



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Manufacturing Engineering

**EFFECT OF FIBER ORIENTATION & VOLUME FRACTION ON
THE MECHANICAL AND THERMAL PROPERTIES OF BAMBOO
FIBER REINFORCED EPOXY COMPOSITE FOR LAPTOP CASE
APPLICATION**

**A Thesis Submitted to the Graduate School of Addis Ababa
University in Partial Fulfillment of the Requirement for the Degree
of Masters of Science in Mechanical Engineering (Manufacturing
Engineering)**

By

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Addis Ababa Ethiopia

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Addis Ababa Institute of Technology
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DECLARATION

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This is to certify that the thesis prepared by **Tigist Mesfin**, entitled: *Effect Of Fiber Orientation & Volume Fraction On The Mechanical and Thermal Properties Of Bamboo Fiber Reinforced Epoxy Composite For Laptop Case Application*, do hereby declare this thesis is my original work and that it has not been submitted partially or in full for a degree in any university/ institution, which complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Protecting one's laptop is an undeniable thing because of its massive personal data stocking, it being one's working media (tool) and its expensiveness to replace it if it got physically damaged by any means. This work aims to investigate the effect of fiber volume fraction and orientation on mechanical (tensile, flexural, and impact) strength, thermal resistance and water absorption properties of bamboo fiber reinforced epoxy composites experimentally. It aims to explore its applicability as a protective casing for personal computers. Bamboo fibers were treated with 6% NaOH for 2 hours and 160⁰c temperature for 3 hours. Laminates were fabricated by hand lay-up technique in a mold and cured under light pressure at room temperature followed by curing for two days. Bamboo laminates were prepared by varying three orientations (0/45⁰, 0/30⁰ & 0/90⁰) of fiber and four fiber volume fractions from 20%, 30%, 40%, and 50%. Specimen preparation and testing were carried out as per ASTM standards. The highest tensile, flexural and impact strength were obtained from composite with 30% fiber 70% epoxy matrix composition at 0⁰/90⁰ orientation having 48.85MPa, 38.17MPa and 170.57 J/m² respectively. The lowest water absorption percentage was obtained from treated composite with 20% fiber 80% epoxy matrix composition at 0⁰/90⁰ orientation having 1.71% of absorption. Evidently 30% bamboo fiber reinforced epoxy composite has very high thermal resistivity almost equal with wood, which makes it non-conductive material. Based on the results and analysis, the selected bamboo fiber - epoxy composite has the potential to be further developed as protective case for laptops.

Keywords: Bamboo fiber, Epoxy, composite characterization, fiber orientation, fiber volume fraction, mechanical, thermal strength laptop casing.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	America Society for Testing and Material
FRC	Fiber Reinforced Composite
FRP	Fiber Reinforced Polymer
UTS	Ultimate Tensile Strength
FS	Flexural Strength
UTM	Universal Testing Machine

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

As such, the fiber-reinforced composites have generated much research interest, owing to their ability to enable customization of properties and hence the ability to replace conventional materials in recent technological advances.

Composite materials are material systems that consist of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other[1]. One constituent indiscreet constituent (the reinforcement) distributed in a continuous phase (the matrix) and that derive their distinguishing characteristics from the properties and behavior, geometry and arrangements of constituents and from the properties of the boundaries between the constituents[2].

As composite materials are increasingly substituted for metallic materials in mechanical structures, the dynamic, as well as static characteristics, should be considered. It is necessary to know the physical, mechanical, electrical, and thermal properties of FRCs for one's effective application. FRCs are currently being employed in copious fields of applications thanks to their significant mechanical properties.

Composites exhibit different physical, chemical, thermal, and mechanical properties depending upon their constituent materials. Composite materials consisting of metals, ceramics and polymers as their matrix and fibers, whiskers and particulates as a reinforcement exhibit different mechanical, physical, thermal and chemical properties and strengths. Furthermore composites of the same material (same reinforcement and same matrix material) exhibit different properties. This difference is because of some parameters like proportion or ratio of reinforcement to the matrix (volume fraction), geometry of fiber, orientation of fiber, and the likes. Of this parameters volume fraction, orientation and geometry play a major role in defining the mechanical properties of composites. Composites of the same reinforcement fiber material, interaction of the phase and the like parameters plus same matrix exhibit different mechanical properties because of their orientation and volume fraction difference meaning that increasing and decreasing the

orientation and volume fraction increase or decrease the mechanical, physical and thermal properties of the composite[3].

Hence it is essential to know the particular effect of fiber volume fraction and orientation in the matrix up on the composite properties since the finding in turn has a very significant contribution for all manufacturing related studies and activities especially in their decision making for material selection process.

Protection for one's laptop is critical like our cell phones, actually even more than our cell phones since it carries an immense amount of data and very necessary files that one can never afford to lose. In addition to that, since they are expensive materials in the market, one cannot easily replace them once they get damaged by any means. Physical damages may cause screen black spot or even blackout, hardware parts loosening and detachment, scratches on the outer surface and hardware malfunctions lead to software malfunctions and failure and eventually data and file lose.

Furthermore, casings also benefit to minimize the heat dissipated from directly reaching the user if they are made from non-conductive materials like natural fibers and designed properly containing fins at the area of the on the laptop.

As the laptop is the portable device, using and carrying it from one place to another should be done with safety and ease. Laptop case is a protective covering case that can be installed upon the external or of the laptop. The purpose of laptop cases is to add another layer of protection for laptop and also keeping the user from heat exposure and to keep the dust away. Fundamentally, a good hard laptop case will be one that's durable, with plenty of padding on the inside, as well as a reinforced outer shell to ensure your laptop withstands any accidental drops or scrapes with little to show for it.

In current market, its known that laptop cases are divided into three types based on their material form such as fabric sleeve, leather and hard plastics. Laptop sleeves come in a variety of materials such as neoprene, EVA, polyester, nylon, and even leather. One should consider their everyday lifestyle, as well as their usual laptop usage habits, when choosing the material for a laptop sleeve[4]. Well, it is necessary to understand the advantages and disadvantages of various materials in the laptop sleeve. Currently, laptop cases are developed by handmade(fabric) and

injection molding[4]. This confirms that it can be prepared using another type of fiber which is natural fiber and hand layup method. It delivers protection without sacrificing access to ports, lights, and buttons.

The composite materials have advantage over other conventional materials thanks to their high specific properties like tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable the structural design to be more versatile. Due to their many advantages, they're widely utilized in the aerospace industry, during a sizable amount of economic engineering applications, like machine components, combustion engine parts, railway coaches, flywheels, process industries, sports and leisure equipments; marine structures; and biomedical devices[5].

Therefore, this research studied the mechanical, thermal and physical properties of bamboo fiber reinforced epoxy composite with different fiber – matrix volume percentage and orientation.

Fibers are a unique class of materials because of their anisotropy. Usually, fibers have a high length compared to their diameter. This so-called high ratio is liable for the unique properties compared to a bulk material. The geometric and structural aspects of anisotropy result in extraordinary mechanical properties. Typical fibers for composite applications have high strength and stiffness in fiber axis direction, while they are weak and flexible perpendicular to it. Also, other physical properties, like electrical or thermal conductivity could also be totally different when measured along or perpendicular to a fiber[6].

The interface between fiber and matrix is liable for the transfer of load to the fiber. By controlling the adhesion between the two components, the failure of a composite part is often adjusted to specific needs. A detailed understanding of the interaction of fiber and matrix is therefore necessary to design tailored fiber reinforced composites[6].

1.2 Problem Statement

Composites exhibit different physical, chemical, thermal and mechanical properties depending up on their constituent materials. But the constituent material is not the only thing that matters. Composites of the same material (same reinforcement and same matrix material) exhibit different properties. This difference is because of some parameters like proportion or ratio of

reinforcement to the matrix (volume fraction), geometry of fiber, orientation of fiber, interaction of the phase, type and source of the natural fiber collected from the likes.

