	Types of tests	Name of machines	ATSM standard	Shape of specimen	Size of specimen	Gage Length of machine	Speed
1	Tensile strength	UTM-50KN	ASTM3039	Dumbbell or dog bone	250x25x 5mm	170mm	2mm/ min
2	Flexural strength	UTM-50KN	ASTM790	Rectangular	125x22x 5mm	170mm	2mm/ min
3	Compression strength	UTM-50KN	ASTM3410	Rectangular	125x23x 5mm	170mm	2mm/ min
4	Hardness strength	Up to 120kgf	Macro, Vickers hardness	Rectangular	30x30x5 mm	_	≤50μ m/sec
5	Impact strength	impact test 5J	ASTMD-6110	Un notched	80x10x4 mm	__	2.9m/s
6	Density determination	Water immersion method	Archimedes principle	Rectangular	35x35x5 mm	_	__
7	Water absorption	Water immersion method	ASTM-D570	Rectangular	35x35x5 mm	_	_

3.4.7 Experimental apparatus

The composites were characterized on tensile properties using tensile test machine ASTM D3039, compression properties ASTM D3410 and flexural strength using ASTM D790-2010, and hardness test was done on Vickers test machine but Tension test, compression test, and bending tests were conducted on the universal testing machine with a capacity of 50 KN, the rate of crosshead was 2 mm/min. For each composite specimen, the thickness was the same for all. The tests were conducted at room temperature. At least three replicate for each specimen were tested and the average result of each tested specimen is reported.

3.4.7.1 Tensile test specimen

The specimen prepared for the tensile test is the dog-bone specimen and straight side specimen, Tensile Test Specimen According to ASTM D3039, the specimen is cut into the required dimension 250×25×5mm with the appropriate size. The geometry of the test specimen of the bamboo composite prepared is shown in figure 3.15 below.

Figure 3.15 Tensile test sample

The samples were loaded along the axial direction. The stress-strain diagram was obtained from integrated UTM. Mostly the stress-strain curves obtained were not used to determine the true ultimate tensile strength of the composite since failure occurred inside and outside the gauge section in the tab region. Six samples were taken in each case triple replication was used and the average values were reported.


Figure 3.16 Specimen under tensile testing

Max. Tensile stress is calculated using the equation 3.1

$$Stress = \frac{max.load}{Original\ area}$$

$$\delta_f = \frac{p}{A_0} \qquad 3.16$$

Where

δ_f = Ultimate tensile stress, Mpa

P = Peak load, N

A_0 = Original cross-sectional area, mm^2

3.4.7.2 Flexural strength test

Flexural strength is measured resistance of materials deformation under load during bending. The flexibility of the material before undergoing permanent deformation is measured as the flexural modulus of the material. Using the three-point bend test 50kN capacity UTM was used for testing with a span-to-depth (L/d) ratio of 16:1 and support span length 125mm, rate of crosshead motion 0.5mm/min. the test is conducted as per ASTM-D790 standard. The dimension of the specimen is cut into (125x22x5) mm. The flexural strength is expressed as modulus of rupture in (Mpa) as shown the figure 3.17 below.

Figure 3.0.17 Specimen under flexural testing

a) Specimen b) bending specimen

Figure 3.18 Flexural Specimen

The maximum stress in the outer fibers occurs at mid-span and this stress is calculated using the equation3.2.

$$\delta_f = \frac{3PL}{2bt^2} \qquad 3.17$$

Where

σ_f = Stress in the outer fiber at the mid-span, Mpa

P = Load at the given point on the load-deflection curve, N

L = Span length, mm

b = Width of beam tested, mm

t = Depth of beam tested, mm

The tangent modulus of elasticity is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated using equation 3.3

$$E_B = \frac{L^3M}{4bd^3} \qquad 3.18$$

Where

E_B = Modulus of elasticity in bending, Mpa,

L = Span length, mm.

b = Width of the beam tested, mm.

d = Depth of beam tested, mm.

m = Slope of the tangent to the initial straight-line portion of the load-deflection curve N/m

3.4.7.3 Compression strength test

The bamboo composite specimen to axial compression loading using the UTM The dimension of the specimen is (125x23x5) mm the samples were then placed between the compressions anvils to commence compression testing during the test, the maximum load attained was recorded by the UTM testing system after the specimen failed.

Figure 3.19 Compression sample specimen

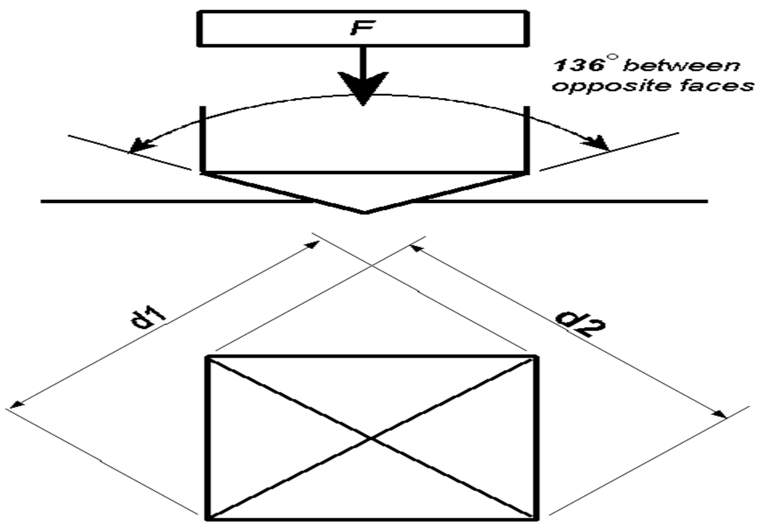
Figure 3.20 specimen under compression set up

3.4.7.4 Hardness test on composite

Hardness is the measure of resistance of a material to plastic deformation. It is determined using indentation hardness tests, which are classified into two types: micro indentation and macro indentation testing. Micro indentation tests use forces of less than 2N, whereas macro indentation uses a greater test load, such as 1kgf or more. The Vickers hardness test (VHT), which has one of the most extensive scales, the Rockwell hardness test (HR), the Brinell hardness test (BHT), and others are among the macro indentation tests available.

The Vickers hardness test involves indenting the test material with a diamond indenter in the shape of a right pyramid with a square base and a 136-degree angle between opposed faces under a weight of 1 to 100 kgf. The square pyramid diamond indenter creates a 136^0 degree angle between the opposite face at the vertex and the opposite face at the base. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average value calculated.

Figure 3.21 Vickers hardness test set up



$$H_V = \frac{\text{Constant x test force}}{\text{Surface indentation}^2}$$

$$HV = \frac{0.102X2f(\sin 136/2)}{d^2} \qquad 3.19$$

Where

HV is Vickers hardness test

F is applied force for indentation (N)

d^2 is the area of indentation (mm^2)

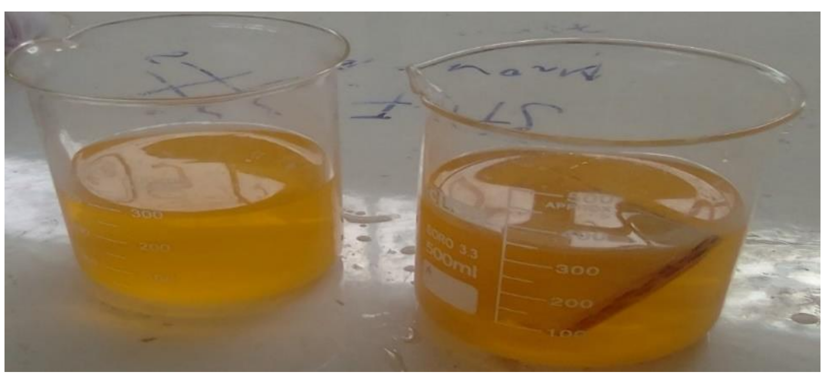
$d^2 = \frac{d1+d2}{2}$, d1 and d2 value of diagonals length 1&2

The hardness of polymer composite is influenced by the critical parameter on the durability and lifespan of the material [48]. Vickers hardness tester used to test the hardness of developed composite materials by indention using diamond indenter tool and conduct the hardness of the materials. Size of specimens Length (L) =30mm, width (w) =30mm, thickness (t) 5mm.

Figure 3.22 Hardness test specimen

3.4.7.5 Density determination of highland bamboo fiber

The density of an object can determine the degree of compactness of a substance. Natural fiber reinforcement has the advantage of lower density and lightweight on the composite materials compared to other reinforcement phases. For this work density measured can be conducted according to Archimedes' principle. Archimedes' principle can be shown the experimental procedures and determine mass and density using a buoyant object. This is demonstrated by simple experiments using graduated beakers [47]. The composite material density was measured based on the density of the water and the volume of the water as follows.



a) Before the object immersed b) After the object immersed

Figure 3.23 Density of the object measured initial and final volume

Where

f is the Density of the fiber

Mf is the mass of the fiber

Vi is the initial volume of the water before immersion

Vf is the final volume of the water the object is immersed

The Archimedes principle used the weight in air and the weight in fluid the dimensionless density can be found.

Where

$$\rho f a = \frac{Mf}{V_T} \quad 3.20$$

$$\rho f L = \frac{Mf}{Vf-Vi} \quad 3.21$$

$$\rho f = \frac{Wa}{Wa-W_L} \quad 3.22$$

Where

$\rho f a$ Is the density of fiber air, WA is the weight of the fiber in air

W_{FL} is the weight of fiber in liquid

3.4.7.6 Impact test

Impact Test is a very important event in governing the life of a structure. Impact tests are used to measure the toughness of the material. Toughness refers to a material's ability to absorb energy during plastic deformation. Brittle materials have low toughness because they can only withstand a minimal degree of plastic deformation that they can endure. The impact value of a material can also change with temperature. Generally, at lower temperatures, the impact energy of a material is decreased. The size of the specimen may also affect the value of the impact test because it may allow a different number of imperfections in the material, which can act as stress risers and lower the impact energy and velocity of the pendulum [50].

The impact resistance test was carried out at 150° clockwise for specimen position using the "Pendulum Charpy Tester Model, Eurotech ET-2206" with a 5J impact force hammer. The operating conditions were 25°C, at an impact velocity of 2.9 m/s for woven bamboo laminate composites. The specimen 80mm×10mm by thickness, which had been composed of both bamboo fiber, alumina, and epoxy compositions, were prepared, respectively.

The test was conducted in accordance with the ASTM-D6110 procedure to determine the values of impact strength in (KJ/m).

After that, the specimen was measured by using a "digital Vernier caliper" and was placed transversally on a specimen holder. Lastly, they were broken with a swinging pendulum.

Two types of impact tests were used in this study that is Charpy and Izod impact test. Charpy impact test un notched specimens were prepared in accordance with ASTM D-6110 to measure impact strength. Figure 3.24 shows the Charpy test configuration for the specimens 80mm x 10mm x 4mm [51]

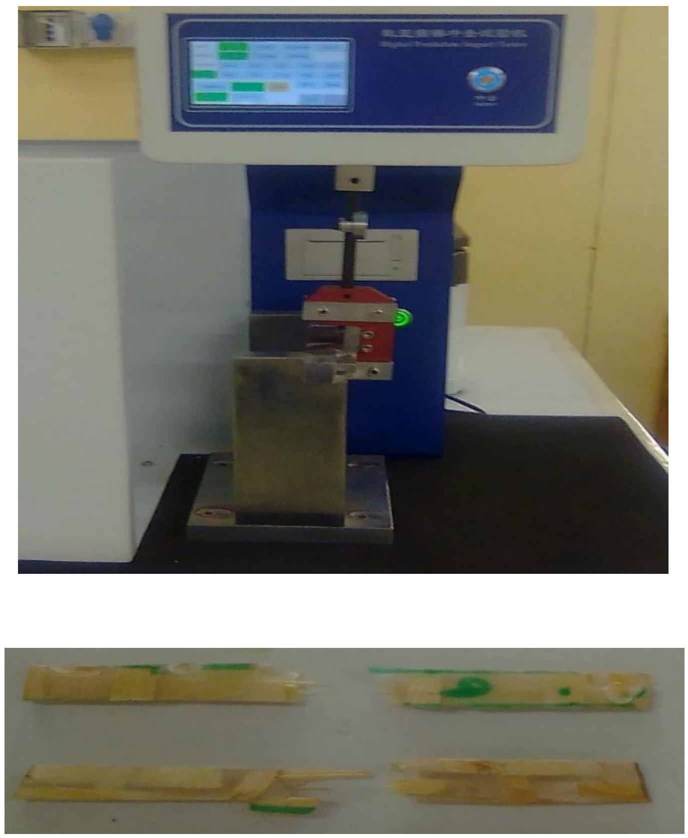


Figure 3.24 Digital Charpy impact test setup

CHAPTER FOUR

4. Result and Discussion

4.1 Tensile test result

Tensile strength interpreted on six specimen groups for different fiber/matrix and filler loading ratio 25:5:70, 20:10:70and (15:15:70) for each $\pm 45^0$ and $0/90^0$ orientation of BFREC total of 18 specimens while the typical stress-strain curve of the composite under tensile load for different bamboo polymer composite specimen is presented in figure 4.1

BREC materials under tensile load depicted stress-strain diagram linear part shown elastic behavior and the slope of the curve defines the elastic modulus. This modulus can be calculated by scant methods is referred to as the Modulus of elasticity, from which the Modulus of Elasticity of the material tested known that Young's Modulus is the ratio of stress to strain and the non-linear part after yield strength or elastic limit indicated plastic region and reach ultimate tensile stress finally rapture.