Thus, it is necessary and very compulsory to know the effect of increasing both the fiber volume percentage and also the fiber orientation on the composite mechanical, physical and thermal properties since the finding in turn has a very significant contribution for all manufacturing related studies and activities especially in their decision making for material selection process in order to get the quality we desire since there are only few researches done investigating both volume fraction and orientation simultaneously, let alone on bamboo fiber.

Carrying and using a laptop without some sort of protection and storage for it is always a risk that a person takes. People usually try to protect and shield their laptop carrying bag manually by shielding with hands or body in crowded or tight areas because a bag is just a carrying luggage which is not a protective safety bag and while using to block the heat transmission, they use their bag, flat boards or planks which are not portable thus are inconvenient for mobilization. The purpose of this laptop cases on top of adding another layer of protection for laptops is also to decrease the amount of heat transmitted from the laptop to the user and it also can help to keep any dust, since there are no protection casings provided except for apple's MacBook series laptops.

This apple MacBook casings are made of ABS plastics which have properties like scratches easily, low continuous service temperature, burn easily and continue to burn once the flame is removed, poor solvent resistance particularly aromatic, ketones and esters and can suffer from stress cracking in the presence of some greases[7]. Hence the research started with hypothesis that, with the best orientation and volume fraction, bamboo fiber reinforced epoxy composite will resolve the above-mentioned problems and become an ideal material for laptop protective case application.

Therefore, the research is focused to investigate that how much increasing volume fraction and fiber orientation contribute on mechanical (tensile, flexural and impact strength) thermal and physical properties of the composite using Ethiopian bamboo fibers for the application of adding another layer of protection for a laptop and also help to keep any dust and avoid heat

transmission to the user since there are no protection casings provided for all types of laptops except for apple's MacBook series laptops.

1.3 Research Questions

From the various process parameters affecting the mechanical, thermal and physical water absorption property of composite, will increasing the fiber volume ratios from 20% - 50% and orientations from $0/30^0$ – $0/90^0$ improve the mechanical, thermal and physical water absorption property of the composite and can that composite be used as a protective casing for any laptop?

1.4 Objective

1.4.1 General objective

The objective of this work is to investigate the effect of volume fraction and fiber orientation on mechanical and thermal properties of bamboo fiber reinforced epoxy composites experimentally and then to evaluate its suitability for laptop protective covering case applications.

1.4.2 Specific objectives

- ❖ Selection of bamboo with better mechanical characteristics that give better fiber properties based on literature reviews.
- ❖ Fabrication of composite sample specimens varying volume fraction and fiber orientation based on literature reviews.
- ❖ Examine the mechanical properties such as tensile properties, flexural strength and impact strength and physical (water absorption) by varying volume fraction and fiber orientation based on literature reviews.
- ❖ Examine the thermal property of the best composite specimen volume ratio and fiber orientation that gave the best mechanical and water absorption result.
- ❖ To analyze the effect of fiber orientation and volume fraction on mechanical & physical properties of fabricated composite.

- ❖ To compare applicability of fabricated composite with the material that is being used currently for the selected application.

1.5 Scope and limitation of the study

1.5.1 Scope of the study

This thesis focused on the effect fiber volume fraction and orientation on mechanical (tensile strength, flexural strength & impact strength) and thermal property of bamboo fiber reinforced composites. In addition physical water absorption property was also tested. It includes fabrication of the composite material and characterization BFREC. The composite fabrication include; fiber extraction and preparation (fiber cutting and alkaline treatment), fiber characterization (length, width, diameter and density), composite manufacturing and tests (mechanical: tensile strength, flexural strength, impact strength and thermal resistance and water absorption tests).

1.5.2 Limitation of the study

During conducting this thesis work many challenging conditions were observed some of them are.

- ❖ There hasn't been any method or technology adopted to extract bamboo fiber except manual extraction method, which is a long and unsatisfying process because the fibers extracted are not fine as desired.
- ❖ Difficulties of finding the desired viscous epoxy (Dr. crafty epoxy) type inside the country therefore had to look and purchase from outside of the country at Amazon store America and wait till it is shipped.
- ❖ A picnometer to measure single fiber density (for volume fraction calculations) was difficult to find in our laboratories, there was only one at chemical laboratory which they do not let students use except their assistants.

1.6 Significance of the study

The significance of this study is that it clarifies the extent of increasing the fiber loading and orientation indeed increases the mechanical strength of the composite. It also contributes in

assisting composite manufacturing industries and researchers in choosing the best fiber and matrix materials, the better fiber extraction methods (manually or technologically) and heat and alkaline fiber treatment purposes and methods, the better composite manufacturing technique, the better fiber orientation and volume fraction ratios in order to get the quality they desire depending on the application of the material. It provides and guides fellow researchers and students about the better fiber orientation and volume fraction in their researches and future natural fiber composite material utilization.

1.7 Organization of the Thesis

Chapter One: contains introduction and the overall background of the topic and the purpose in doing the research.

Chapter Two: addresses the detailed science behind natural fiber composite and protective case by reviewing different literatures.

Chapter Three: Explains the materials used, preparation methods, process and condition for setting up the needed specimens for test.

Chapter Four: presents different results obtained from the experimental tests and the results are discussed in detail.

Chapter Five: gives conclusion and recommendations on the research done. In addition, future work is proposed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

In this chapter different literature about composites, types of composites, composite constituent materials (reinforcement and matrix), natural fibers and polymeric matrixes, the factors affecting the properties of natural fibre polymer composites, fiber treatment methods, composite fabrication methods, and application areas of natural fiber composites are discussed and presented.

2.2 Composite materials

Composite materials emerged in the middle of the twentieth century as a promising class of engineering materials providing new prospects for modern technology[8]. Composite materials are macroscopic combinations of two or more distinct materials having a discrete and recognizable interface separating them[9].

Composite materials have been introduced into almost every industry in some form or fashion. Composites have added new dimensions to the design and construction of buildings. Their ease of manufacture, light weight, high strength, low maintenance, decorativeness, and functionality have had a significant impact on the industry. Composite materials generally have higher strength- and modulus-to-weight ratios than traditional engineering materials. These features can reduce the weight of a system by as much as 20 to 30%. The weight savings translates into energy savings or increased performance. Since composite materials can be manufactured into almost any shape, they allow great design flexibility and offer reduced parts count for articles[8].

The use of composite materials will continue to grow. As more engineers come to understand composites, more opportunities will be recognized for their use. As the use of composites increases, more developments will take place in the areas of constituent materials, analysis, design, and fabrication. Composite materials offer tremendous for tailor ability, design flexibility, and low-cost processing with low environment impact. These attributes create a very bright future composite materials[12].

2.3 Constituents and types of composite materials

2.3.1 Constituents of composite materials

A composite material is the union of two or more materials, different from each other, to get better properties (mechanical, physical, thermal, electrical)[13]. Composite material's comprise of two parts:

I. Discontinuous phase (reinforcements)

Reinforcements need not necessarily be in the form of long fibers[14]. One can have them in the form of particles, flakes, whiskers, short fibers, continuous fibers, or sheets. It turns out that most reinforcements used in composites have a fibrous form because materials are stronger and stiffer in the fibrous form than in any other form.

II. Continuous phase (matrix)

The matrix is basically a homogeneous and monolithic material in which a fiber system of a composite is embedded. It is completely continuous. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, color, durability and functionality[15].

2.3.2 Types of composites materials

According to the type of matrix material, composites are classified as:-

I. Metal matrix composites (MMC)

Metal matrix composites (MMCs), as the name implies, have a metal matrix. Examples of matrices in such composites include aluminum, magnesium, and titanium[3]. Metal matrix composites are mainly used to provide advantages over monolithic metals such as steel and aluminum. These advantages include higher specific strength and modulus by reinforcing low-density metals, such as aluminum and titanium; lower coefficients of thermal expansion by reinforcing with fibers with low coefficients of thermal expansion, such as graphite; and maintaining properties such as strength at high temperature[16].

II. Ceramics matrix composites (CMC)

Ceramic matrix composites (CMCs) have a ceramic matrix such as alumina calcium aluminosilicate[17]. Combination of a fiber and ceramic matrix makes CMCs more attractive for applications in which high mechanical properties and extreme service temperatures are desired. Ceramics by themselves have low fracture toughness under tensile or impact loading, they fail catastrophically.

III. Polymer matrix composites (PMC)

The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane)[1]

2.4 Reinforcement

Fiber reinforced composites are the most widely used class of polymer composites. Recently, fiber reinforced polymer matrix composites have found applications in various areas such as automotive, marine, aerospace etc. due to their high specific stiffness and strength[18]. The fibers are the most important constituents of the FRCs. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices[3]. They occupy the largest volume fraction in the laminate. Thus, they bear a major portion of the load acting on the composite structure. The fibers in a fiber reinforced composite influence the following aspects [6].

- ❖ Density
- ❖ Tensile Strength and Modulus
- ❖ Compressive Strength and modulus
- ❖ Fatigue strength and Failure mechanisms
- ❖ Electrical and Thermal conductivities
- ❖ Cost of composite structure

A. Particle reinforced polymer (PRP)

These are composites in which particles are used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials, including polymers and carbon black[19]. Particles are used to increase the modulus of the matrix and to decrease the ductility of the matrix.

B. Fiber reinforced polymer

These are composites composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while the matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers[3]. Sometimes, fillers might be added to smooth the manufacturing process, impart special properties to the composites, and/or reduce the product cost. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices.

2.5 Natural fibers

The term “natural fibers” may refer to a very wide category of fibers[2]. All the fibers are derived from natural sources. They may either be animal fibers (animal hair, chicken feather etc.) or Plant Fibers (Leaf, seed, fruit, wood, bast fiber, grasses and reeds etc). the following table 2.1 lists the tensile strength and modulus for different natural fibers and shows that bamboo fiber has about 520MPa tensile strength having the least density of all of them.

Table 2-1 Tensile strength and modulus for different natural fibers[5]

Fiber	Specific gravity(kg/m³)	Tensile strength (MPa)	Tensile modulus (GPa) (average)
Coir	1.15	95-230	4.4
Jute	1.3	393	55
Sisal	1.3	510	28
Banana	1.35	180-914	12
Kenaf	1.4	223-930	34
Flax	1.5	344	27
Cotton	1.55	287-800	9.

Sun-hemp	1.7	389	35
Pineapple	1.56	170	40
Bamboo	0.863	520	36

The exploitation of natural fiber composites in various applications has opened new avenue for both academicians as well as industries to manufacture a sustainable module for future applications of composites[20]. Below figure 2.1 shows the strength comparison of natural fibers.

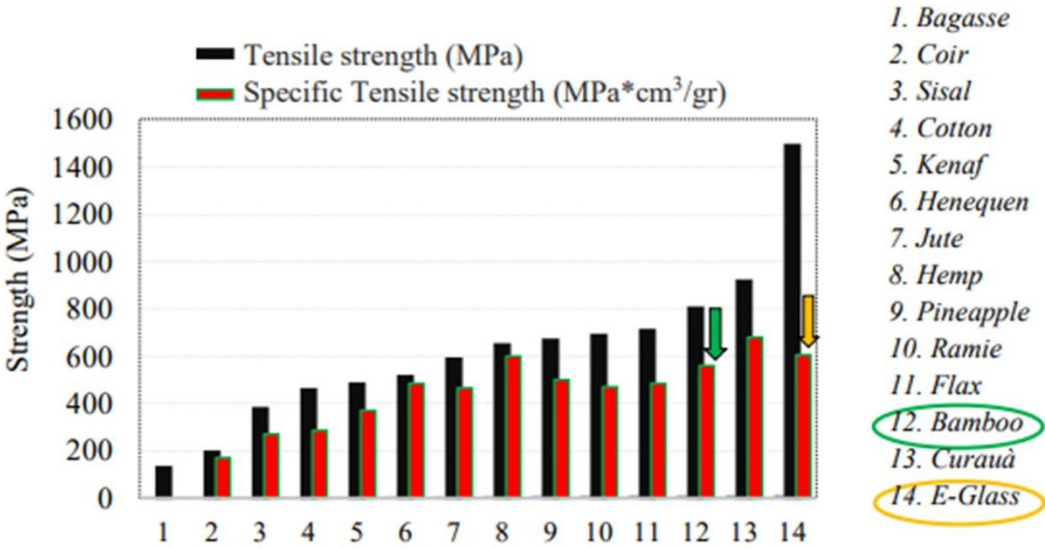


Figure 2-1 Strength comparison of natural fibers[21]

The main reason for natural fibers utilization is that, when they are added to plastic or polymer matrices, they significantly improve mechanical performance[22] [2]. An improvement in strength and stiffness is obtained without significant increase in density or the cost of the material.

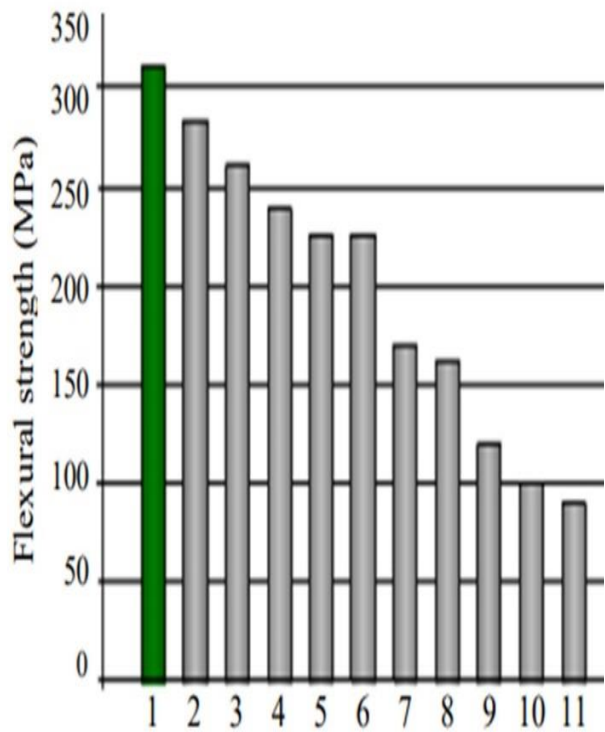
2.5.1 Bamboo fibers

Bamboo, which is belonging to the family of the Bambusoideae, encompasses approximately 60– 90 genera and 1100–1500 species which mainly grows in tropical and sub-tropical regions. Ethiopia has the largest area of bamboo in Africa by constituting 67% of the total bamboo forest area of the continent and about 7% of the world total bamboo resource. These resources are

distributed in the highlands and lowlands of Ethiopia. Assosa, Injibara, Gimbi, Ambo, Gurage, Bale, Masha, Chenchu and Hagere-Selam are rich in naturally occurred and planted bamboo forests. The largest source of bamboo plant present in Assosa is lowland type which has solid culm.

The bamboo fiber length and fiber wall thickness increase with increase of age of bamboo plant[23]. Moreover, the strength of bamboo fiber increases with an increment of age. The optimum strength value occurs between 2.5 and 4 years.

The structure of bamboo itself is a composite material, consisting of long and aligned cellulose fibers immersed in a ligneous matrix (lignin and hemicellulose)[24]. Bamboo is an orthotropic material with high strength along axial and low strength transversal to its fibers. This is due to the longitudinally alignment of its fiber to its body while at the same time this is attributed by its polylamellate wall structure that consists of alternating broad and narrow layers with different fibrillary orientation. Furthermore, high cellulose and lignin content and relatively small microfibril angle of bamboo plant contribute to this high strength[23][25]. The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%) Bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin.[26].