$$Modulus\ (Mpa) = \Delta Stress / \Delta Strain\ (mm/mm) \qquad 4.1$$

$$E = \frac{\delta}{\varepsilon} \qquad 4.2$$

$$\delta = \frac{p}{A} \qquad 4.3$$

$$\varepsilon = \Delta L / L_0 \qquad 4.4$$

$$\%E = \frac{L - L0}{L0} \qquad 4.5$$

Where

E= young's modulus, Mpa

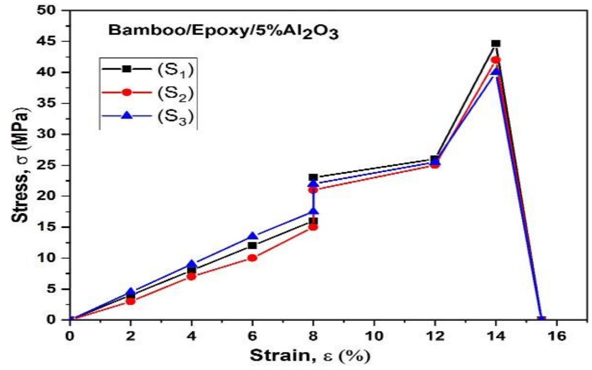
P= load of the specimen, N

A= area of the specimen, mm^2

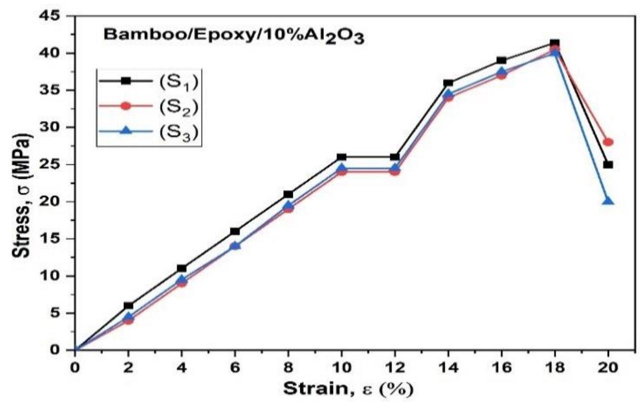
δ= stress of the specimen, N/mm^2

$L-L_{O}$= displacement of specimen, mm

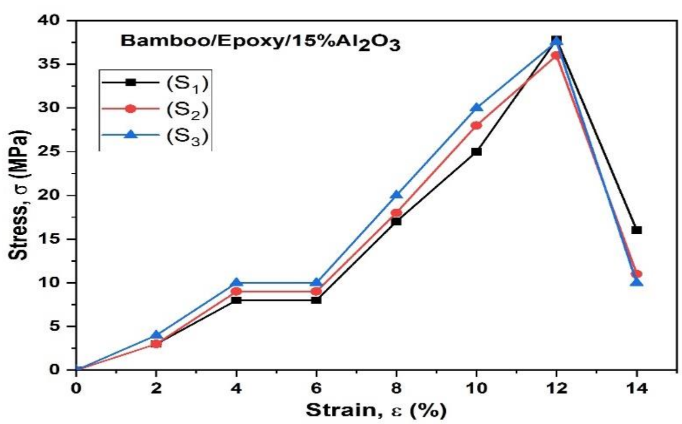
Lo= original length of specimen, mm



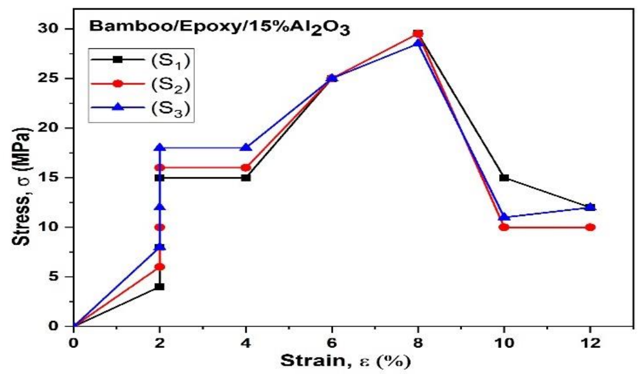
a) Tensile stress vs strain 5%Al_2O_3



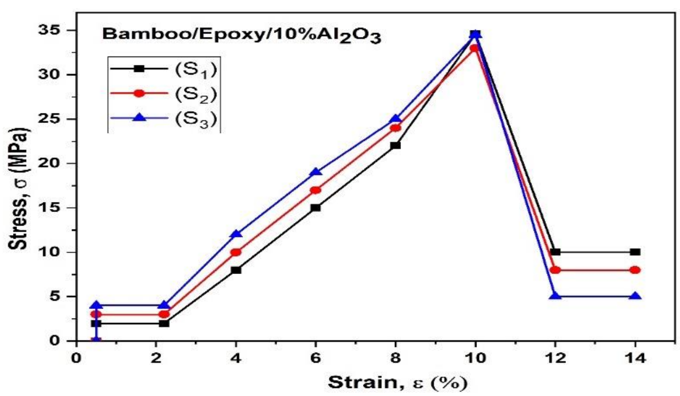
b) Tensile vs strain 10%Al_2O_3



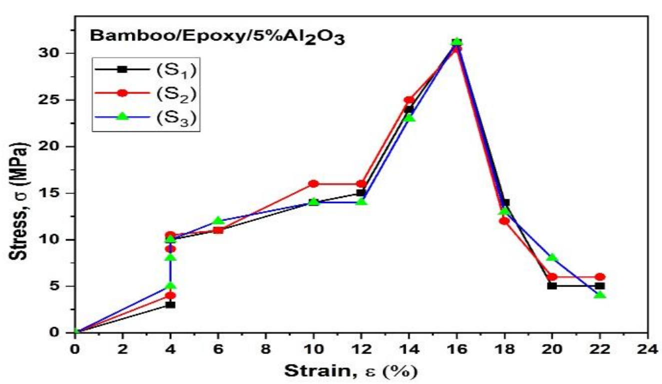
c) Tensile stress vs strain 15% aAl_2O_3



a) Tensile stress vs strain 5%Al_2O_3 in $\pm45^0$



b) Tensile stress vs strain 10%Al2O3 in $\underline{+}45^0$



c) Tensile stress vs strain 15%Al_2O_3 in $\pm45^0$

Figure 4.1 Tensile stress vs strain on $0/90^0$&+/-45^0 orientation

4.2 Flexural test

The flexural test measures the force required to bend a beam and the Flexural modulus indication of a material's stiffness during deflection on a three-point bend test on the UTM machine in accordance with ASTM standard to measure the flexural strength of the composites. The load was applied in the middle span of the specimen at a speed of 2mm/min the span length was 125mm and data were collected from the computer integrated on UTM. Figure 4.2 shown below

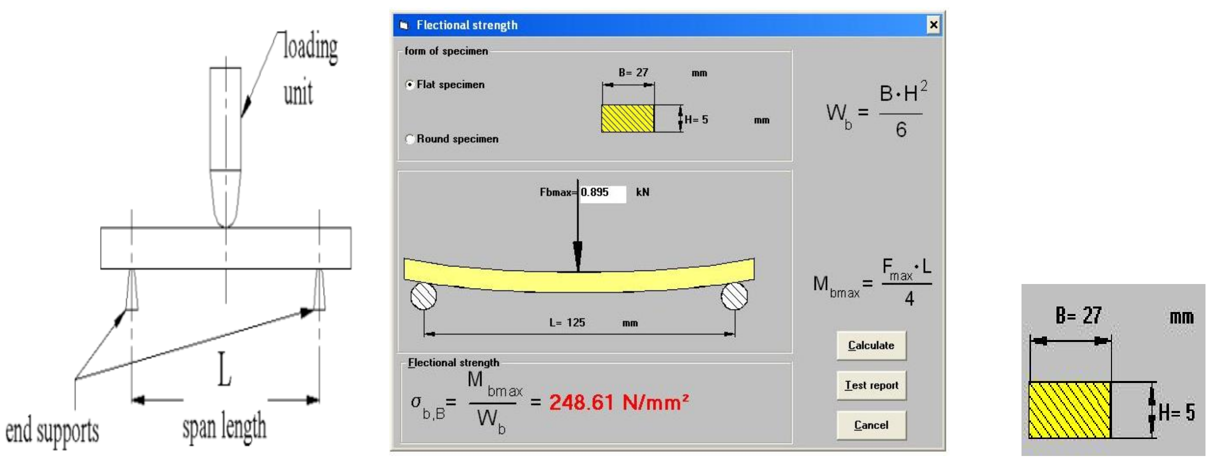
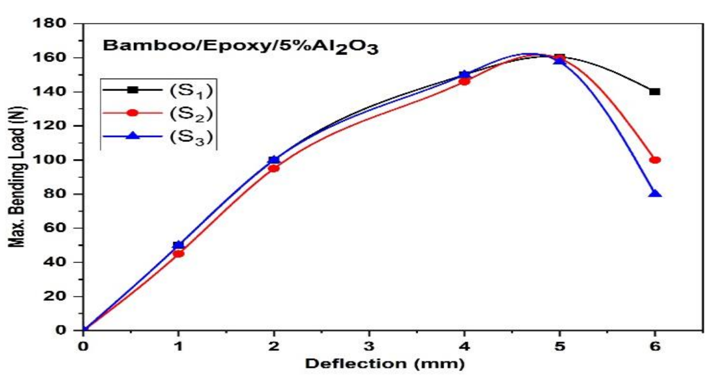
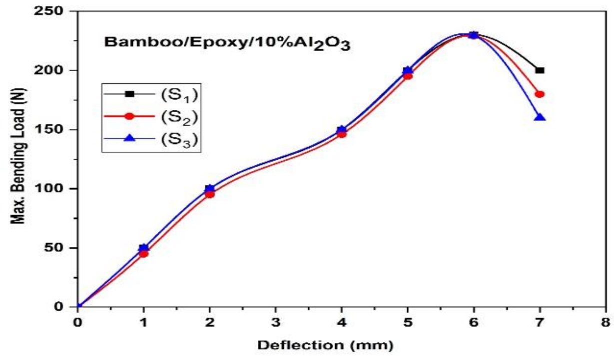


Figure 4.2 Geometry of flexural test specimen

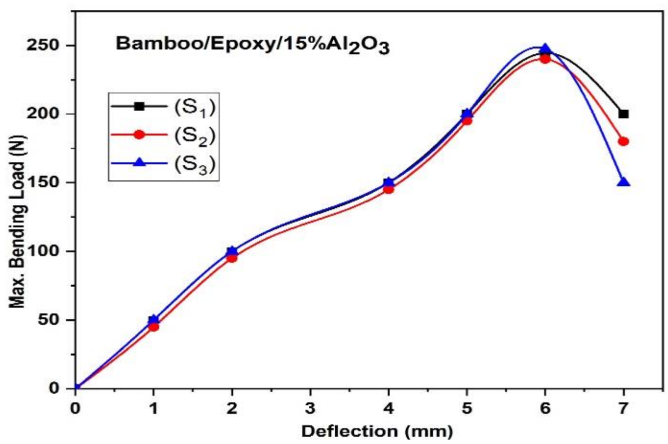
A typical force-displacement graph for different weight loads of alumina particulate in the composite specimen is observed that all curves increase linearly with respect to displacement up to the maximum force from figure 4.3 shown below.



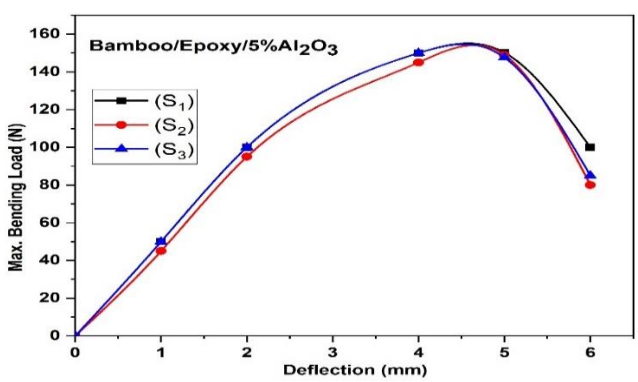
a) Transverse bending at 5wt% of Al_2O_3 on $0/90^0$



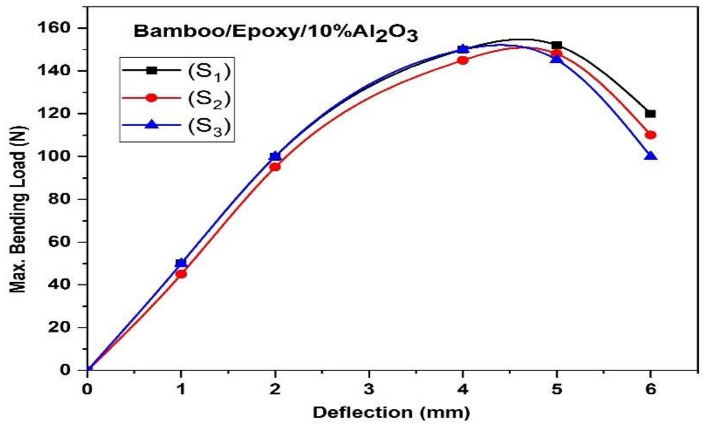
b)Transverse bending at 10wt% Al_2O_3 on $0/90^0$



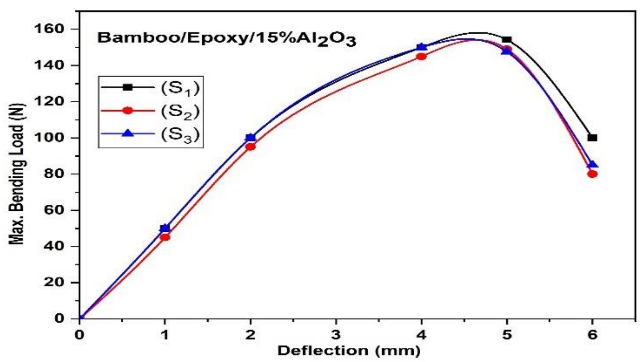
c) Transverse bending at 15wt% Al_2O_3 on $0/90^0$



d) Transverse bending at 5wt% Al_2O_3 on $\underline{+}45^0$



e) Transverse bending at 10wt% Al_2O_3 on $\underline{+}45^0$

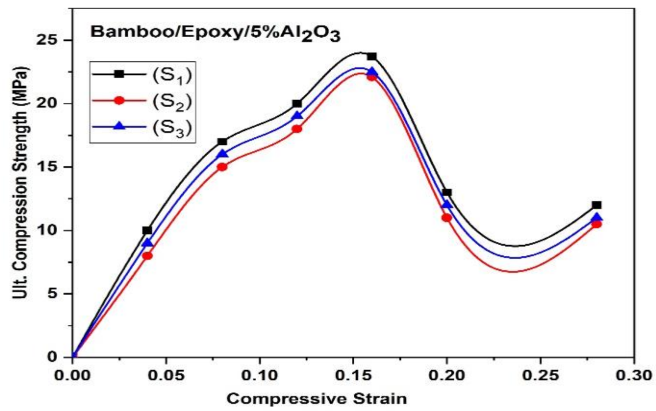


F) Transverse bending at 15wt% Al_2O_3 on $\underline{+}45^0$

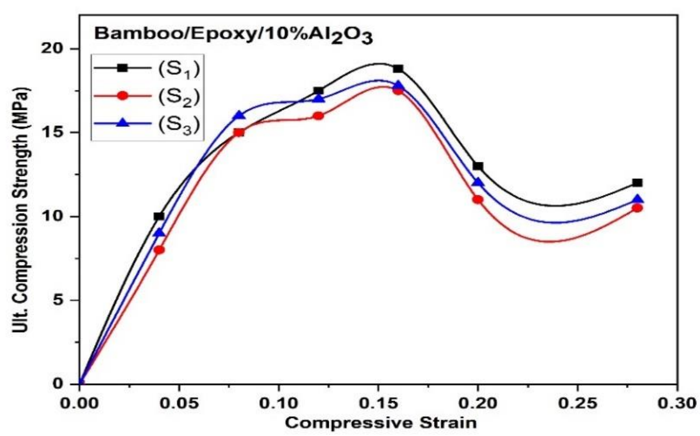
Figure 4.3 bending vs. deflection of different wt% loading

4.3 Compression test

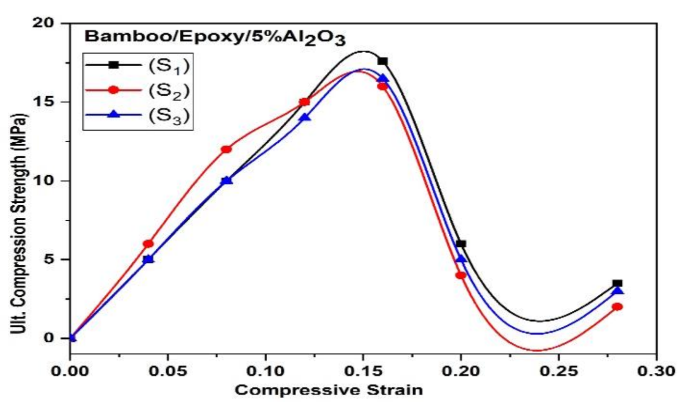
The composites under compression loading in figure 4.4 the stress-strain diagram for all curves indicate non-linear behavior. The point of deviation from linearity is the indication of failure initiation due to the development of crack between the fiber and the matrix. Young's modulus was determined from the slope of the Stress-Strain curve until the elastic limit. The interface bonding or adhesions between the fibers, filler, and the matrix is not homogeneous filler dispersion have a great effect on the mechanical properties of the particulate reinforced process.



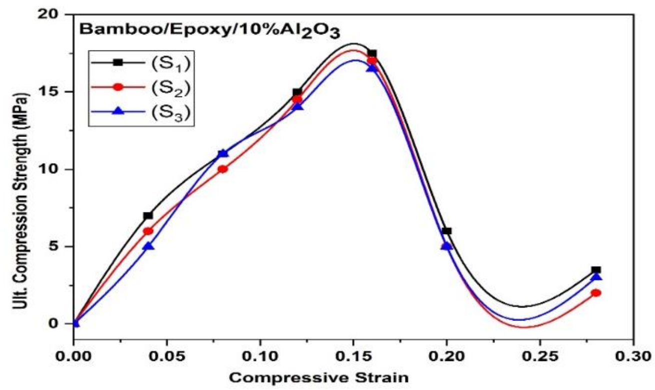
a) Compression strength vs strain on 5wt%Al2O3



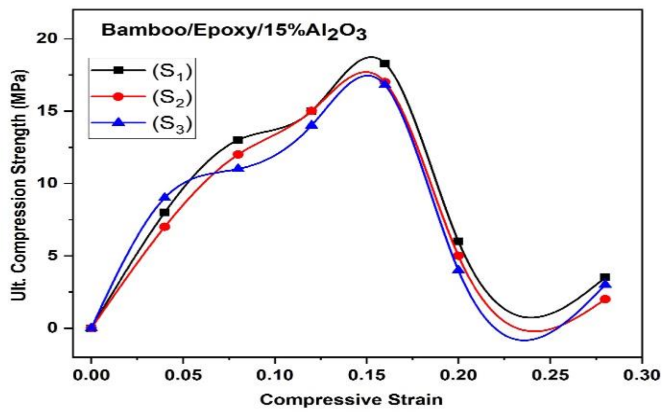
b) Compression strength vs strain on10wt%Al_2O_3



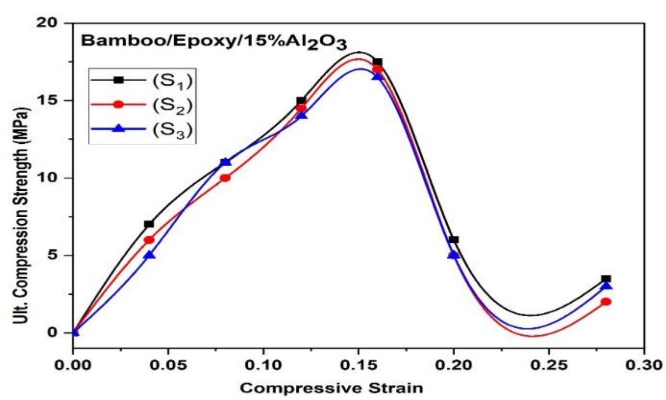
c) Compression strength vs strain on 15wt% alumina



d) Compression strength vs strain on 5wt% alumina



e) Compression strength vs strain on 10wt% alumina



f) Compression strength vs strain on 15wt%Al_2O_3

Figure 4.4 Compression strength vs compressive strain for each specimen

4.4 Fourier transform infrared radiation (FTIR) analysis

The intermolecular interaction among bamboo fiber and epoxy matrix of composite materials. The infrared spectra on bamboo samples composite were used to identify the chemical compounds by using FTIR spectroscopy. The Bamboo strip fibers were grind in a ceramic pestle until powder, Fibers are mixed with KBr at the defined ratio then the mixer is pressed under vacuum to form pellets suitable for FTIR analysis. FTIR spectra are recorded between 4000 cm^{-1} and 400 cm^{-1}.

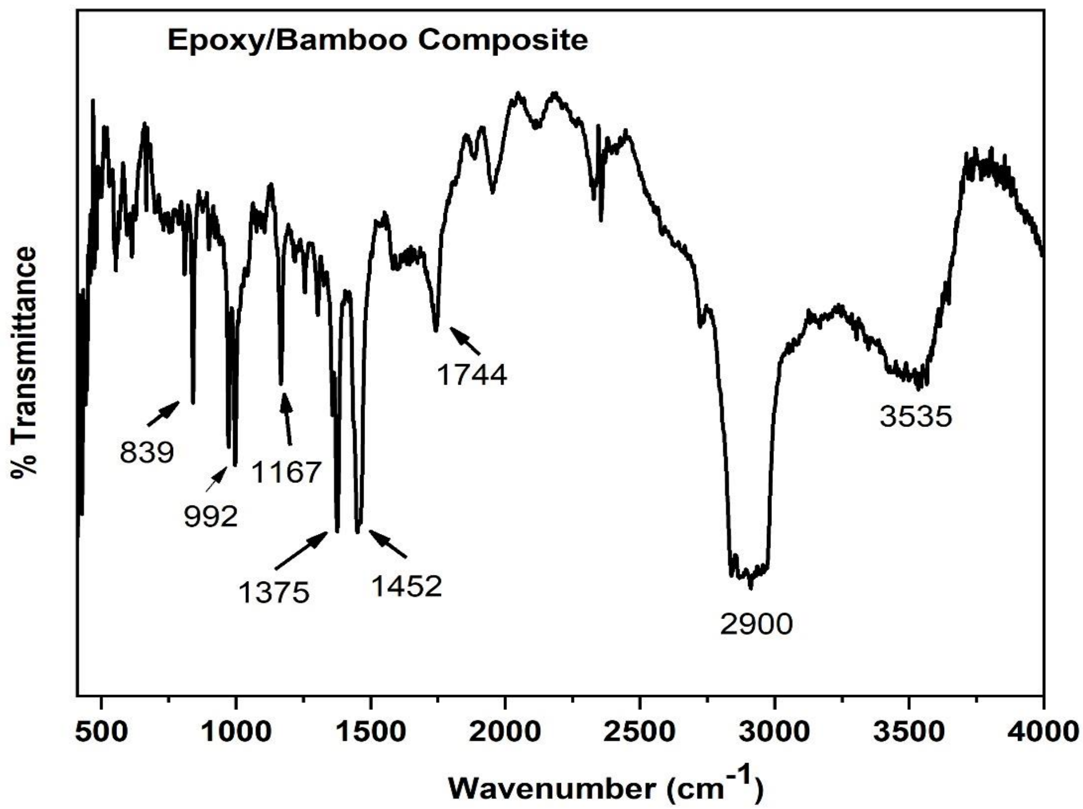


Figure 4.5 FTIR Analysis of composite material

The FTIR analysis is used to observe functional groups and to identify the changes in the chemical compound of natural fibers. The absorption bands for characteristic compounds of the composition of the natural fiber are shown in Figure 4.5. A broad absorption band at the 3535 cm^{-1} regions is characteristic of polymeric association of the –OH groups and hydrogen-bonded –OH stretching vibration in carbohydrates and lignin. The band at 2900 cm^{-1} is relative to the C-O vibration attributed to the presence of high water absorption of the fiber.

The band at 839 cm^{-1} hydrogen stretching band with cellulose decomposition. The peaks at 1744 are almuna reduces the hydrophilic hydroxyl groups in the cellulose molecules thus ensuring reduction in moisture uptake of the composites. Effective fibre surface area increases by the Al2O3 which assists in better adhesion with the hydrophobic polymer matrix.

The band at around 3535 to 4000 cm^{-1} is associated with the amount of the crystalline structure of the cellulose, while the band at 1750cm^{-1} to 2500cm^{-1} is assigned to the amorphous structure in cellulose.

At this point of the present investigation, it is only possible to speculate that the relatively small O-H stretching band at 1375-1452 cm^{-1} region. It might be associated with the limited reactive efficiency of the hydroxyl at the Bamboo fiber strip surface.

The absorption band around 992 cm^{-1} is certainly due to hydroxyl (OH) stretching vibration frequency band was due to filler and matrix layer isometric stretching of –CH2 groups. According this O-H stretching may be associated with absorbed alcohols found in cellulose, hemicellulose, lignin, extractives, and carboxylic acids.

This could represent a facility for water desorption as well as hemicellulose and lignin decomposition. Bamboo fibers composite is the best choice for reinforcement and is used to produce laminated composites for structural parts.

4.5 DISCUSSION

The result obtained from the experimental test of the developed composite specimen is interpreted on tensile strength, flexural strength, hardness, compression strength, and water absorption test, and density determination are shown below.

4.5.1 Tensile test

The tensile test is the ability of the materials to stretch up to fracture on stress-strain curves of the BRC under tensile loading was presented in figure 4.6 tensile stress increased linearly up to yield strength with an increase in strain until the point of ultimate tensile strength. Above this point, the stress-strain curve shows a sharp, scattered decrease, and fracture.

Laminate under a tensile loading bend is observed on stress-strain curve, indicating that BRC the curve continues with increasing peak load, but with a smaller slope, a reduced stiffness in the direction of the load. Tensile fracture of bidirectional fiber is mainly the transverse cracking of fibers. The stress-strain curves under tensile loading are regular up to the ultimate point.

Table 4.1 Tensile test result

Specimen No	Alumina wt%	Elongation at break (%)	Ave.elongaion at break %	ult.tensile strength (Mpa)	Ave.tensile strength (Mpa)	Young's modulus (Gpa)	Ave.modulus (Gpa)
1	5%c_1	13.75		91		6.63	**6.63**
2	5%c_2	12.45	**12.92**	88	**87.6**	7.12	
3	5%c_3	12.55		84		6.73	
4	10%c_1	13.93		77		5.54	**6.51**
5	10%c_2	13.63	**12.34**	76	**75**	5.64	
6	10%c_3	9.6		72		8.35	
7	15%c_1	8.64		71		8.17	**7.95**
8	15%c_2	9.6	**8.96**	72	**71**	7.5	
9	15%c_3	8.64		70		8.17	
10	5%c_{45}	12.80		64		5	**4.81**
11	5%c_{45}	12.47	**12.32**	60	**59.3**	4.8	
12	5%c_{45}	11.69		54		4.62	
13	10%c_{45}	10.48		48		4.58	**4.2**
14	10%c_{45}	9.95	**10.14**	39	**42.3**	3.92	
15	10%c_{45}	10.0		40		4	
16	15%c_{45}	10.5		40.5		4.5	
17	15%c_{45}	10	**10.5**	40	**40.5**	4.2	**4.0**
18	15%c_{45}	11		41		4.0	

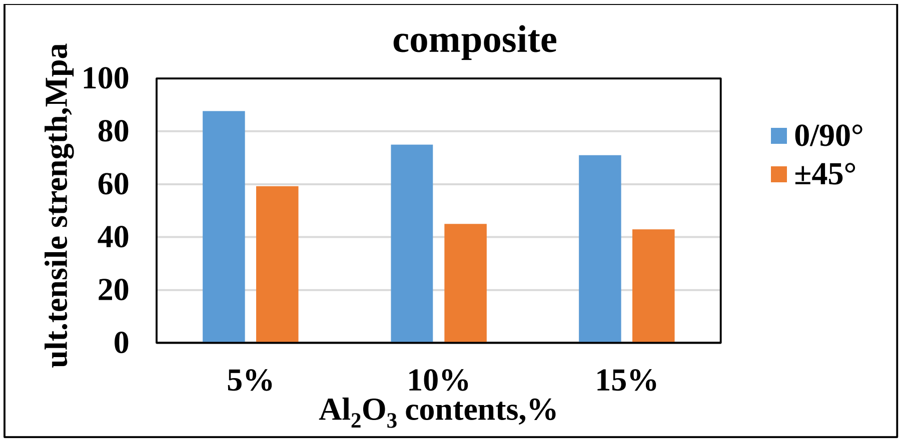


Figure 4.6 Tensile strength vs alumina on the different specimen

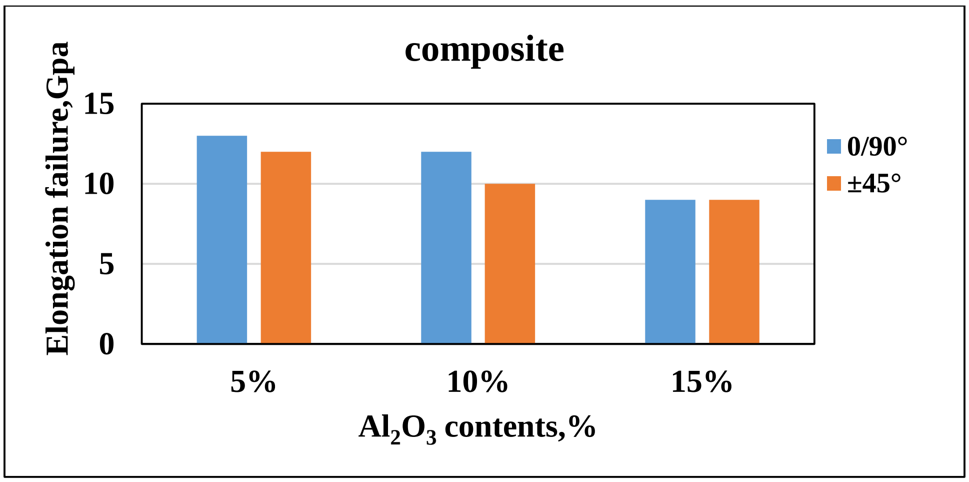


Figure 4.7 Elongation failure vs Al_2O_3 bamboo composite

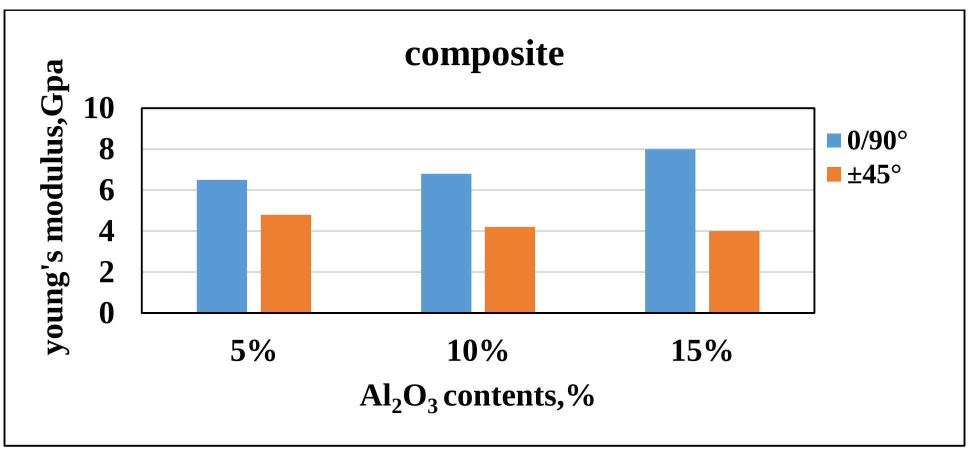


Figure 4.8 Tensile modulus of composites with different particulate filler

4.5.1.1 Effect of alumina contents and orientation in the tensile strength

Tensile strength is the measure of the resistance of material up to rapture under tensile loading. The tensile strength of the developed bamboo composites with a different weight loading of alumina fillers such as 5%, 10%, 15% on the $0/90^0$ orientation and 5%, 10%, and 15% at $\pm45^0$ orientation of weave mates is presented in Figure 4.6. the result interpret on the graph and bar graph indicated that many factors considered on the composite sample strength variations are ply arrangement, fiber orientation, fiber volume loading on the laminated composite specimen.

Lamina arrangement are lay-up of woven layer on a different angle of $0/90^0$ and $\pm45^0$ Orientation of fibers are on the BFRCM is bidirectional into the longitudinal and transverse way of the woven mat with $0/90^0$ and other orientation of fiber is $\pm45^0$ compared the two orientation and alumina content best ultimate tensile strength is obtaining on the $0/90^0$.

The bamboo reinforced composite maximum tensile strength obtained is 87.6Mpa at 5wt%of Al_2O_3 contents on $[0/90]^0$ and the minimum value obtained is 40.5Mpa in the addition of 15Wt% Al_2O_3 content in the $[\pm45]^0$ orientation. However, beyond 5wt% of the alumina filler of the tensile strengths of different weight loading composites are found to be decreasing with increasing the filler contents of the composite at $0/90^0$ and $\pm45^0$ orientation.

The decrease in strength may be attributed to two reasons: one possibility is due to the presence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress the other is corner points of the irregularly shaped particulates result in stress concentration in the matrix body.

The bamboo reinforced composite young's modulus and total percentage elongation v/s alumina filler. The Young's modulus maximum value is 12.92Gpa on the filler contents addition of 15wt% prior it decreased slowly.

Better young's modulus was obtained at 15wt% of Al_2O_3 particulate in $0/90^0$ orientation of BRC but the minimum value obtained is 4.0 Gpa in the addition of 15%ceramic on the $\pm45^0$ orientation. Young's modulus of the Bamboo composite was increased in the $0/90^0$ and decreased $\pm45^0$ orientation of tensile strength.it is improved by tensile strength 20% and young's modulus is 21.5%. Percentage elongation of failure decreased with an increase in the Al_2O_3 particle content.

4.5.1.2 Tensile test failure behavior of BFCM

The failure characteristics of composite material are quite complex to analyze. Since the failure took place in the gage area or tab region, at the center and the side fiber pullout, breakage or delamination of the lamina. Its failure behavior is also highly dependent on each fibers straightness, placement, and adhesion of fiber to the matrix. In the hand lay-up technique, the main difficulty is placing fibers in parallel. Some fibers are tilted or wrinkled or weaker than the others. It has a great impact on the failure behavior of the specimen. Due to that, to minimize such problems proper adhesion, use emery paper for gripe end, keep the homogenous distribution of matrix between fibers and use composite test machine.