1. Bamboo + Epoxy (Vf: 48%)
2. Flax + Epoxy (Vf: 40%)
3. Jute + Epoxy (Vf: 40%)
4. Jute + Vinylester (Vf: 35%)
5. Hemp + Epoxy (Vf: 35%)
6. Sisal + Epoxy (Vf: 37%)
7. Kenaf + Cashew nut Shell
8. Bamboo + Polyester (Vf: 15%)
9. Kenaf + Polyester (Vf: 60%)
10. Hemp + Polyester (Vf: 60%)
11. Hemp + Cashew nut Shel

Figure 2-2 comparison of mechanical properties of natural & glass fiber composites[21]

The figure 2.3 illustrates the comparison of mechanical properties of natural fiber composites & fiber glass composites and depicts that bamboo has a superior flexural strength value [19][21]. These results indicate that the mechanical properties of bamboo fiber is super higher than that of other natural fibers.

Many researchers have reported advantages of bamboo fibers, such as being abundantly available in nature, nontoxic, renewable, cost-effective, and also providing necessary bonding[27]. Being widely and easily available, being exceptionally cheap, eco-friendly, renewable and having a high specific mechanical performance are some of the most important properties of bamboo fibers, which make it a favorite option for the replacement of Synthetic fibers. Table 2.2 and 2.3 demonstrates the tensile, flexural and compressive strengths of bamboo fiber

Table 2-2 Tensile, flexural and compressive strengths of bamboo fiber[23]

Mechanical Properties	Values	Tests Standards
Density	1.12g/m ³	
Tensile Strength	187.73MPa	ASTM D3039
Flexural Strength	190.32MPa	ASTM D790
Compressive Strength	114.13MPa	ASTM D695
Water absorption	2-3%	ASTM D570

Table 2-3 Mechanical properties of bamboo fiber[28]

	Density (g/m³)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (MPa)	Elongation (MPa)
Bamboo(across the fibre)	0.802	806	9.04	3.02	0.1
Bamboo (along the fibre)	0.802	200.5	230.09	63.54	10.2

Among the well-known natural fibers, bamboo has one of the most favorable combinations of low density and high mechanical strength, that is, it has high specific stiffness and strength, as shown in the table above[29]. In terms of specific properties, it is claimed they can be compared with glass fiber.

Lowland bamboo specimens were having higher tensile strength than highland bamboo specimens with respect to tensile load[30]. The maximum tensile strength of solid bamboo without node specimens for year two, three and four were found 227.5MPa, 270.9MPa and 322.7MPa respectively, at the top portion except year two which is in the middle portion. The maximum tensile strength of hollow bamboo without node specimens were found at the top portion 215.0MPa, 298.4MPa and 295.0MPa at year two, three and four respectively. The lowest tensile strength of hollow bamboo without node specimens were registered at the bottom portion 140.5MPa, 177.7MPa and 195.4MPa at year two, three and four respectively.

The average tensile strength without node of hollow bamboo ranges between 179.7MPa to 246.1MPa and solid bamboo ranges between 211.5.0MPa to 260.2MPa[30]. The lowest tensile strength of solid bamboo without node specimens were registered at the bottom portion 183.8MPa, 236.3MPa and 211.2MPa at year two, three and four respectively.

Unfortunately, the high content of hydroxyl group of short fibers, i.e., its hydrophilic character, is the main cause responsible for poor compatibility between cellulose fibers and the polymer, which lead to composites with unsatisfactory mechanical properties, and durability issues such as weather ability, moisture resistance, thermal performance, fungal attack[31].

Heat treatment changes the chemical composition of bamboo fibers, leading to the degradation of hemicelluloses, the increase of cellulose content and condensation of lignin, respectively. In addition to degradation during thermal treatment, hemicelluloses can also undergo dehydration reactions with a decrease of accessible hydroxyl groups[31]. Heat treatment helps to improve the durability of BF. There is less water absorbed by fibers as a result of chemical change with a decrease of accessible hydroxyl groups, and thus the decrease of the equilibrium moisture content. It also indicates that sufficient thermal treatment is in favor of the increase of thermal stability and anti-UV aging property of bamboo fiber[31].

Compared with that of non-treated bamboo fiber reinforced composite, hygroscopicity and dimensional stability of composites reinforced with thermally treated BF improved due to the reduction of hemicelluloses, increased destruction of accessible hydroxyl groups, and thus decreased affinity with water (decreased EMC)[31]. However, immoderate treatment resulted in slightly increased hygroscopicity and deformation. It is important to optimize the process parameters in order to optimize the chemical transformation that are responsible for equilibrium moisture content (EMC) of treated BF, hygroscopicity and dimensional stability of treated-BF based composite. The following graph on figure 2.4 illustrates moisture content in natural fibers at equilibrium condition.

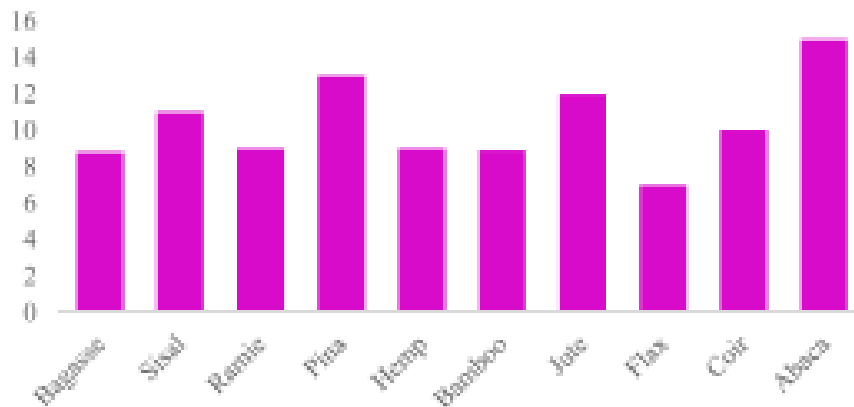


Figure 2-3 Moisture content in natural fibers at equilibrium condition[12]

The properties of the fiber reinforced composites depend on various fiber parameters, the most important being fiber length, fiber orientation and fiber loading[32]. The effect of fiber content and fiber length on the mechanical behavior of bamboo fiber reinforced epoxy composites was investigated. The results confirmed that fracture toughness and flexural modulus of the composites monotonically increased with fiber length and content. That's why continuous long fibers were chosen.

2.6 Matrix Materials

The matrix is basically a homogeneous and monolithic material in which a fiber system of a composite is embedded[33]. It is completely continuous. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, color, durability and functionality.

2.6.1 Polymer matrix

The polymer matrix can impart great chemical and corrosion resistance to composites[11]. The light weight and high strength and the ability to easily manufacture takes the topmost advantage. The lack of corrosion of the materials and the low maintenance cost have reduced the cost of ownership and extended the service life of many parts and products. Examples of products in this industry include auto and truck bodies and parts, trailers, tanks, special-purpose vehicles, and manufacturing equipment.

This is the most widely used group of matrices. A polymer is a long chain molecule having one or more repeating units of atoms joined together by strong covalent bonds[16][34][2]. They may either be oriented in a random fashion (amorphous polymers) or in a mixture of random fashion and orderly fashion (as found in semi-crystalline polymers). They have extremely good properties such as high stiffness and fracture toughness, good corrosion and abrasion resistance. Polymer matrix composites are the subject of growing interest in recent times due to the immense versatility in their applications. They can further be classified into the following two types.

2.6.1.1 Thermoplastic Resins

Thermoplastics are formable at high temperatures and pressure because the bonds are weak and of the van der Waals type[33].

2.6.1.2 Thermosetting Resins

Thermoset polymers are insoluble and infusible after cure because the chains are rigidly joined with strong covalent bonds[2]. The most commonly used resins are Epoxy, Unsaturated Polyester and Vinyl Ester[16][34]. The liquid resin is generally converted into a hard solid by the process of chemical cross linking. This leads to the formation of a tightly bound three-dimensional network, which lends the strength to the polymer block. The mechanical properties of various resins depend on the molecular units making up the networks. They also depend on the length and density of the cross links. The most notable property of the thermosetting resins is they have lower strains to failure. These may be essentially considered to be brittle materials.

Since thermoset matrices are formed due to an irreversible chemical transformation of a resin into an amorphous cross-linked polymer matrix[35]. Due to huge molecular structures, thermoset resins provide good electrical and thermal insulation. Thermosets have low viscosity, which allow proper fiber wet out, excellent thermal stability and better creep resistance. The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics[1]. Mostly thermoset resins can be formulated to give a wide range of properties upon the requirement. Epoxy resin has excellent adhesion property compared to other resins. More than two-thirds of the polymer matrices used in aerospace applications are epoxy based.

As can be seen, each of the resin systems has its advantages and drawbacks[1]. The use of a particular system depends on the application. These considerations include mechanical strength, cost, temperature excursions, etc. Figure 2.5 shows the comparison of five common resins based on smoke emission, strength, service temperature, and cost. It shows that epoxy has superior maximum strength, good thermal resistance and medium cost. Figure 2.5 illustrates comparison of performance of several common matrices used in polymer matrix composites, showing that epoxy matrix has the maximum strength, moderate service temperature and cost and low smoke emission.

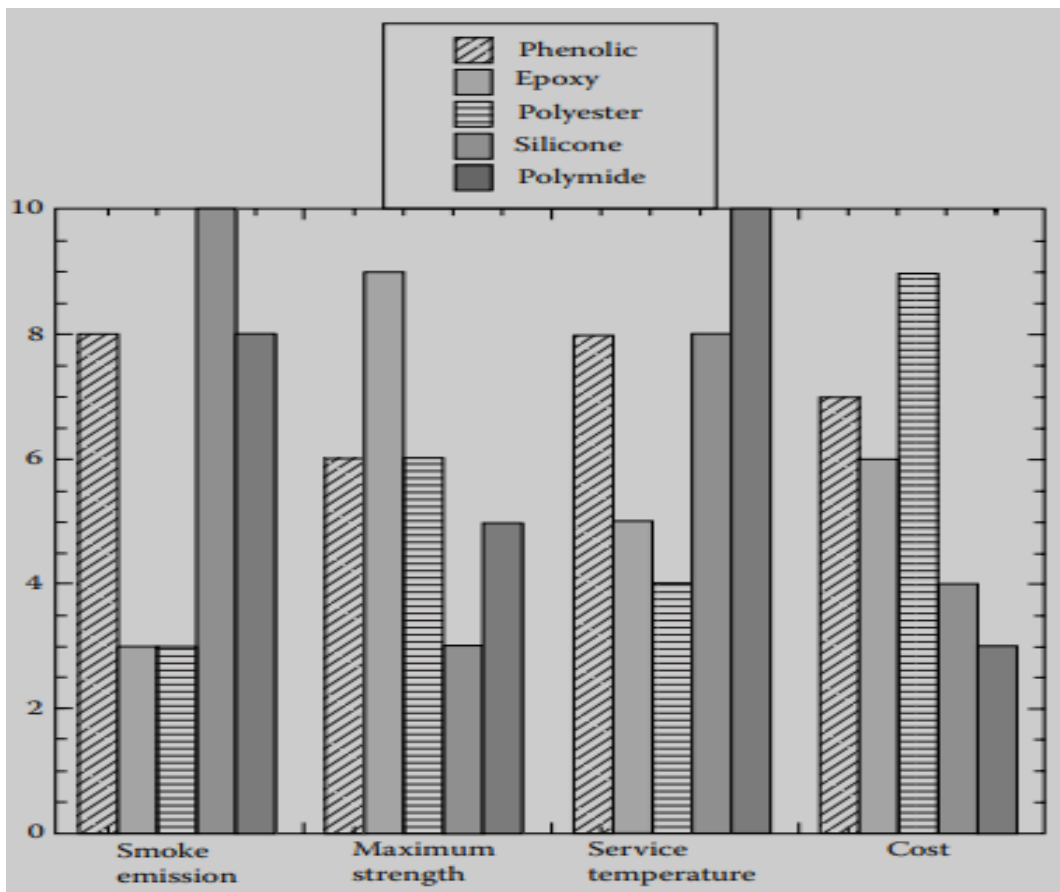


Figure 2-4 Comparison of performance of several common matrices used in polymer matrix composites[1].

In addition to that it has low shrinkage upon curing, good chemical resistance, excellent mechanical properties[35]. Epoxies have been used for advanced composites due to their adhesion to wide variety of fibers, with superior mechanical and electrical properties, good

performance at elevated temperatures. The neat epoxy sample tested has an average thermal conductivity of 0.244 W/m K.

The resin that was used for this study is Epoxy Resin. It has superior flexural strength, tensile strength, bond strength, adhesive characteristics and fatigue resistance than other types of resins. In general, epoxy resins have the following advantage over the other resin types:

- ❖ Better adhesive properties (the ability to bond to the reinforcement or core)
- ❖ Superior mechanical properties (particularly strength and stiffness)
- ❖ Improved resistance to fatigue and micro cracking
- ❖ Low volatility during cure
- ❖ Low shrink rates, which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement
- ❖ Reduced degradation from water ingress (diminution of properties due to water penetration)
- ❖ Increased resistance to osmosis (surface degradation due to water permeability) Quantity of resin required

The main advantages of polymer matrix composite materials are their strength and stiffness. Other qualities that come with the reinforcement of polymers are as follows[17]. Table 2.4 describes other qualities of polymer matrix apart from strength and stiffness.

Table 2-4 Other qualities of polymer matrix[17]

Improved processing	Density Control	Thermal Conductivity	Thermal Expansion Control
Flame retardancy	Cost reduction	Greater toughness	Impact resistance
Fatigue resistance	Fracture resistance	Abrasion resistance	Corrosion resistance
High specific strength to weight ratio	High specific stiffness to weight ratio	Improved fatigue strength	High creep resistance

The bamboo fiber reinforced epoxy composites has a better tensile strength (200MPa), flexural strength (230MPa) and impact strength (63KJ/m²) at 60% volume fraction, compared with other polypropylene, polylactic acid, polyester and 0.5wt% of fly ash, epoxy and 1.5wt% of cenosphere, epoxy and 3wt% of nano clay polymer and polymer with filler matrixes[28].

The BFRCs with fiber volume fractions ranging from 0% to 40% embedded in three thermoset resins (epoxy, polyester, vinyl ester) were subjected to tensile and flexural tests and the fracture pattern was examined[36]. It was found that the bamboo fiber reinforced epoxy composite (BFREC) with 40% fiber volume fraction exhibited the highest tensile and flexural strength compared to polyester and vinyl ester composite. Figure 2.6 illustrates the effect of types of thermosetting matrix on tensile and flexural properties of bamboo fiber showing that bamboo fiber reinforced with epoxy matrix has superior tensile and flexural strength than the polyester or vinyl ester matrix.

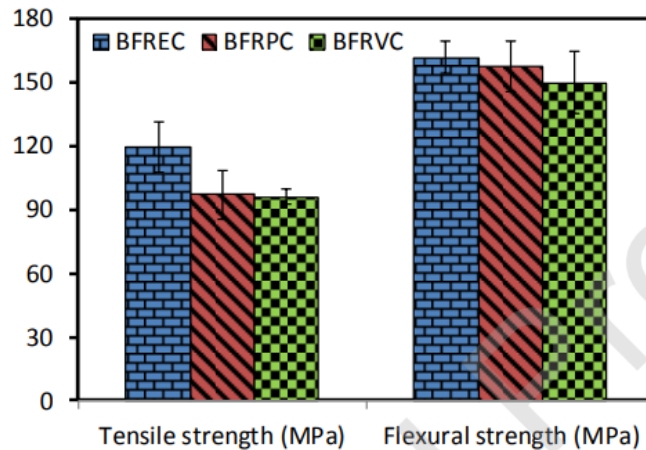


Figure 2-5 Effect of types of thermosetting matrix on tensile and flexural properties of bamboo fiber[36]

The effect of types of thermosetting matrix on the mechanical properties of BFRC plates with 40% fiber volume fraction is presented in figure above[36]. The specimen 40ET had shown the highest tensile strength, which was approximately 11% and 45% higher than the specimens 40PT and 40VT, respectively. BFREC at 40% fiber loading also showed 3% and 8% higher ultimate flexural strength than the BFRPC and BFRVC, respectively. Both BFRPC and BFRVC possessed similar lower tensile and flexural strength compared to BFREC. On the other hand, the ultimate tensile modulus of BFRPC and BFRVC were slightly higher than that of BFREC by

12% and 3%, respectively. In addition, BFRPC also had a slightly higher ultimate flexural modulus at the 40% fiber loading, which represented 0.18 and 0.40 times more than BFREC and BFRVC, respectively.