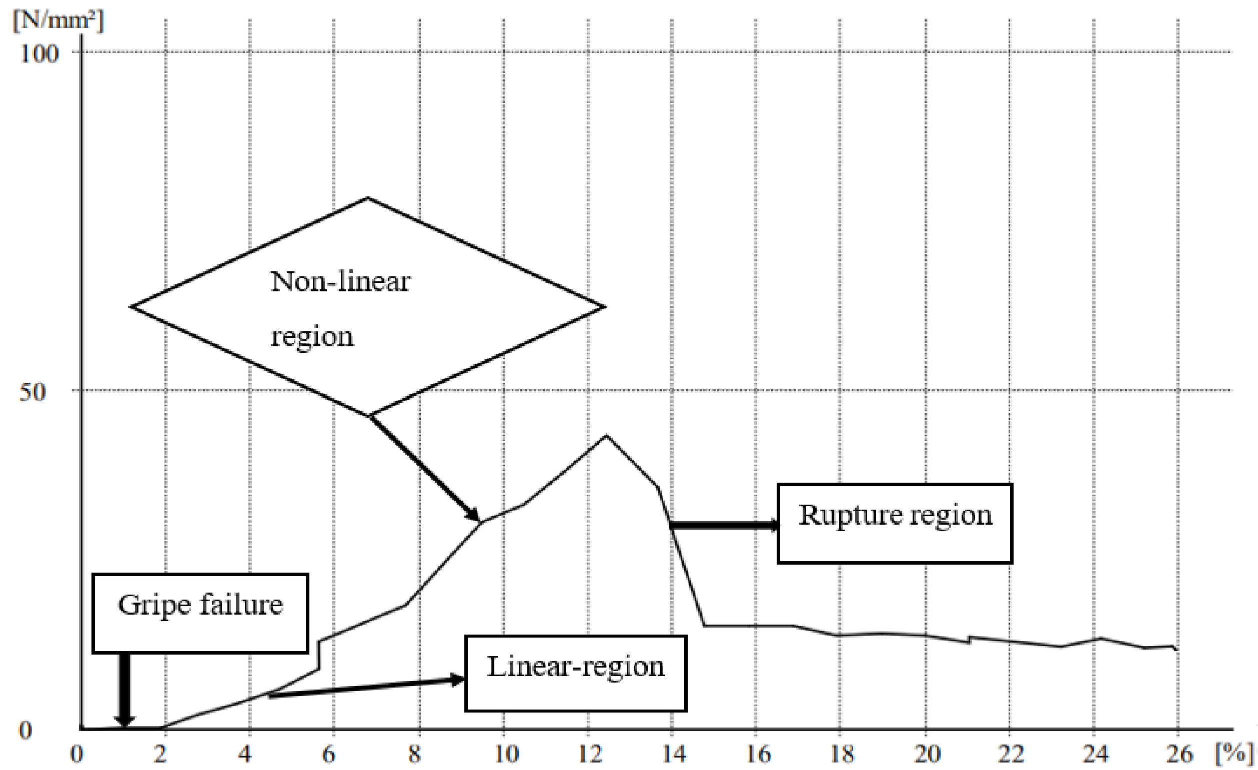


Figure 4.9 Stress-strain behavior of composite material.

In lower strain, the specimen behaves elongate linearly in the liner region. However, its linearity is also smooth indicated that proper adhesion of fiber to the matrix but twisting some regions and continuous. At higher strain, bending occur in some region also continuous after the non-linear region, the fibers are made rupture of the specimen gets failure.

The failure modes of the developed BCM are different for each type of fiber orientation and ply arrangement. For the above BCM, the failure in some areas of longitudinal twist. For wt% fiber volume ratio on $0/90^0$ fiber orientation and $0/90^0$ ply arrangement, the failure mode is less-brittle manner.

The failure surface was with less fiber pullout, porosity, and some longitudinal twist and the delamination of the layer occurred. Since the insufficient matrix prevents transmitting the load among fibers and failures in the gripe of the composite specimen are the lower ultimate strength of the composite.

This is creating porosity and Fiber Bridge in the BFCM. Due to the presence of a stress singularity at the tab tip premature failure in the gripe area of tensile specimens. The fabric specimen tab was selected according to ISO 527.

4.5.2 Flexural strength

The load is applied Under three-point bending in figure 4.4 at mid-span of a rectangular specimen of span length L between two rollers, the highest flexural strength is determined from flexural bending stress(σbf), maximum flexural strain(εf) and bending elastic modulus(E).

Table 4.2 Flexural strength of bamboo fiber composite

Alumina wt.%	specimen No	Max. load (KN)	Max.deflection (mm)	Ave.M Defle. (mm)	M.bending stress(Mpa	Ave.Max. stress (Mpa)	Fle.modulus (Gpa)	Ave. Modulus(Gpa)
5%	Bc1	0.435	4.7	**4.5**	163.2	**161.6**	2.834	**2.85**
	Bc2	0.430	4.4		161.24		2.13	
	Bc3	0.420	4.0		160.50		2.91	
10%	Bc1	0.825	4.0	**3.75**	229.17	**230.35**	2.842	**2.95**
	Bc2	0.84	4.4		231.33		3.161	
	Bc3	0.83	2.8		230.56		3.286	
15%	Bc1	0.89	5.88	**5.84**	247.22	**247.5**	3.032	**3.25**
	Bc2	0.88	5.70		246.44		3.431	
	Bc3	0.95	5.95		248.61		3.286	
$5\%45^0$	Bc1	0.55	3.85	**3.65**	152.78	**150.24**	2.328	**2.72**
	Bc2	0.45	3.61		150.5		2.636	
	Bc3	0.45	3.50		150.61		2.729	
$10\%45^0$	Bc1	0.41	3.23	**3.47**	152.61	**152.04**	2.328	**2.34**
	Bc2	0.4	4.18		153.5		2.366	
	Bc3	0.4	3.02		150.2		2.314	
$15\%45^0$	Bc1	0.4	4.17	**3.48**	154.5	**153.43**	2.14	**2.28**
	Bc2	0.42	3.24		152.6		2.33	
	Bc3	0.4	3.04		153.2		2.56	

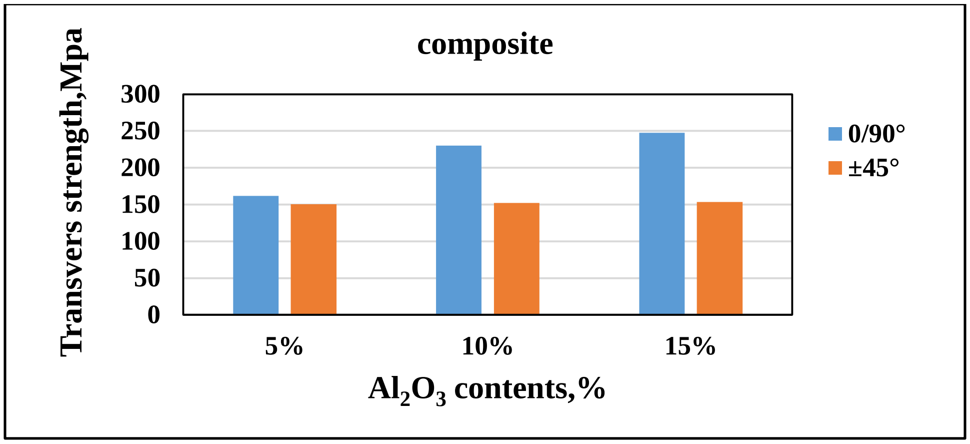


Figure 4.10 Flexural strength vs Al_2O_3 bamboo composite

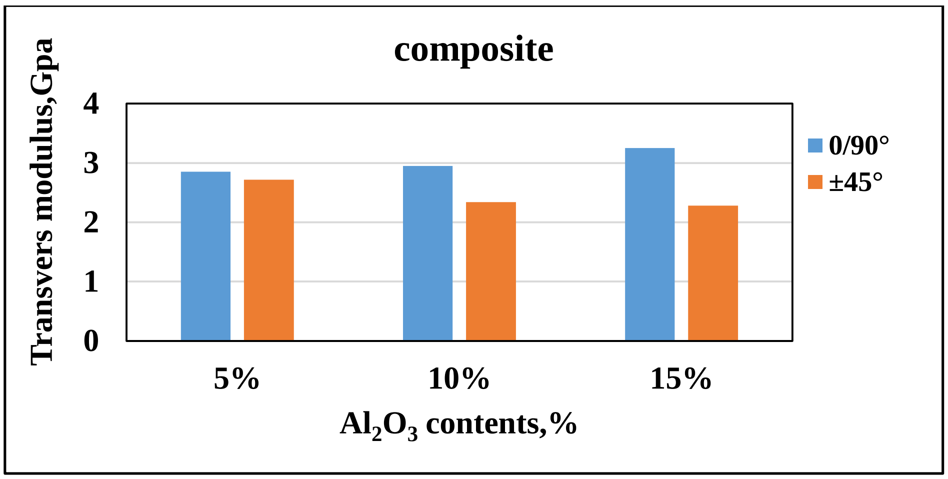


Figure 4.11 Flexural modulus vs alumina of different composite

4.5.2.1 Effect of alumina contents and fiber orientation on flexural strength

The flexural properties such as flexural strength, modulus, and total deflection of the Bamboo reinforced composites are contained Al_2O_3 particle content. Flexural strength of the composites increased from 5wt% Al_2O_3 contents up to 15wt% of Al_2O_3 filler content on the $0/90^0$ and$\pm45^0$ orientation.

Maximum flexural bending stress occur in the addition of 15wt% alumina filler of woven mat expressed 247.5Mpa on $0/90^0$ orientation and the minimum value obtained 150.24Mpa in the addition of 5wt.%Al_2O_3 particulate on the $\pm45^0$ orientation on the BFRCM. The increase in alumina powder contents also increases the flexural strength.

Young's modulus of composite is higher value obtaining at 15wt% Al_2O_3 ceramic particle in the $[0/90]^0$ fiber orientation is 3.25Gpa. The flexural modulus and deflection were also increased gradually with a filler content of up to15wt% alumina on bidirectional orientation. The flexural strength and modulus of the composite are improved by 31.3% and 11.8% of the bamboo reinforced composite.

4.5.2.2 Flexural test failure behavior of BFCM

The flexural test is the three-point bending test that shows that for each considered parameter the required load to bend the specimens was varying for every change of parameters. This implies that parameters such as fiber orientation, ply arrangement, fiber volumetric ratios, and wt.% Al_2O_3 are the main factor to be considered in the flexural strength of designed BFRCM.

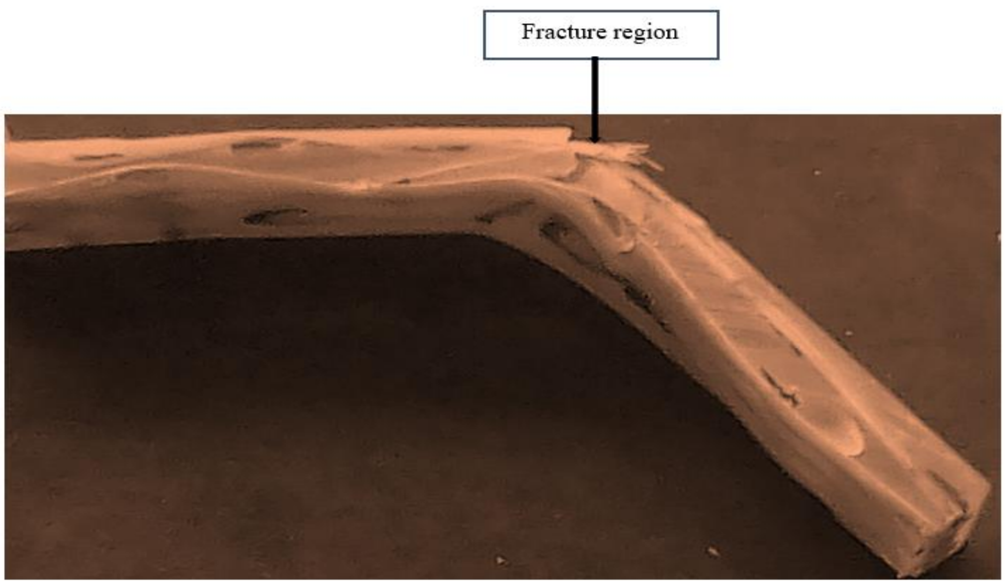


Figure 4.12 Flexural failure behavior of the specimen

When the bending strain increases due to bending load, both tension and compression stress are developed in the specimen. The fracture occurs was taking place in the middle of the specimen where the matrix cracked, which is the opposite side of the loading. As the bending load continued, the crack was propagated to the upper side of the specimen. Then fiber pullout in the tension zone and delamination of plies in the compression side took place.

Finally, the failure of the specimen is existing. In the lower fiber volume ratio, the specimen shows that the fibers breakage instead of the pullout of fibers from the matrix. These indicate that there is better interfacial strength between the laminas, especially in 15wt% fiber volume ratio samples.

4.5.3 Compression strength

Compression testing of the composite materials is one of the most difficult types of testing because of the tendency to premature failure due to buckling or end crushing. Compression testing of the composite materials is essential to determine the behavior of the material. The properties of the material vary subjected to tensile as well as compressive loads. Compared to the tensile test, conducting a compression test on the sample is quite complicated since it is difficult in stabilizing the sample as the compressive load is applied. During the applications of the compressive load to the composite material, buckling may take place. This buckling effect causes delamination of the composite laminate, and there will be some misalignment during the applications of load.

Table 4.3 Compression of specimen

Alumina wt.%	Specimen No	Load at yield (KN)	Ave.load at yield (KN)	Output Stress(N/mm^2)	Ave.stress.elong. (N/mm^2)	Compression strength (Mpa)	Ave,Compression,Strength. (Mpa)	Youngs modulu (Gpa)	Ave. youngs modulu (Gpa)
5%	Bc1	3.51	**3.26**	7.10	**7.1**	28.7	**27.5**	1.7	**1.56**
	Bc2	2.95		7.2		26.5		1.5	
	Bc3	3.32		7.0		27.3		1.5	
10%	Bc1	1.6	**2.58**	3.9	**4.5**	17.18	**20.8**	1.4	**1.36**
	Bc2	2.26		5.4		19.65		1.4	
	Bc3	1.30		4.1		22.69		1.3	
15%	Bc1	0.75	**1.57**	1.81	**4.1**	16.52	**18..3**	1.0	**0.93**
	Bc2	2.34		5.44		20.35		1.0	
	Bc3	1.61		4.98		18.2		0.8	
5%45^0	Bc1	1.32	**1.12**	4.1	**4.0**	17	**17.06**	0.8	**0.86**
	Bc2	1.02		4.0		17.2		1.0	
	Bc3	1.01		4.02		17		0.8	
10%45^0	Bc1	2.02	**1.76**	3.92	**4.2**	17.5	**17.2**	0.7	**0.73**
	Bc2	1.91		4.9		17.2		0.8	
	Bc3	1.36		3.7		16.8		0.7	
15%45^0	Bc1	1.5	**1.5**	4,6	**4.3**	17	17.1	0,7	0.75
	Bc2	1.68		4.4		17.8		0.75	
	Bc3	1.32		3.8		16.4		0,8	

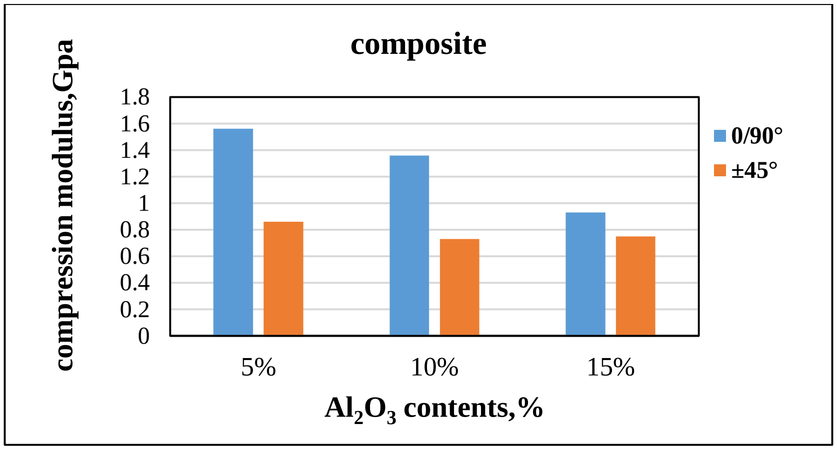


Figure 4.13 compression modulus vs wt% of Al_2O_3 specimen

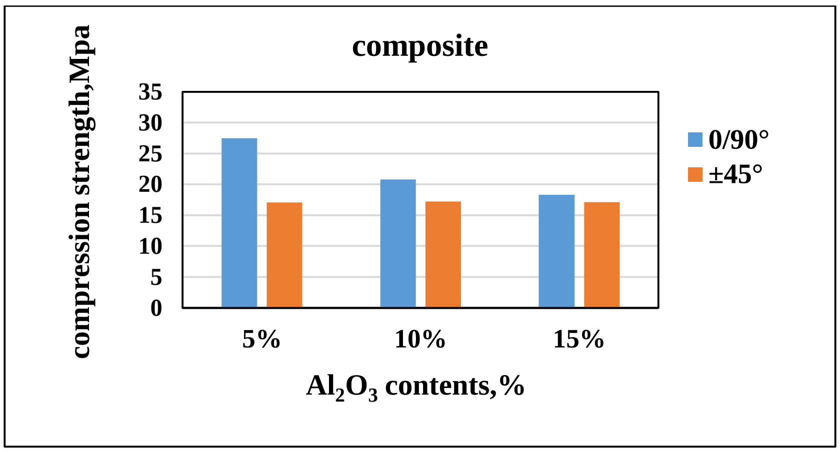


Figure 4.14 Compression strength vs wt. % Alumina contents

4.5.3.1 The effect of alumina filler on the compression strength of composite

Laminated composite material specimen Compression strength is obtained Maximum value is 27.5Mpa at 5wt% of Al_2O_3 particulate on the $0/90^0$ orientation beyond it decrease the strength, with increase contents of alumina and minimum value is 17.1Mpa obtained at 15wt% of Al_2O_3 alumina content on the 45^0 orientation and Compression modulus highest value is 1.56Gpa obtained in the addition of 5wt% alumina and modulus minimum value is 0.73Gpa obtained at the addition of 10% Al_2O_3.The compression strength composite improved by 11.5%.

4.5.3.2 Compression failure behavior of BFRC

In the compression of composite sample materials test, two events occur that is tension in the outer part and compression in the inner part such unwanted failure is fiber pullout, lamina de-bonding and matrix pull out during the test.

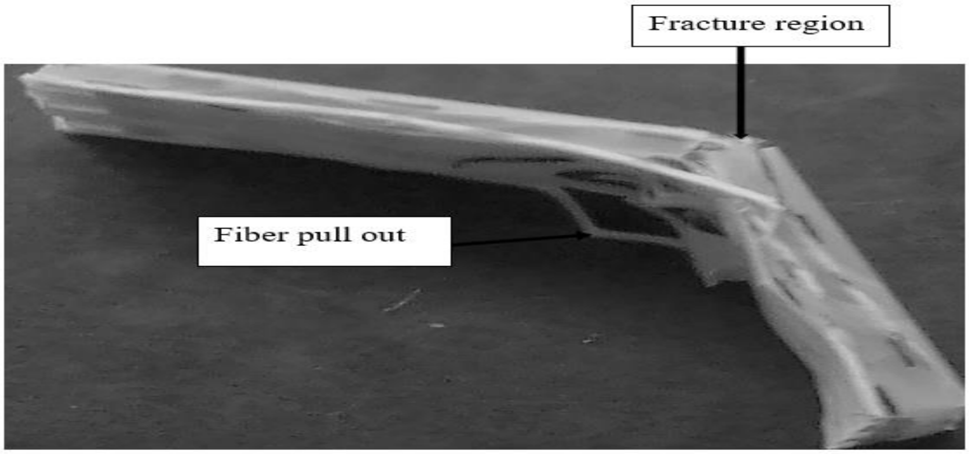


Figure 4.15 Compression failure behavior of composite

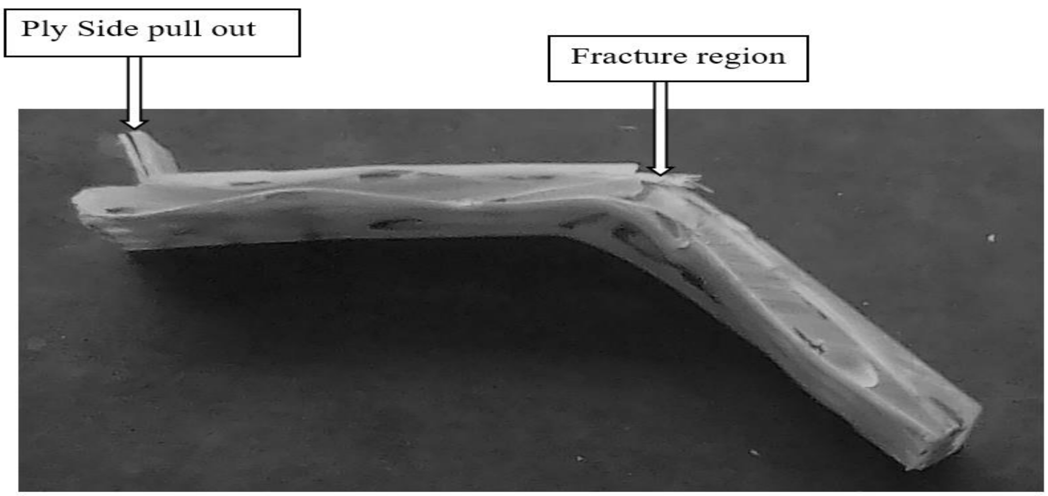


Figure 4.16 Compression specimen failure behavior

The presence of alumina filler material in the polymer composite gives rise to poor bonding between the matrix and the fiber. It may occur porosity, no homogeneity adhesion, and voids in the composites deteriorate on the mechanical properties. Poor interfacial bonding between the fiber and matrix contributes to lower compressive properties.

The decrease of the compressive modulus of the bamboo polymer composites filled with Al_2O_3 particles may be attributed to the bulk of filler material concentrated at the particular region which causes lower compressive behavior. Fig 4.16 above shows the fracture that occurs in the compression specimen.

4.5.4 Impact test

The experiment to test the aspect of impact had been carried out to determine the capability of energy absorption in the various samples. The absorbed impact of energy refers to the total energy required to fracture a specimen. As such, the impact strength had been obtained by dividing the un-noted absorbed impact energy with the cross-section area of the specimen.

When the cantilever beam impact test is performed on the impacted strength the specimen with Qiu=W/hxb_N (no-notched specimen) is calculated as follows:

Q=W/hxb

W=shock absorption work by the sample

H=sample thickness mm

B=sample width mm

b_N = the remaining width of the bottom of the sample notch mm

Table 4.4 impact test result

Angle	Specimen (wt %)	Shock absorption (KJ/m^2	Impact strength (kJ/m)	Speed (m/s)	Energy (J)
$0/90^0$	S1	279.35	6.894	2.9	5
	S2	199.70	4.993	2.9	5
	S3	166.41	4.160	2.9	5
45^0	S4	148.56	3.714	2.9	5
	S5	144.43	3.611	2.9	5
	S6	144.56	3.614	2.9	5

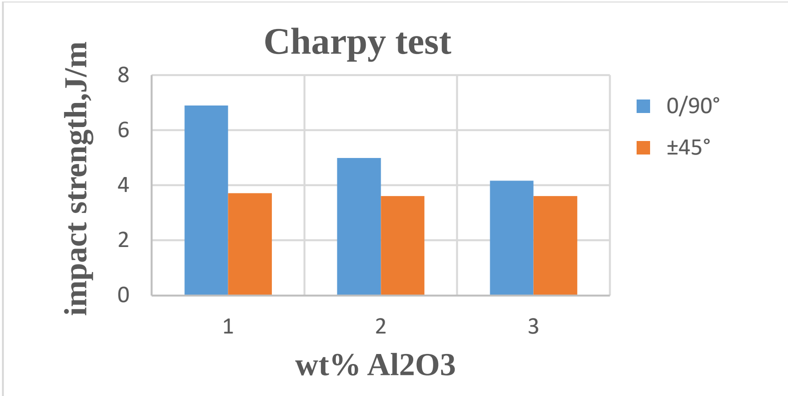


Figure 4.17 shock absorption of the composite

The impact strengths of the laminated bamboo composite in addition of 5wt%, 10wt%, 15%Al_2O_3 in $[0/90]^0$ orientation and 5wt%, 10wt%, 15wt% at $[\pm 45]^0$ orientation. The developed laminated composite are presented in Table 4.4 shows the impact strength of unsaturated polymer composite of bamboo, the delamination area of the specimens after testing. The impact strengths of woven bamboo fabric and laminated composite at 4mm thicknesses were from 279.35Kj/mm^2 to 144.43kJ/mm^2 in the $0/90^0$ and 45^0 respectively. The values show that the energies absorbed by the different alumina contents of laminated bamboo composites are lower than for the 5wt%Al_2O_3 at $0/90^0$ orientation. The highest impact strength value, 6.894kJ/m, was observed at the 5wt% Al_2O_3 contents in $0/90^0$ orientation.

However, impact strengths decreased from 5wt% to 15wt% but the 5wt% alumina contents have the highest impact strength due to their ability to absorb high energy under shock. Meanwhile, this indicates that the increase in the fiber content and orientation of bamboo increase the impact strength of the laminated composite. A similar result has been reported by [50, 51]

4.5.5 Hardness test result in the different orientation and alumina contents

Table 4.5 Hardness test on the composite specimen

Orientation	Wt.% Alumina	Vickers hardness with 5and10kgf value			Ave.Vickers hardness value
$0/90^0$	10%	165.7	227.7	230.9	207
$\pm 45^0$	10%	130	227.2	162.9	173.1
$0/90^0$	5%	130	124.8	132.5	129.3
$\pm 45^0$	5%	120	127.2	119.2	122.13

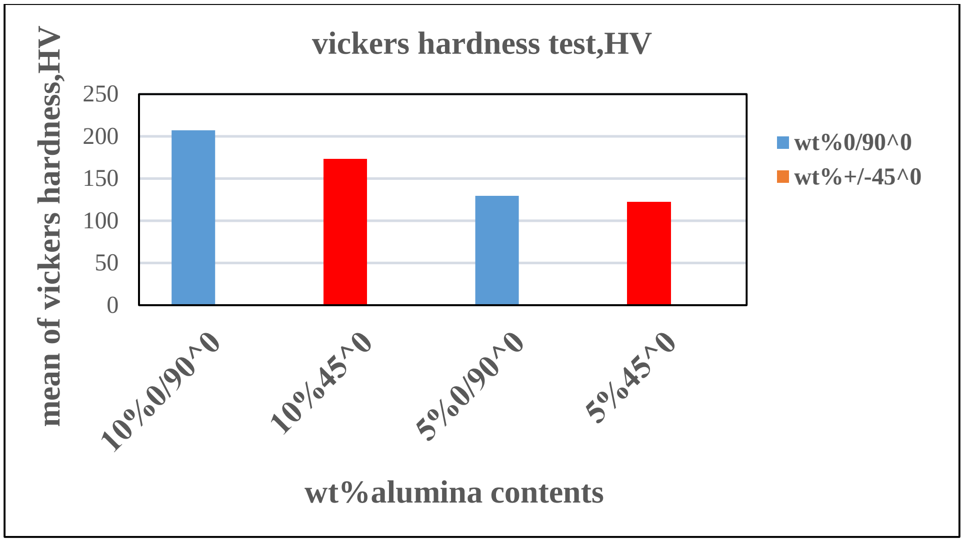


Figure 4.18 Mean of hardness result vs wt% of Al_2O_3 contents

The Vickers hardness test depicted that the woven laminated bamboo fiber was reinforced with alumina in the epoxy composite. The Highest Vickers hardness value obtains in the 10kgf is 207 HV on the $0/90^0$ orientation of composite. The minimum value of HV is at 10and 5wt% Al_2O_3 contents in the $\pm45^0$ orientation of composite sample evaluation is obtained 122.13HV. From hardness result of specimen composite material in $0/90^0$ orientation obtain the highest value but $\pm45^0$ orientation of laminated BFREC sample has shown that the minimum value.

4.5.6 Density measurement

The importance of natural fiber-reinforced polymer composite material has a low density and is lightweight than other reinforcement phases. The density had been determined by Archimedes' principle. Archimedes' principle says that an object fully or partially immersed in a fluid is floating by a force equal to the weight of the water that the object displaces. To express the linear density, the fiber mass measured on balance and fiber length measured with the ruler is necessary. The density measure the fiber it was used. To find weight differences in the fiber, the fiber can be measured on a weight balancer before and after immersion in the fluid. To remove water absorption of the fiber was covered with aluminum foil having a weight of 0.095g.

To measure the density can be used according to Archimedes' law of weight of the materials on air is equal to the weight of materials in water using the formula.

The density calculated above dimensionless factor in order to get the dimensioned density of the fiber the methods of immersion of the liquid water for one minutes and taking the volume difference before immersed and after immersed the density can be obtained.

$$VL=\frac{Wa-Wl}{\rho} \quad 4.6$$

$$\rho f=\frac{mf}{V2-V1} \quad 4.7$$

The specific density of the fibers is

$$S=\frac{\rho f}{\rho w} \quad 4.8$$

$$\rho f=\frac{50-0.095g}{350-300ml} \quad 4.9$$

$$\rho f=\frac{51.905}{50ml}g=1.1302g/cc$$

4.5.7 Water absorption test

Water absorption is a useful character to predict the durability of bamboo fiber reinforced epoxy composite tested as per ASTMD570 standard. The specimen was immersed in pure water (PH=7) at room temperature the water absorption test was conducted on normal water at different times. Water absorption by the specimen was measured using a precise digital balance machine.

The normal water absorption was carried out for 24, 48, and 72 hours. Specimens were prepared from natural highland bamboo with epoxy. The formula used to calculate the water absorption percentage was as shown below. Water absorption is used to determine the amount of water absorption under specified conditions, factors affecting water absorption include the type of plastic. The composite specimen initial weight measuring digital balance accuracy is 0.0001g

Where

$$\text{Percent of the water absorption sample}=\frac{(\text{Wet weight}-\text{Dry weight})}{\text{Dry weight}}X100$$

$$W\%=\frac{W_2-W_1}{W_1}X100 \quad 4.10$$

W% is the percentage of water absorption

W_1 is the initial weight of the sample before immersed

W_2 is the final weight of the sample after immersed

4.5.7.1 Test Procedure

For the water absorption test, the specimens are exposed to sunlight for a specified time and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then immersed in water at room temperature for prescribed hours or until equilibrium. Specimens are removed, patted dry with a lint-free cloth, and weighed.

4.5.7.2 Water absorption measurement

Table 4.6 Initial weight of the sample of composite for water absorption test

%contents	5%	10%	15%	5%at 45^0	10%at 45^0	15% at 45^0
Initial weight(g)	15.2g	19.8g	24.0g	27.2g	30.2g	32..4g
Time (hrs.)	Sample1	Sample2	Sample3	Sample4	Sample5	Sample6
24hr	20.2	24.48	27.29	31.52	33.29	35.5
48hr	21.92	25.92	29.42	32.96	35.12	37.2
72hr	22.94	26.62	30.43	34.18	35.01	37.99

The Specimens water absorption test is indicated in the figure 4.19 below

a) Specimen prepared b)sample immersed in water

Figure 4.19 Water absorption test

Table 4.7 Weight percentage result of water absorption test

Types of bamboo composite	immersed time (hrs.) and water absorption wt.%			Average water absorption results	Orientation of fiber
% wt. Contents	24hr	48hr	72hr	-	$0/90^0$
5%	32.9	44.2	50.78	42.6	
10%	23.6	30.9	34.4	29.6	
15%	13.7	22.6	26.8	21.3	
5%	15.9	21.2	25.7	20	$\pm 45^0$
10%	10.2	16.3	15.9	14.1	
15%	9.6	14.8	17.8	13.9	

Based on the result in table 4.7 depicted on developed laminated bamboo-composite shows high water absorption in 5wt% alumina (Al_2O_3) is obtained 42.6% at $[0/90]^0$ orientation. This is indicated that due to the nature of bamboo fiber has a high tendency to absorb water (hydrophilic character of natural fiber) in woven specimen composite but low water absorption observed in the 15wt% alumina contents is 13.9% at $[\pm 45]^0$ orientation in the composite.

The weight percent of alumina (Al_2O_3) increases the absorption of water becomes deceased and this is due to the properties of the matrix material (hydrophobic) with alumina properties of which bind the fibers.

This reduction may be due to the Al_2O_3 particles being impermeable in nature. Also, the voids present in the 5wt% alumina-filled composites contribute to gaining high water absorption. The Increase in filler particles results in the reduction of moisture gain on Al_2O_3 filled composites.