2.6.1.3 ABS plastics

Given the current trend in natural materials, laptop bodies(cases) are made of metal or a mixture of ABS(Acrylonitrile butadiene styrene) and polycarbonate[37]. Acrylonitrile butadiene styrene (ABS) (chemical formula $(C_8H_8)_x(C_4H_6)_y \cdot (C_3H_3N)_z$) is a common thermoplastic polymer. Its glass transition temperature is approximately 105 °C (221 °F) ABS is amorphous and therefore has no true melting point.

ABS provides favorable mechanical properties such as impact resistance, toughness, and rigidity when compared with other common polymers[38][39]. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. Thus, by changing the proportions of its components, ABS can be prepared in different grades. Table 2.5 lists the mechanical properties of ABS plastic.

Table 2-5 mechanical properties of ABS plastic [32]

Density	1040kg/m ³
Strength at Break (Tensile)	29.8 - 43 MPa
Strength at Yield (Tensile)	29.6 - 48 MPa
Flexural strength	35-58 MPa
Impact strength(charpy)	180KJ/m ²
Thermal conductivity	0.1W/mK
Temperature range of usefulness	-20 – 80 °c
Elongation at Break	10 - 50 %

Elongation at Yield	1.7 - 6 %
Hardness Shore D	100
Young Modulus	1.79 - 3.2 GPa

2.6.2 Limitations of ABS

The polymer ABS not only have some advantages but also have some limitations such as[7]

- ✓ Poor weathering resistance
- ✓ Ordinary grades burn easily and continue to burn once the flame is removed
- ✓ Scratches easily
- ✓ Poor solvent resistance, particularly aromatic, ketones and esters
- ✓ Can suffer from stress cracking in the presence of some greases
- ✓ Low dielectric strength
- ✓ Low continuous service temperature[7]

2.7 The Factors Affecting the Properties of Natural Fibre Polymer Composites

Four factors play the chief role in determining the property of a composite[40]:

1. The constituent material(matrix and reinforcement) and its ratio or volume fraction
2. Orientation of the reinforcement
3. The interaction interface of the phase
4. The geometric shapes of the constituents - the reinforcing phase in – and the resulting structure of the material.

Composites physical chemical and thermal property can be manipulated by varying its process parameters. And of those parameters only changing the volume fraction and orientation of the fiber without changing the constituent reinforcement and matrix material can be one. By varying the volume fraction and orientation of fiber one can find which volume fraction and orientation

of fiber can provide the maximum and minimum tensile strength, flexural strength and impact strength[41].

Aside from the types of matrix and reinforcement used, other factors affecting the properties of a PMC are the constituents' relative proportions, the reinforcement geometry and the nature of the interphase[42].

2.7.1 Effects of orientation on mechanical, thermal and physical properties of a composite material

Fiber orientation is one of the crucial parameters of the composite material. Fibers show excellent tensile properties in the longitudinal direction. Thus the direction of orientation enables us to tweak the anisotropic properties of the composite material. The material will show better ductile properties along the direction of orientation of the fibers. Similarly, it can be safely assumed that the randomly oriented fibers have isotropic properties, as the fibers are then oriented in all possible directions[22].

On an experiment conducted on the mechanical characterization of Natural Fiber Reinforced Composites (NFRC) consisting of epoxy resin reinforced with jute fiber and bamboo fiber. Hand lay-up technique was used for fabrication of the composite specimens. The effect of fiber orientation ($0/90$, $15/-75$, $30/-60$, and $45/-45$) was analyzed and it shows that the fiber orientation of $0/90$ provides higher strength and stiffness than other fiber orientations used in this work[43].

An increase in maximum tensile strength and a reduction in strain is observed. Composite with $0/90^0$ fiber orientation has demonstrated a factor of improvement in tensile strength when compared with the $45/45^0$ fiber orientation. The maximum tensile strength of jute fiber composites is 22.01 MPa with a strain at ultimate strength of 2.1%. The same trend of higher tensile strength is observed in case of bamboo composites[22][29].

The tensile, shear, flexural and compressive properties of BREC composites depend fundamentally on the angle and orientation of lamina and bamboo to E-glass fiber percentage present. From these points of view, the result obtained from the $\pm 45^0$ offset tensile test in this study is much better[21].

A comparison of tensile strength between jute and bamboo specimens with different fiber orientation can be seen that the tensile properties of jute composites compare well with those of bamboo composites for $0/90^0$ and $45/45^0$ fiber orientation. The tensile strength of jute $0/90^0$ composites is 535% more than that of jute $45/45$, while jute $45/45$ is 230% more than that of bamboo $0/90$ and bamboo $0/90$ is 191 % more than that of bamboo $45/45$ [44]

The values of strain at maximum strength and also as a function fiber orientation for composites containing both jute and bamboo composites can be observed that there is improvement in composite stiffness with an increase in fiber orientation [45]

The strain–stress curve for bamboo composites with $45/45^0$ and $0/90^0$ fiber orientation shows an increase in maximum flexural strength and strain with an increase in the angle of fiber orientation. The flexural strength in the case of bamboo composites laminates with $45/45^0$ and $0/90^0$ fiber orientation can be observed that as the fiber orientation increases, there is an increase in the bending strength and stiffness. This is similar to the results obtained from tests conducted on tensile testing[45].

However, there is a decrease in the maximum flexural strength from bamboo $0/90$ to bamboo 45 by a factor of 94.12%. In the case of bamboo composites laminates at $0/90$ orientation, the bending strength and the modulus at 1% strain are 44.59 MPa and 685 MPa, respectively. This could be attributed to the insufficient interface bonding between fibers with epoxy matrix to transfer shear strength[26].

Among all the combinations, the hybrid FRP composites with $\pm 45^\circ$ orientation exhibited high tensile strength, when compared with other combination. Further, the other combinations such as hybrid with $0^\circ/90^\circ$ orientation and pure bamboo with $0^\circ/90^\circ$, $\pm 45^\circ$ orientation showed a very significant increase in tensile strength, when compared to non-woven bamboo strip mat and glass hybrid fibre. Flexural strength of woven hybrid FRP composites with $\pm 45^\circ$ orientation shows higher strength when compared to other combinations including flexural strength of reformed bamboo which has 276.6 MPa. When compared to pure bamboo FRP composites, the hybrid composites expressed very high impact strength. Higher values of impact strength were observed in hybrid FRP with $\pm 45^\circ$ orientation[46].

The tensile behavior is severely dependent on the fiber orientation because if the fibers are in line with the external load, then the load is uniformly distributed and fiber failure is minimal. For composite laminates, orientation at $0^0/90^0$ and 45^0 results in highest and lowest tensile strengths, respectively. The results of the experimentation reveal that tensile strengths are significantly affected by the fiber orientation. The tensile strength is superior in the case of $0/90^0$ fiber oriented as compared to specimens having 45^0 fiber orientation. This is attributed to the reason that, in case of $0/90^0$ orientation the external tensile load is equally distributed on all the fibers and transmitted along the axis of the fibers[47].

2.7.2 Effect of volume fraction on mechanical, thermal and physical properties of a composite material

The bamboo fiber reinforced epoxy composites has a better tensile strength (200MPa), flexural strength (230MPa) and impact strength (63KJ/m^2) at 60% volume fraction, [28].

The BFRCs with fiber volume fractions ranging from 0% to 40% embedded in three thermoset resins (epoxy, polyester, vinyl ester) were subjected to tensile and flexural tests and the fracture pattern was examined. It was found that the bamboo fiber reinforced epoxy composite (BFREC) with 40% fiber volume fraction exhibited the highest tensile and flexural strength compared to polyester and vinyl ester composite[36].

The tensile strength and modulus of elasticity improved as the fiber volume fraction increased[48]. The tensile strength at the break for the neat (0%) epoxy composites scored around 30 MPa. By adding 15% fiber volume fraction, the strength of the composites almost hit 60 MPa. The trend continued to increase up to 100 MPa with a fiber content of 45% [43]. Below table 2.6 indicates tensile strength of bamboo fiber epoxy composite at different volume fraction.

Table 2-6 tensile strength of bamboo fiber epoxy composite at different volume fraction[43][48]

Designation	Composition	Fiber content (%)	Orientation	Tensile strength (MPa)
B	Pure epoxy	0		18.16
B1	Epoxy (95%) + Bamboo Fiber (5%)	5	Random	26.22

B2	Epoxy (90%) + Bamboo Fiber (10%)	10	Random	37.98
B3	Epoxy (80%) + Bamboo Fiber (20%)	20	Random	45.28
B4	Epoxy (75%) + Bamboo Fiber (25%)	25	Random	53.61

As expected, there was an increase in the rate of water absorption when the residue quantity of the composite was increased. We can conclude that when samples (composites) stayed in water more hours, water absorption also increases at the intervals of every 2hrs, 4hrs, 6hrs and 24hrs. The higher the adhesion (bond) between the matrix and the fiber, the fewer will be the sites that could store water, leading to lower water absorption. According to literature, a special treatment with alkalis like sodium hydroxide is at times given to this fiber, which can minimize water absorption of specimens[49].

The tensile, flexural and impact strengths of pure BFREC were 80MPa, 105MPa and 43MPa respectively and the water absorption weight gain was about 50% of the initial[50].

And on the other side the thermal conductivity of BFGC (bamboo fiber reinforced green composite) with 60 wt% fiber is approximately equal to that of woods, as compared with the same density level[51].

2.8 Preparation of bamboo fibers

2.8.1 Alkaline treatment

An improvement in the mechanical properties of the composites was achieved with the treatment of the bamboo fibres with sodium hydroxide. This improvement is due to the enhancement in the adhesion between the bamboo fibres and the polyester resin. Alkali concentration of 6% was found optimum and resulted in the best mechanical properties for bamboo composites. Bamboo composites with the fibres treated with this alkali concentration have bending, tensile and compressive strength and stiffness of 7, 10, 81, and 25% higher, respectively than the untreated

composites[52]. The bending, tensile and compressive strength of this composite is 44.2, 21.0, 111.2 MPa, respectively higher than the untreated composites[52]

A reduction in the mechanical properties was observed for composites with bamboo fibres treated with 8% NaOH. This was attributed to the substantial delignification and degradation resulting in a damaged fibre weakening the load transfer and the bonding with the matrix. The bending and tensile strength of composites with 8% NaOH treated bamboo fibres is 3 and 15% lower than the untreated composites. However, the compressive strength and the stiffness are 12 and 4% higher than the untreated composites as the polyester resin governs these mechanical properties[52].

2.8.2 Heat treatment

Thermally treating bamboo has many advantages over the untreated ones[31][52][53][54]. These are

- ❖ Decrease of equilibrium moisture content (EMC) of treated BF
- ❖ Improvements(decrement) of hygroscopicity: - The contents of holocellulose and a-cellulose decreased significantly when samples were heat-treated above 160 C, the maximum reductions were 26.3 and 52.9 %, respectively[53].
- ❖ Dimensional stability of its reinforced composite[54]
- ❖ Mass loss therefore density decrement: - this is mainly attributed to water evaporation in bamboo. Mass loss increased significantly with increasing treatment temperature and duration, and reached the maximum reduction of 29.0 % when samples were heat-treated above 160⁰C for 3 hours[53].
- ❖ Improve fungal resistance
- ❖ Improve the thermal stability
- ❖ Improve anti-UV aging properties.

2.8.3 Liquor ratio

Results have shown that the optimum condition for sodium hydroxide treatment on jute fabric reinforcement is 1:10 MLR than 1:5 and 1:15 ratios[55].

The liquor ratio 1:10 improved the maximum load capacity compared to untreated and unreinforced specimens. The treatment improved the behavior of the Jute fibers. This was noticed by the reduced number of cracks and failures that appeared on the reinforced specimens, which can be explained by the fact that the composite becomes stronger as a result of the bonds created, which improved the adhesion[56].

2.9 Fabrication techniques of PMC

2.9.1 Hand lay up

Natural fibres are known for their non-uniformity, porosity and moisture affinity, they are susceptible to temperature. They are therefore affected by the manufacturing method used in the manufacture of their composites. According to [10] the factors mitigating the manufacturing techniques for natural fibre composites include the hydrophilicity of the fibre, its sensitivity to temperature and the resin rheological properties of the impregnating resin. Spray and hand lay up are adopted for low performance composite parts, however this can result to increased void percentage in the formed composites. For more expensive and higher performance composites parts, vacuum bagging, compression moulding, hot compaction using steel mould plates and autoclave have been recommended[40].

In hand layup, impregnation of the fibres are manually carried out therefore hand lay up are affected by the expertise and experience of the manufacturer. The materials usually used to aid hand lay up for even and smooth impregnation includes rollers, resin injectors and brushes. After impregnation, the samples can be left to cure at room temperature for a day or more depending on the temperature and humidity of the environment however, post cure usually takes place in air or vacuum oven for a specific period of time. Critical factors in the manufacture of natural fibre composites include processing temperature and mixing time[57].

Open mold processes: only one mold (male or female) is needed and may be made of any material such as wood, reinforced plastic or for longer runs, sheet metal or electroformed nickel. The final part is usually very smooth[58].

I. Advantages of the Hand Lay-Up Process

The wet lay-up process is one of the oldest composite manufacturing techniques with the following advantages:

- ❖ Very low capital investment is required for this process because there is an negligible equipment cost as compared to other processes.
- ❖ The process is very simple and versatile, any fiber type material can be selected with any fiber orientation.
- ❖ The cost of making a prototype part is low because a simple mold can be used to make the part. In addition, the raw material used for this process is resin, mat, and fabric material, which are less expensive[57].

II. Disadvantages of the Hand Lay-Up Process

The wet lay-up process has the following limitations:

- ❖ The process is labor intensive
- ❖ The process is mostly suitable for prototyping as well as for making large structures.
- ❖ The quality of the part produced is not consistent from part to part.
- ❖ The process is not clean[2].

2.10 Application of PMCs

2.10.1 Summary of applications

Today's technological innovations call for continual improvement in the field of material science to substitute the heavy structures with lightweight materials without compromising the strength. The incorporation of natural fibers as reinforcing agent in both thermoset and thermoplastic

polymer composites has gained increasing applications both in many areas of engineering and technology[59]. Below table 2.7 is summary of application area of polymer fiber composites.