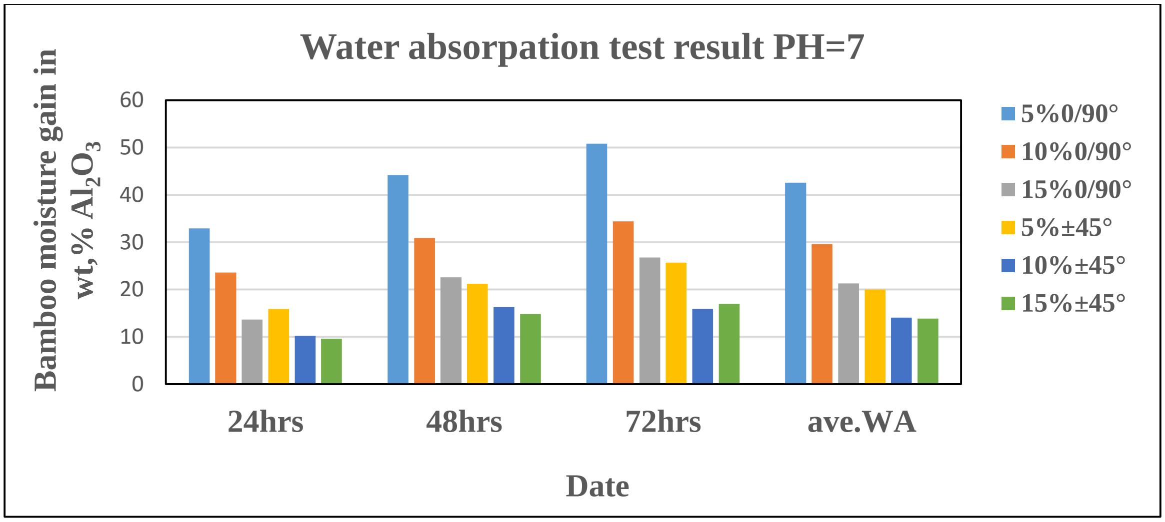


Figure 4.20 Water absorption test vs. weight loading on the specimen

Water absorption test indicated that from bar chart maximum water absorption on the specimen of highland bamboo composite on the different orientation that means wrap and weft direction $[0/90]^0$ weave strips, in laminated composite different weight percent of Al_2O_3 shown that 5wt% alumina absorbed high amount of water, the volume fraction of alumina contents increase the moisture absorption decrease But in $\pm 45^0$ orientation less water gaining compared to $0/90^0$.

4.5.8 Verification

Verification shows that current work validity by comparing with other related work as well as previous work has done. The fiber selected was found in the highland part of our country. So the verification has been done by referring to the literature. The verification could be done on:

- Tensile strength
- Flexural strength
- Compression strength
- Hardness strength
- Charpy impact test
- Water absorption
- Density determination

Table 4.9 Tensile strength, Flexural strength, Compression, density, and water absorption test validate with different works of literature.

Types of test	Highland bamboo fiber with epoxy	Reference
Density(g/cc)	0.6-1.2g/cc	[47],[52]
Tensile strength (Mpa)	38,92,84.4,57.5,159.73,73,129.11,48.8	[39],[53],[36],[40],[7],[6]
Flexural strength(Mpa)	184.5,56.7,149,133,151.1,126.70,85.6	[39],[53],[35],[19][25]
Compression strength(Mpa)	26,114.13,33.23	[45],[54],[32]
Water absorption wt (%)	16,11.4	[38],[57]
Hardness test(Hv)	80,57.125,158.68,120	[49],[51],[54],[56],[57]
Impact strength(J/m)	0.331,4.2,4.5,2.75,5.6, 3.46,4.9	[50],[51],[52],[53],[55],[56],[58]

CHAPTER FIVE

5.1 CONCLUSION

Bamboo strips were extracted manually from Ethiopia's highland bamboo plants. The bamboo fiber reinforced epoxy composite was manufactured and its mechanical properties on the tensile, flexural, compression, hardness, impact strength, FTIR, water absorption behavior, and density determination were determined using a laboratory experiment. The test result exhibited important information is obtained about the composite of the material.it confirms that the reliability of the material on the structural applications. Also, the effect of alumina powder on the composite plate preparation was mentioned below.

1. the developed bamboo reinforced composite depicted that higher tensile strength obtained at 5wt%Al_2O_3 filler is 87.6Mpa on the 0/90^0 orientation of composite indicated that the bamboo fiber has better tensile strength due to increase in weight of fiber contents.

2. The laminated composite at 5%, 10%, 15wt.% Al_2O_3 particulate filler on the different orientation showed that 5wt% alumina has high tensile strength beyond its tensile strength decrease with increased the filler contents.

3. The tensile strength of composite improved by 20% and the modulus of bamboo reinforced composite is increased by 21.5%.

4. Higher flexural strength obtained 247.5Mpa in the addition of 15wt% Al_2O_3 particulate on [0/90]^0 orientation and the minimum value obtained 150.24Mpa in the presence of 5wt% of alumina filler on the $\pm45^0$ orientation.

5. The young’s modulus and deflection of flexural strength increased with the filler contents increased up to 15% then decreased with small amount of alumina content on both orientation, and flexural strength, and flexural modulus is improved by 31.3% and 11.8% of the composite.

6. Developed bamboo fiber-reinforced composite material shows higher flexural strength at 15wt% Al_2O_3 filler on the 0/90^0 orientation with the properties of the fiber to carry the load on them. Therefore, bamboo fibers reinforced epoxy composite material has the ability to replace different products for households on different luxuries products such as the frame for door and windows, kitchen cabinets, partition walls, flooring, ceiling, chairs, tables, honeycomb, automobile body to advanced level of application such as for luxury boat, house, turbine blade shells, car compartment, interior body panel.

7. the maximum compression strength value is obtained 27.5Mpa on $0/90^0$ orientation and the minimum value is 17.1Mpa and young's modulus of composite higher value at 5wt% Al_2O_3 is obtained 1.56Gpa and the lower value is 0.73Gpa at 10wt% of Al_2O_3 particulate on the $0/90^0$ and 45^0 orientation respectively. The compression strength and modulus of stiffness are decreased with an increase in the weight of alumina filler due occurrence of the void, porosity, and inadequate adhesion of fiber and resin interaction.

8. Hardness of composite has the highest value obtained in both 10 and 5kgf load is 207 HV on 10wt%Al_2O_3 in $0/90^0$ orientation and the lowest value is 129.3HV at 5wt%Al_2O_3 in 45^0 orientation but the maximum value that obtained is 207Hv of composite is indicate that longitudinal and transversal orientation of fiber in addition to alumina (Al_2O_3) is a capability to increase the hardness of composite materials.

9. Bamboo reinforced composite absorbed minimum amount of moisture gained at 15wt% Al_2O_3 contents obtained 13.9% in 45^0 orientation. This shows that alumina is a High potential to decrease moisture absorption when increasing Al_2O_3 content decrease moisture gain in the bamboo composite. This show bamboo reinforced composite capability to replace indoor as well as outdoor application Hussein et, al [41]

10. The hydroxyl stretching band around 1744cm^{-1} is peak region this shown that Al_2O_3 reduced water absorption and better fiber to resin adhesion at the interface region.

11. From the above conclusion bamboo fiber reinforced composite can replace different construction materials as well as household products like indoor, selling, flooring, partition walls, and also different type of chairs and tables, kitchen cabinets, and office equipment export to other countries.

5.2 RECOMMENDATION

The current work focused on the mechanical properties by the addition of Al_2O_3 particulate give attention to the orientation, volume fiber loading, and laminate of the composite materials. Mechanical properties of bamboo fiber reinforced polymer especially bamboo/epoxy composite are comparable to synthetic fiber polymer composites. However, many factors that affect the final mechanical properties of the bamboo reinforced polymer include fiber length, fiber orientation, volume fraction contents, the interfacial bond between fibers to resin, and to improve the bond between matrix and bamboo fiber the alumina is introduced.

Bamboo fiber reinforced composite materials are a strength to weight ratio is very reliable and eco-friendly materials, it has high carbon dioxide absorption capability in contrast to the synthesized one. Many researchers conducted many works around the world on the bamboo fiber based on the species available around them, materials used for the construction purpose the costs are increased tremendously, the production cost is also difficult and they are not eco-friend. These materials are nearly 90% synthetic. From this, it is possible to conclude that the output result of BFREC material can have the potential to replace synthetic fibers such as glass, aramid, and carbon fiber alone composite.

5.3 Future work

- Effect of woven bamboo strip reinforced laminated composite material manufacturing process on fracture property.
- Reinforcement and matrix volume fraction difference and its significance on fracture property of woven bamboo fiber reinforced laminated composite material.
- Characterization can be done using different manufacturing fabrication techniques on bamboo fiber reinforced polymer composite.
- SEM and Finite Element Analysis (FEA) can be done on the bamboo composite.
- Characterized tests like Fatigue test, shear test, and thermal test.
- Design of bamboo fibers extraction processing machine.
- Replace the bamboo strip fiber in the form of powder, chopped, flake and by orienting the fiber randomly, conduct mechanical test and characterization, is essential to explore the overall properties and performance of the materials.

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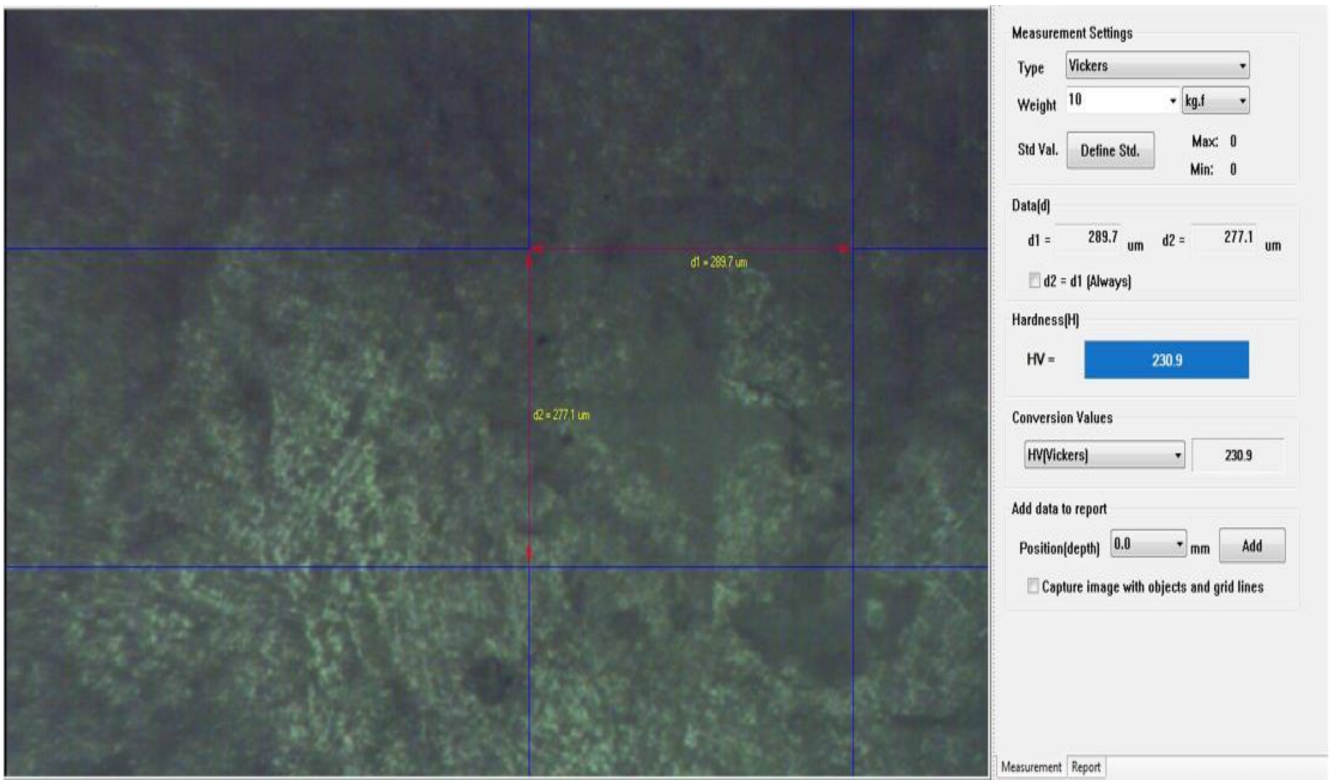
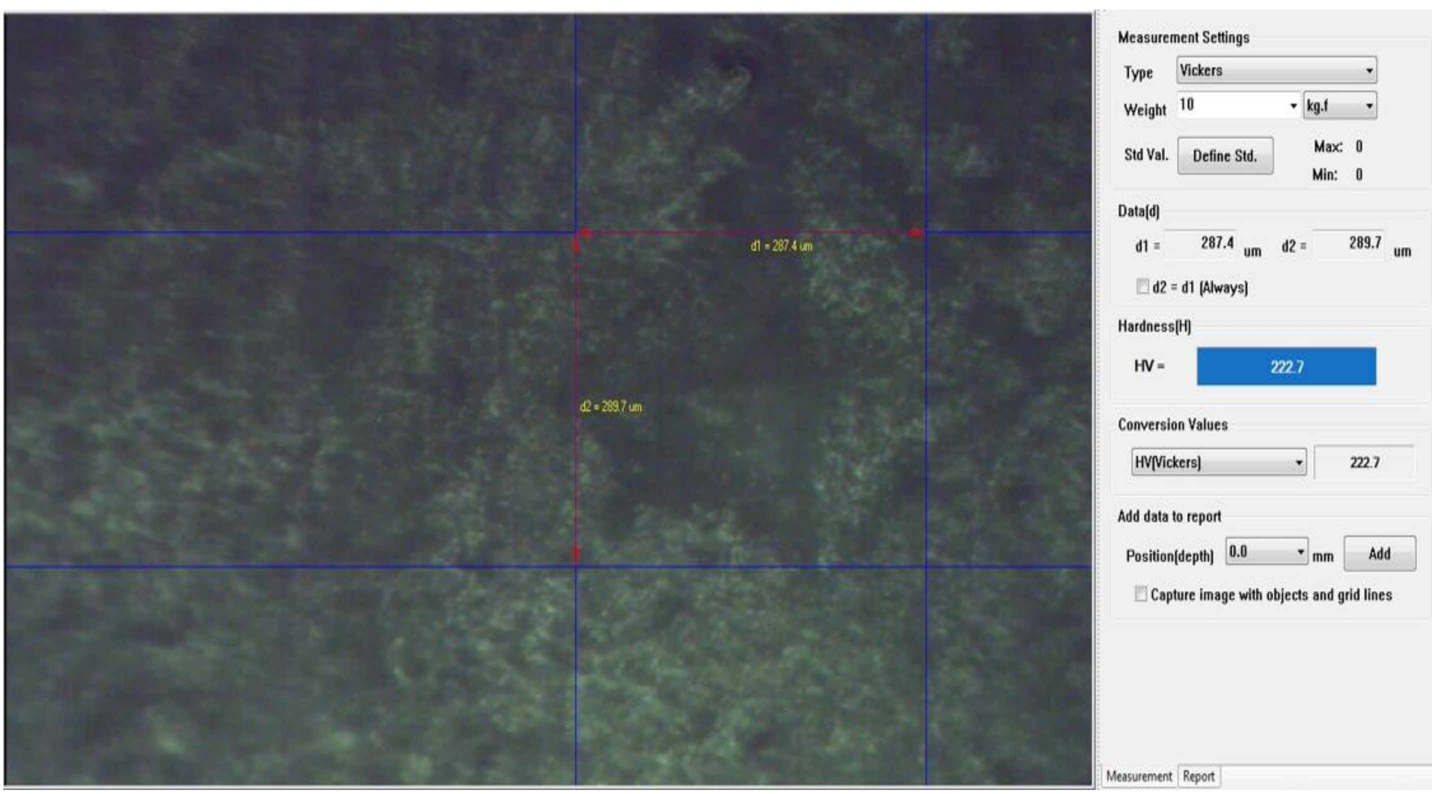
Appendixes

Appendex A : Vickers hardness test on $0/90^0$ with the 10 kgf



Vickers hardness test on $\pm\mathbf{45}^{0}$ with the 10kgf

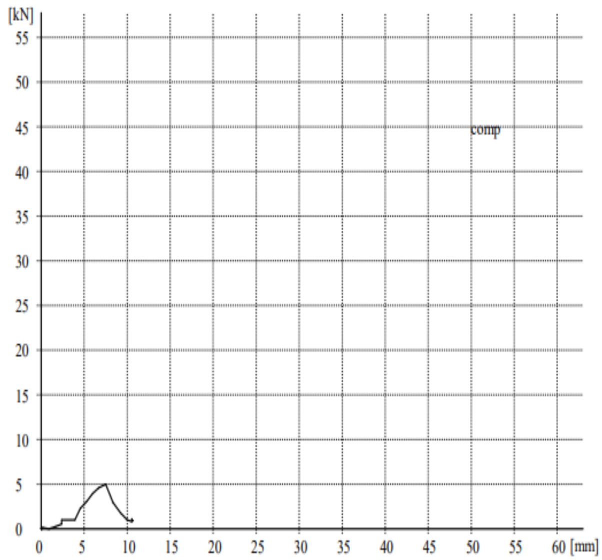



Measurement Settings
Type Vickers
Weight 10 kg.f
Std Val. Define Std.
Max: 0
Min: 0
Data(d)
d1 = 369.0 um
d2 = 386.3 um
d2 = d1 (Always)
Hardness(H)
HV = 130.0
Conversion Values
HV(Vickers)
NA
Add data to report
Position(depth) 0.0 mm
Add
Capture image with objects and grid lines
Measurement
Report


Measurement Settings
Type Vickers
Weight 10 kg.f
Std Val. Define Std.
Max: 0
Min: 0
Data(d)
d1 = 327.6 um
d2 = 347.2 um
d2 = d1 (Always)
Hardness(H)
HV = 162.9
Conversion Values
HV(Vickers)
162.9
Add data to report
Position(depth) 0.0 mm
Add
Capture image with objects and grid lines
Measurement
Report

Appendix B : Tensile strength and load diagram

15% alumina



Output force-elongation-table

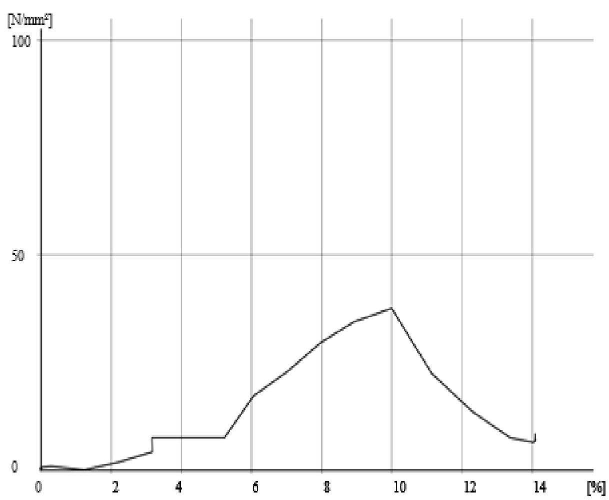
Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.12	0.22
2	0.01	0.92
3	0.25	1.66
4	0.56	2.38
5	1.00	2.37
6	1.00	3.92
7	2.29	4.54
8	3.04	5.27
9	3.94	5.98
10	4.59	6.70
11	4.99	7.50
12	2.98	8.35
13	1.81	9.21
14	1.01	10.02
15	0.85	10.52
16	0.96	10.56
17	1.12	10.56
18	1.01	10.56

Stress elongation tensile specimen

Stress-elongation-diagram for tensile specimen

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021



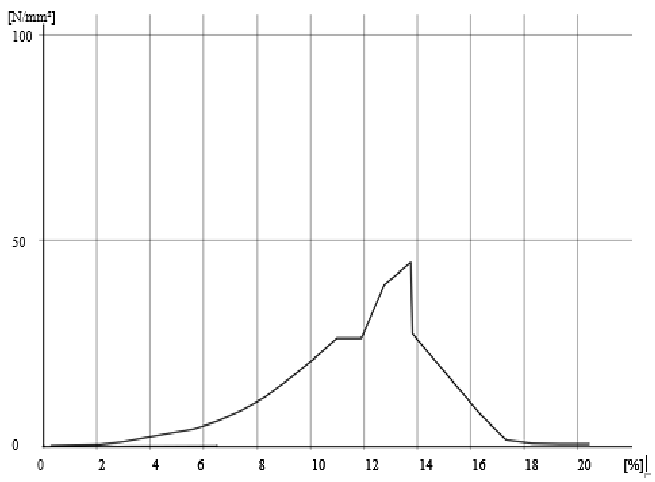
Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.30	1.40
2	0.98	2.25
3	1.88	3.19
4	3.16	4.18
5	4.52	5.16
6	6.48	6.10
7	9.04	7.05
8	12.13	7.98
9	15.82	8.92
10	15.82	9.88
11	25.16	10.80
12	28.40	11.74
13	32.09	12.69
14	37.29	13.63
15	32.55	15.90
16	10.40	16.92
17	8.14	17.85
18	8.36	18.08

5%alumina

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 28.04.2021



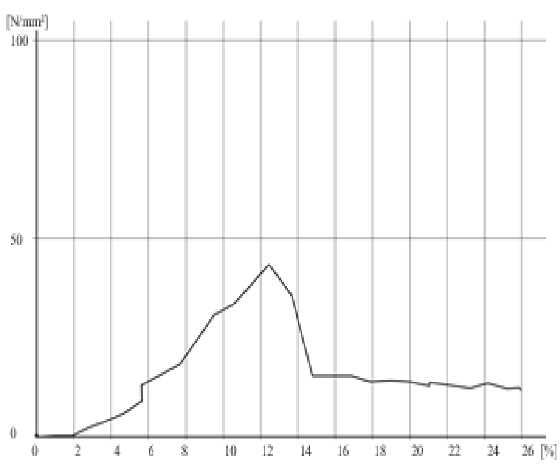
Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 28.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	3.01
2	0.00	6.37
3	0.00	0.00
4	0.00	0.29
5	0.45	2.13
6	1.05	2.94
7	2.11	3.83
8	3.09	4.74
9	4.22	5.64
10	6.10	6.51
11	8.66	7.40
12	11.98	8.29
13	16.27	9.18
14	21.02	10.09
15	26.22	10.99
16	26.22	11.91
17	39.18	12.77
18	44.68	13.75
19	27.35	13.81
20	7.61	16.40
21	1.51	17.33
22	0.68	18.32
23	0.60	19.32
24	0.60	20.21
25	0.60	20.41

Stress-elongation-diagram for tensile specimen

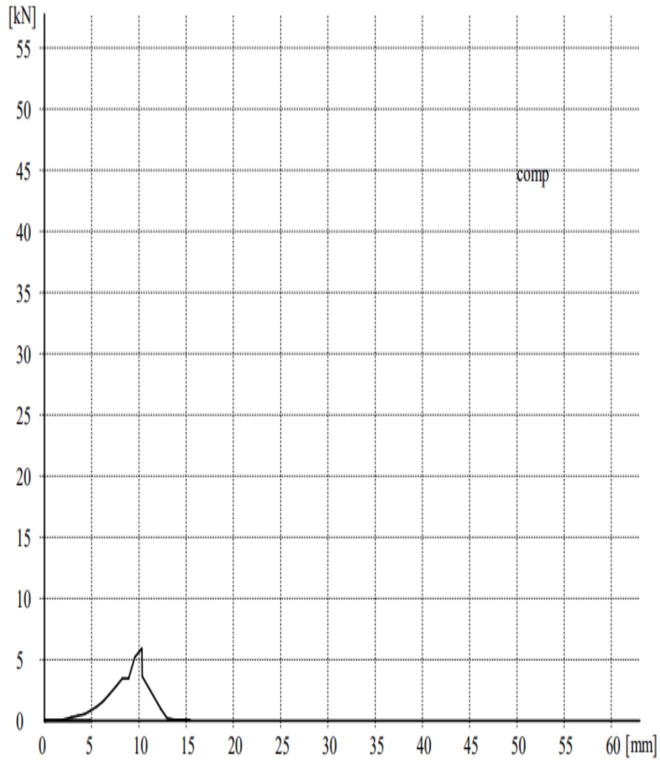
Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021



Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

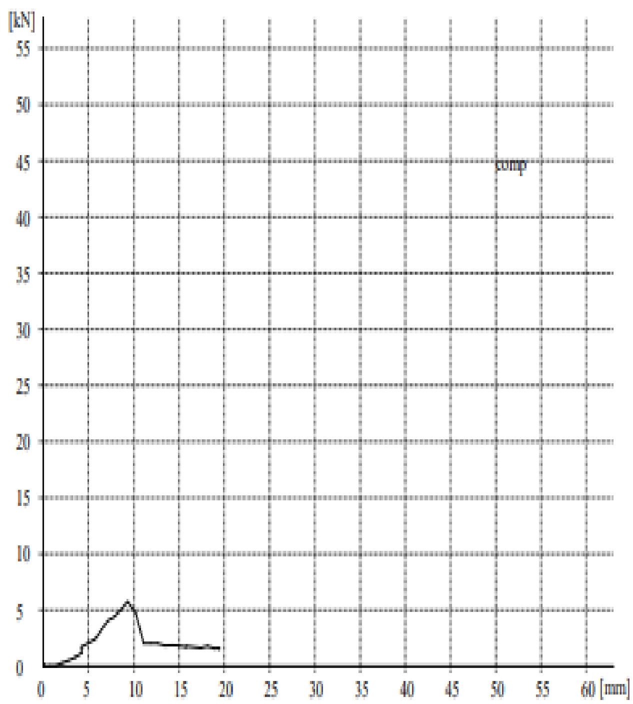
No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.23	0.63
2	0.75	1.53
3	1.96	2.45
4	3.24	3.39
5	4.52	4.32
6	6.18	5.23
7	8.14	6.14
8	11.07	7.04
9	15.07	7.95
10	19.29	8.85
11	24.18	8.83
12	24.18	10.74
13	35.79	11.51
14	41.36	12.55
15	14.31	13.79
16	0.08	14.16



Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.04	1.06
2	0.13	1.69
3	0.25	2.40
4	0.42	3.13
5	0.60	3.87
6	0.86	4.57
7	1.20	5.29
8	1.61	5.99
9	2.10	6.69
10	2.10	7.41
11	3.34	8.10
12	3.77	8.80
13	4.26	9.51
14	4.95	10.22
15	4.32	11.92
16	1.38	12.69
17	1.08	13.39
18	1.11	13.56

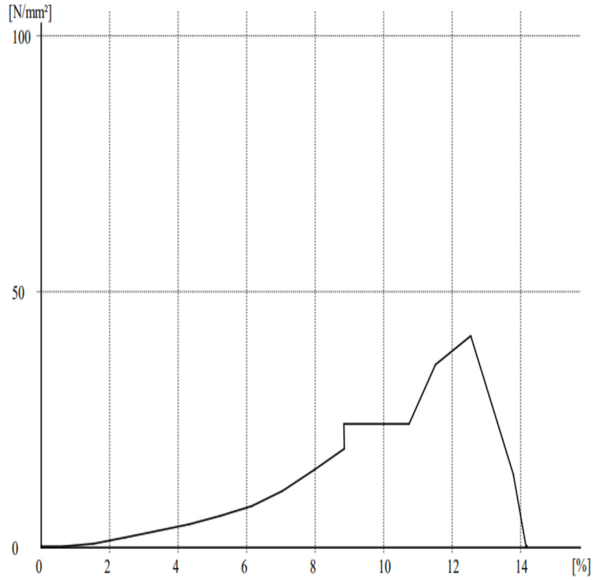


Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.05	0.47
2	0.10	1.15
3	0.26	1.83
4	0.43	2.54
5	0.60	3.24
6	0.82	3.92
7	1.08	4.61
8	1.47	5.28
9	2.00	5.96
10	2.56	6.64
11	3.21	6.63
12	3.21	8.06
13	4.75	8.64
14	5.49	9.41
15	1.90	10.34
16	0.01	10.62

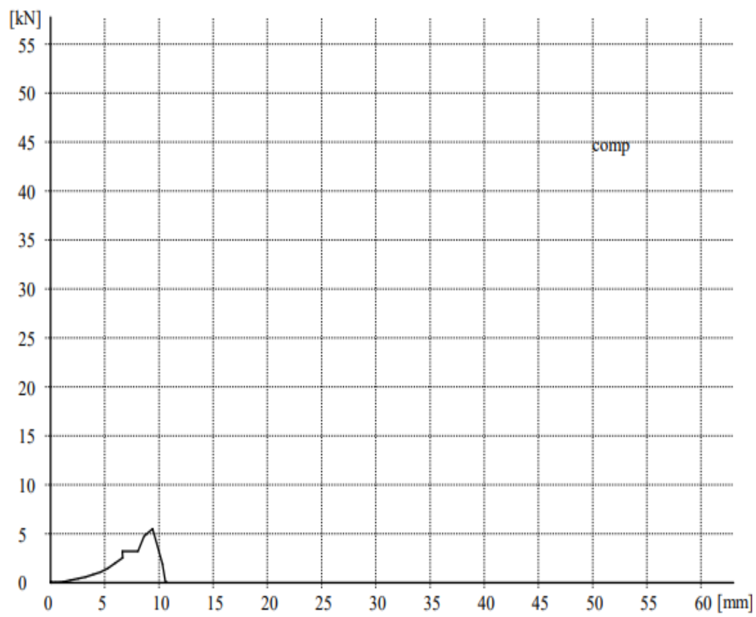
10%alumina



Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	0.19
2	0.23	0.96
3	0.23	1.87
4	2.18	2.77
5	3.84	3.71
6	5.95	4.67
7	8.97	5.63
8	12.96	5.62
9	18.31	7.68
10	24.18	8.54
11	30.59	9.49
12	33.15	10.48
13	38.12	11.45
14	43.40	12.45
15	35.79	13.66
16	15.29	14.77
17	15.29	15.83
18	15.29	16.88
19	13.86	17.91
20	14.16	18.98
21	13.86	20.00
22	12.81	21.05
23	13.64	21.05
24	12.21	23.24
25	13.41	24.18
26	12.05	25.21
27	12.28	25.88

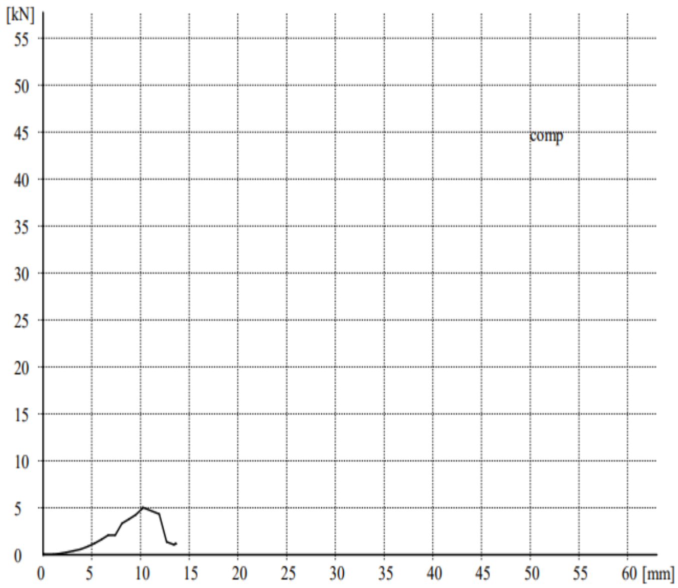


Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.14
2	0.03	0.72
3	0.03	1.40
4	0.29	2.07
5	0.51	2.78
6	0.79	3.50
7	1.19	4.23
8	1.72	4.22
9	2.43	5.76
10	3.21	6.41
11	4.06	7.12
12	4.40	7.86
13	5.06	8.59
14	5.76	9.33
15	4.75	10.25
16	2.03	11.08
17	2.03	11.87
18	2.03	12.66
19	1.84	13.43
20	1.88	14.23
21	1.84	15.00
22	1.70	15.79
23	1.81	15.78
24	1.62	17.43
25	1.78	18.13
26	1.60	18.91
27	1.63	19.41

15%alumina45^0



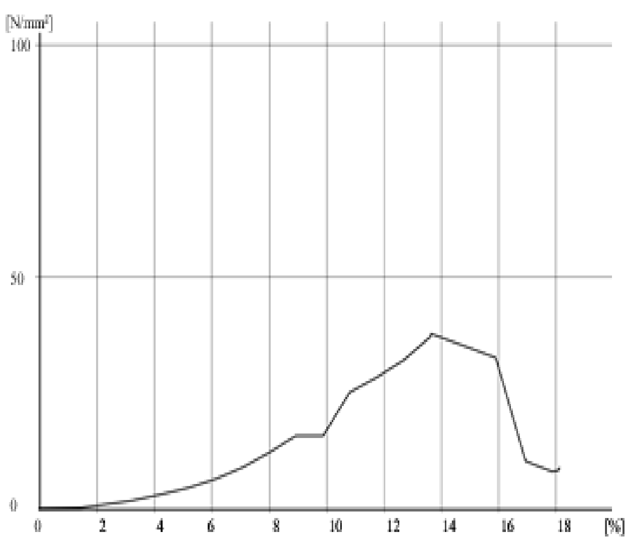
Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.14
2	0.03	0.72
3	0.03	1.40
4	0.29	2.07
5	0.51	2.78
6	0.79	3.50
7	1.19	4.23
8	1.72	4.22
9	2.43	5.76
10	3.21	6.41
11	4.06	7.12
12	4.40	7.86
13	5.06	8.59
14	5.76	9.33
15	4.75	10.25
16	2.03	11.08
17	2.03	11.87
18	2.03	12.66
19	1.84	13.43
20	1.88	14.23
21	1.84	15.00
22	1.70	15.79
23	1.81	15.78
24	1.62	17.43
25	1.78	18.13
26	1.60	18.91
27	1.63	19.41

Stress-elongation-diagram for tensile specimen

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021



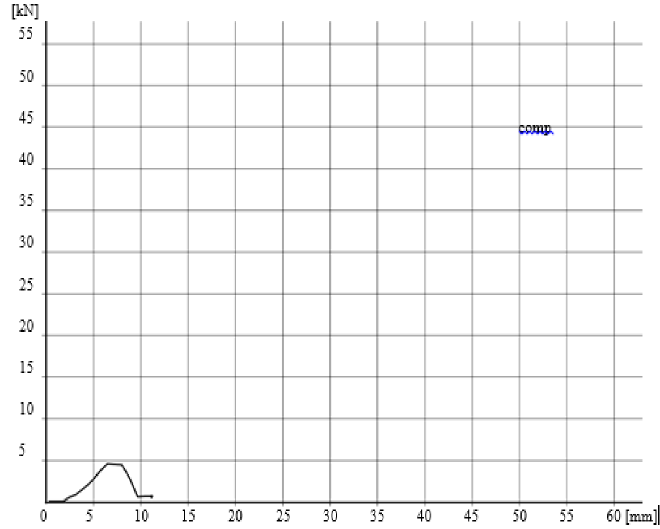
Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 28.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	2.60
2	0.00	0.00
3	0.68	0.48
4	0.38	0.91
5	0.23	1.15
6	0.15	1.95
7	1.66	3.89
8	2.79	4.70
9	3.84	5.35
10	3.62	5.75
11	5.73	6.57
12	8.14	7.42
13	10.85	8.28
14	14.09	9.14
15	18.08	10.00
16	26.67	11.88
17	31.19	12.80
18	20.79	14.26
19	0.68	15.88

10%alumina45^0

Force-elongation-diagram for tensile test specimen



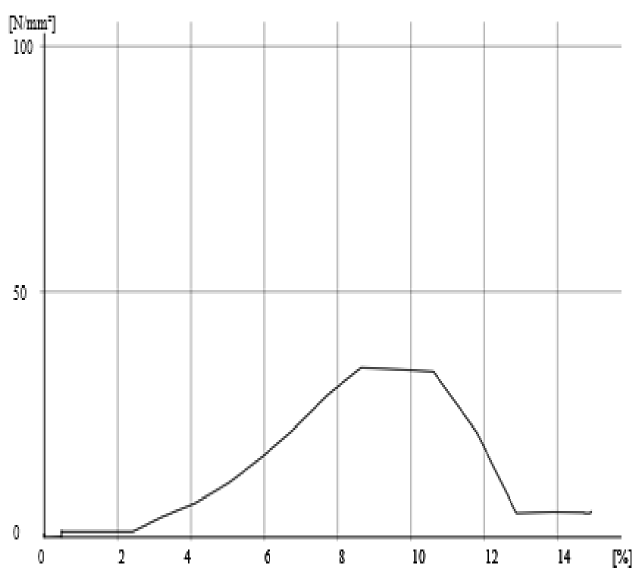
Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.04	1.05
2	0.13	1.69
3	0.25	2.40
4	0.42	3.13
5	0.60	3.87
6	0.86	4.57
7	1.20	5.29
8	1.61	5.99
9	2.10	6.69
10	2.10	7.41
11	3.34	8.10
12	3.77	8.80
13	4.26	9.51
14	4.95	10.22
15	4.32	11.92
16	1.38	12.69
17	1.08	13.39
18	1.11	13.56

Stress-elongation-diagram for tensile specimen

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

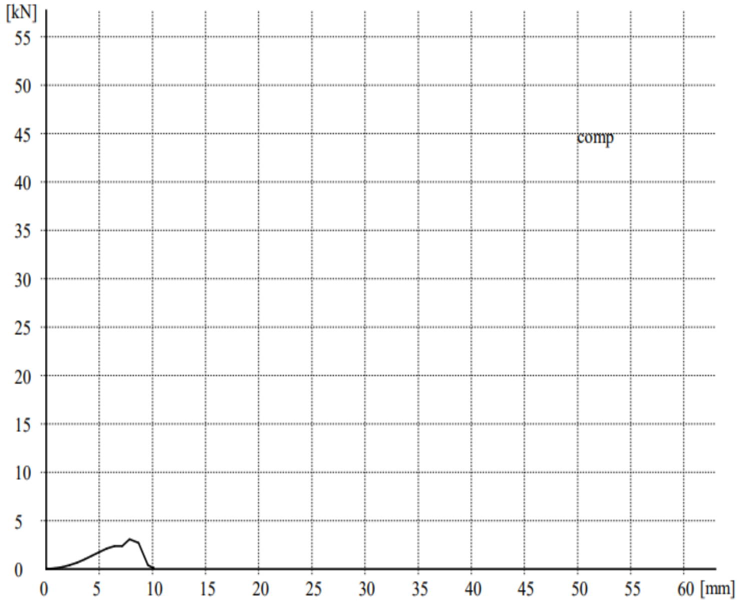


Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.08	0.48
2	1.05	0.48
3	1.05	2.41
4	4.07	3.24
5	7.01	4.14
6	11.00	5.03
7	16.12	5.93
8	22.15	6.83
9	28.86	7.72
10	34.58	8.64
11	34.13	9.63
12	33.68	10.61
13	21.17	11.81
14	4.82	12.88
15	4.97	13.88
16	4.90	14.74
17	4.75	14.90

5% alumina 45^0



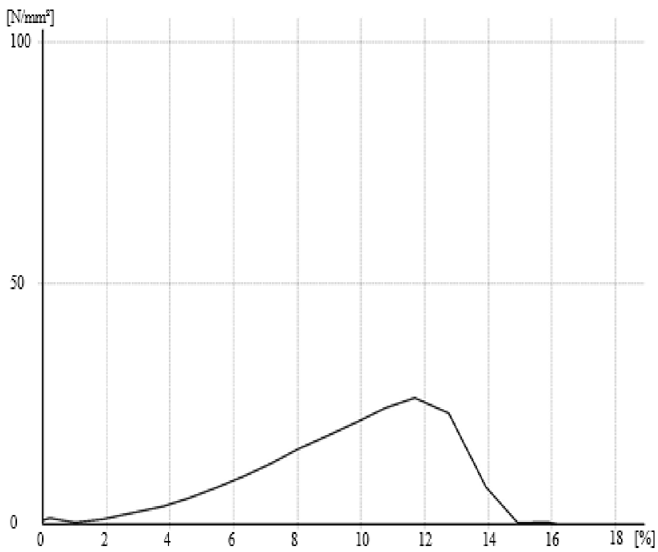
Output force-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.07	0.83
2	0.22	1.54
3	0.41	2.23
4	0.67	2.93
5	1.00	3.62
6	1.36	4.31
7	1.75	5.01
8	2.14	5.72
9	2.38	6.42
10	2.38	7.14
11	3.10	7.86
12	2.71	8.71
13	0.41	9.56
14	0.13	10.05

Stress-elongation-diagram for tensile specimen

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021



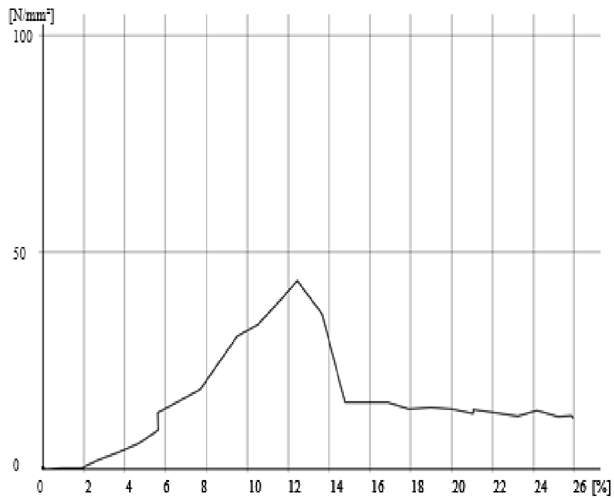
Output stress-elongation-table

Material: comp
Free Text:
Initial measurement length: 75mm
Specimen width: 13mm
Date: 29.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.08	0.48
2	1.05	0.48
3	1.05	2.41
4	4.07	3.24
5	7.01	4.14
6	11.00	5.03
7	16.12	5.93
8	22.15	6.83
9	28.86	7.72
10	34.58	8.64
11	34.13	9.63
12	33.68	10.61
13	21.17	11.81
14	4.82	12.88
15	4.97	13.88
16	4.90	14.74
17	4.75	14.90

Stress-elongation-diagram for tensile specimen

Material:	comp
Free Text:	
Initial measurement length:	75mm
Specimen width:	13mm
Date:	29.04.2021

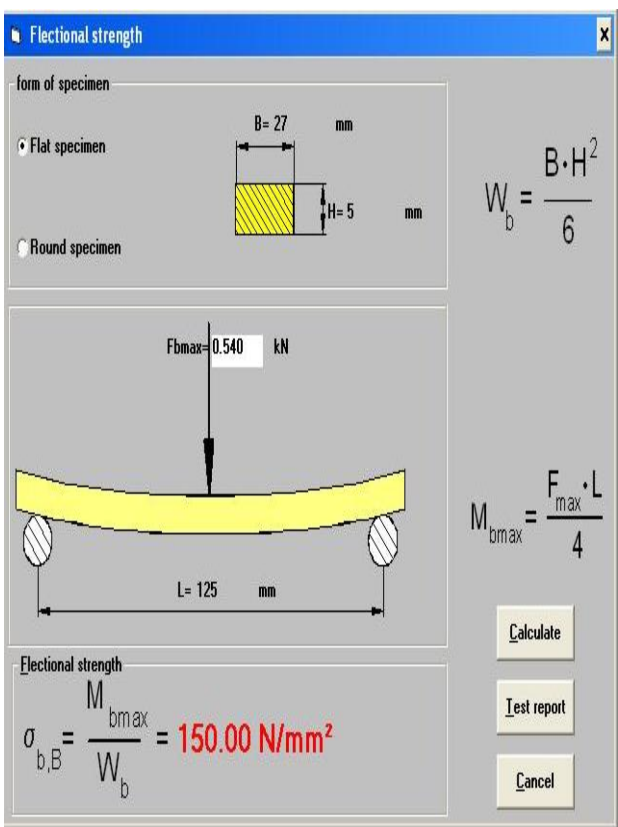


Output stress-elongation-table

Material:	comp
Free Text:	
Initial measurement length:	75mm
Specimen width:	13mm
Date:	29.04.2021

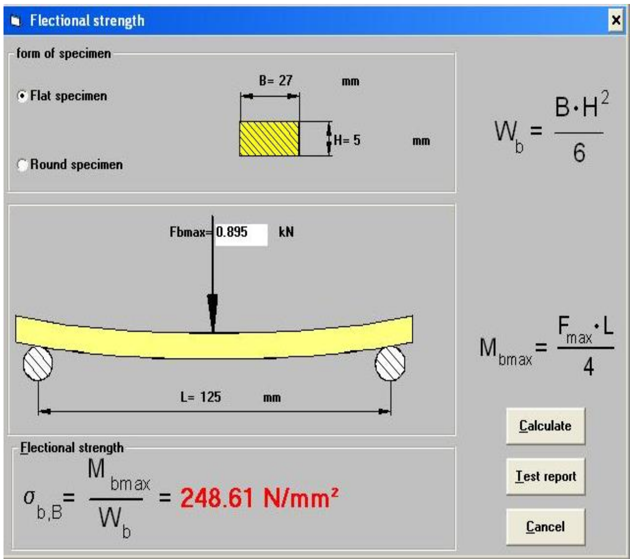
No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.23	0.63
2	0.75	1.53
3	1.96	2.45
4	3.24	3.39
5	4.52	4.32
6	6.18	5.23
7	8.14	6.14
8	11.07	7.04
9	15.07	7.95
10	19.29	8.85
11	24.18	8.83
12	24.18	10.74
13	35.79	11.51
14	41.36	12.55
15	14.31	13.79
16	0.08	14.16

Appendix C : Flexural strength test/bending load



Test report

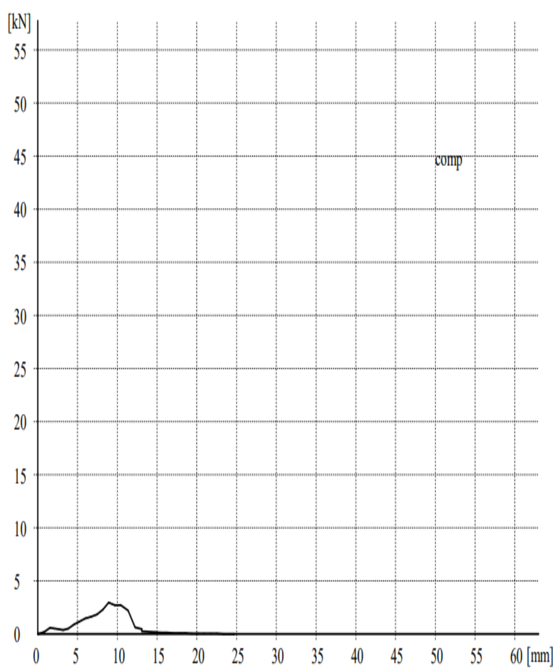
Kind of test:	Bending test DIN 50110
Material of specimen:	____________
Kind of specimen	Bending specimen 27 DIN 50110
Temperature:	20°C
max.test force:	540.0 N
flectional strength	150.00 N/mm²
Ductile yield	____________
Description of the fracture area:	____________
Distance between supports:	125 mm
Date:	28.04.2021
Name of tester:	____________
Signature:	____________



Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	____________________
Kind of specimen	Bending specimen 27 DIN 50110
Temperature:	20°C
max.test force:	895 N
flectional strength	248.61 N/mm²
Ductile yield	____________________
Description of the fracture area:	____________________
Distance between supports:	125 mm
Date:	28.04.2021
Name of tester:	____________________
Signature:	____________________

Appendix.D **: Compression test**



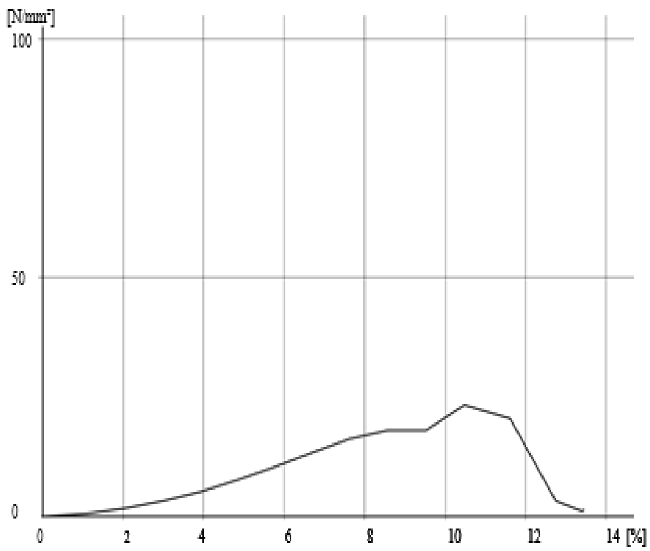
Output force-elongation-table

Material:	comp
Free Text:	
Initial measurement length:	75mm
Specimen width:	13mm
Date:	29.04.2021

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.07	0.83
2	0.22	1.54
3	0.41	2.23
4	0.67	2.93
5	1.00	3.62
6	1.36	4.31
7	1.75	5.01
8	2.14	5.72
9	2.38	6.42
10	2.38	7.14
11	3.10	7.86
12	2.71	8.71
13	0.41	9.56
14	0.13	10.05

Stress-elongation-diagram for tensile specimen

Material:	comp
Free Text:	
Initial measurement length:	75mm
Specimen width:	13mm
Date:	29.04.2021



Output stress-elongation-table

Material:	comp
Free Text:	
Initial measurement length:	125mm
Specimen width:	23mm
Date:	27.04.2021

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.07	0.21
2	0.46	0.68
3	1.42	1.23
4	0.94	2.55
5	1.25	3.06
6	2.07	3.63
7	2.82	4.20
8	3.54	4.78
9	3.90	5.37
10	4.38	5.96
11	5.54	6.54
12	7.10	7.14
13	6.47	7.76
14	6.47	8.37
15	5.34	9.09
16	1.52	9.80
17	1.06	10.46
18	0.55	10.46
19	0.39	11.82