Table 2-7 summer of application area of polymer fiber composites[60][61][62]

Area	Explanation
Construction	include the replacement, repair, retrofitting, or reinforcement of a structural component manufactured from a traditional structural material with fiber-reinforced polymers, as well as the emerging technology of composite panels used for the modular construction of buildings. Impellers, blades, housings, and covers
Transportation	<ul style="list-style-type: none"> - in automotive (belts and hoses, bodies, as bumpers, body panels, engine parts, fuel tanks, and mirror housings) - in aerospace (fiber-reinforced polymer matrix composites can be optimized to combine high strength, stiffness, and toughness, and low density, and thus to obtain exceptional strength-to-density and stiffness-to-density ratios along with superior physical properties) - in marine applications (Fiberglass boats are among the most familiar examples but the growing use of lighter, stiffer, and stronger carbon fibers instead of glass fibers is an emerging trend in boatbuilding)
Medical	such as MRI scanners, C scanners, X-ray couches, mammography plates, tables, surgical target tools, wheelchairs, and prosthetics.
Industrial equipment	they are used as the main material of construction, or as components of equipment, or in some instances both as the main material of construction and as components.
Protection equipment	for use in harsh environments (as in extreme heat or cold), when exposed to fire (as firefighters often are), when facing deadly weapons (as soldiers and law enforcement personnel often face), and in many other hazardous situations. Protection against temperature extremes, moisture, rain, chemical exposure, fire, clothing puncture, projectiles, abrasion, biohazards, radiation, explosions, high voltage, static electricity, and more can be achieved through the use of composites

Other	<ul style="list-style-type: none"> ✓ Packaging ✓ Electronics & optics ✓ Oil & gas exploration ✓ Production ✓ Storage ✓ Sporting goods
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2.10.2 Laptop Protective Case application

Evidently, everyone want to get assured the device’s safety, as the laptop is the portable device, carrying it from one place to another should be done with safety and ease. The laptop cases make it carrying them safely while you travel to places. Laptop cases also help your laptop to look stylish but most importantly protect it.

Laptop case is a protective covering case that can be installed upon either the external or if necessary on the appropriate sections of the internal parts of the laptop. The purpose of laptop cases is to add another layer of protection for laptop and it also can help to keep the dust or scratch[4].

Currently people use laptop sleeves as protective option. Laptop sleeves are divided into four types based on their material form such as;

- ❖ rubberized
- ❖ leather and
- ❖ plastic
- ❖ hard plastic (thermoset polymer)[4].

Currently, laptop cases are developed by handmade(fabric) and injection molding[4]. This confirms that it can be prepared using another type of fiber which is natural fiber and hand layup method. It delivers protection without sacrificing access to ports, lights, and buttons.

Protective Laptop cases

There are many great benefits of using laptop case. Many people travel with their devices and stores a lot of sensitive data and work or personal related information with them. Carrying a laptop without some sort of protection and storage for it would not be a thing a laptop owner

would look upon. A laptop case helps not only to shield the device from the elements, but it also adds a level of cushion to it.

i. Protection

Do you carry your laptop on a daily basis? Well, then a laptop case is a sure-shot way to protect the laptop. This is one of the most crucial benefits provided by laptop covers. Laptops get hit and knocked several times while travelling. Thus, it is advisable to buy one of these designer sleeves and protect the laptop against scratches. Laptops are expensive devices which require your care and attention at all times. Thus, laptop cases are a definite must-have if you travel with your laptop[4].

ii. Cleanliness

Cleanliness is crucial for smooth functioning of the laptops. Sometimes, dirt or fluids like water gets collected inside the laptops and causes problem in its functioning. Laptop cases let you protect your laptop from dirt. Increase your laptop’s lifespan with designer sleeves[4].

2.11 Summary of Literatures

Table 2-8 literature review table

Materials used		Process	Material	Reference
Reinforcement	Matrix	parameters used	property evaluated	
Bamboo/E glass	Epoxy	Vf	Mechanical	[8]
Jute/bamboo	Epoxy	Orientation & fiber type	Mechanical	[9]
Bamboo	Epoxy	Orientation	Mechanical, Thermal Morphology	[14]
Epoxy urea formaldehyde resin, phenolic, polyurethane, polypropylene,	polyester, polylactic acid,	Matrix type	Mechanical	[16]

polyester, poly (butylene succinate) and different filler materials				
Nonwood plant fiber bundles of ramie, pineapple, sansevieria, kenaf, abaca, sisal, and coconut fiber bundles		Fiber diameter	Mechanical Physical Morphology	[17]
Bamboo		Hollow/solid bamboo	Tensile	[18]
E glass	vinyl ester	Vf & orientation	Thermal	[22]
Bamboo	epoxy/polyester/vinyl ester	Vf & matrix type	Mechanical Thermal	[23]
Jute	Epoxy	Orientation	Tensile	[24]
Carbon	epoxy/polyamide	Matrix type	Tensile Failure behavior	[25]
Bamboo/glass fiber		Orientation	Mechanical Morphology	[26]
Glass fiber/satin fiber	epoxy	Vf & orientation	Mechanical	[27]
Bamboo	Epoxy	Mild steel comparison	Equivalent stress	[28]
Kenaf	Epoxy	Vf	Mechanical Morphology	[29]
Banana fiber	Gypsum	Vf	Mechanical Water absorption	[30]
Bamboo	Epoxy / nano clay	Vf	Mechanical Thermal Water absorption	[31]

Bamboo	Polylactic acid (PLA)	Density of fiber	Thermal	[32]
--------	-----------------------	------------------	---------	------

Studying and investigating this parameter give a very great advantage in all composite manufacturing industries and studies. It can help fellow researchers and students. The investigation outcome can be used in composite manufacturing industries to identify the better fiber orientation in order to get the quality they desire for material specification and quality assurance for structural analysis.

2.12 Gaps identified

Dheeraj Kumar studied on characterization of tensile properties of treated bamboo natural fiber polymer composite[48]. From Dheeraj Kumar's results, we can see that the strength increases as the fiber loading (VF) increases from 0% fiber VF (pure epoxy) to 25% VF (25% fiber 75% epoxy matrix) but no way of roving that 25% is the optimum. Steping from this, on this experiment 20% VF was taken as the minimum VF and proceeded to the higher VFs.

In most literatures, researchers either study the effect of volume fraction or orientation of fibers separately not together simultaneously therefore this research contributes in both parameter studies and studies three (mechanical (tensile, impact and flexural), thermal and physical) properties of the manufactured composite.

Carrying and operating a laptop without some sort of protection and storage for it is always a risk that one takes. As mentioned earlier we usually try to protect and shield our laptop carrying bag manually by shielding with our hands or our body in crowded or tight areas because our bag is just a carrying luggage which is not a protective safety bag. Therefore, it's necessary to protect our loads of sensitive data and work or personal related information carrying laptop and use it without being exposed to heat coming out of it. But there are no protection casings provided except for apple's MacBook series or other military laptops which are shown below in the figure 2.6. This apple MacBook casings are made of ABS plastics which have properties like scratches easily, low continuous service temperature, burn easily and continue to burn once the flame is removed, poor solvent resistance particularly aromatic, ketones and esters and can suffer from stress cracking in the presence of some greases[7].



Figure 2-6 MacBook plastic cases[63]

CHAPTER THREE

3. RESEARCH METHODS AND MATERIALS

3.1 Introduction

In approaching the problem, different methods of analysis and data collections were followed. Reviewing Literature: this was done by collecting and studying different articles, journals, books concerning composites, natural fibers, in order to have better understanding of the problem and solution and ways to achieving the objective of the research.

Setting Criteria for selecting plants: natural fiber properties are affected by the age/maturity/ of the plant. Therefore, the selected bamboo plant was collected accordingly. Designing fiber matrix composition: based on different literatures different fiber-matrix composition were selected. Selection of treatment: NaOH was used for treatment to improve the adhesion between the fibers and matrix, bleaching and cleaning the surface of natural fibers. The extraction of Bamboo fiber was conducted at AAiT chemical engineering laboratory

Selection of fabrication method: there are different methods to fabricate composite materials. Hand layup, compression molding, resin transfer, vacuum bagging assisted hand lay-up technique. In this study Hand layup followed by compression as a curing method was used because of its simplicity. In the fabrication of natural composite epoxy, hardener, mold, releasing agent, were prepared and composite specimens were fabricated with different compositions and orientations.

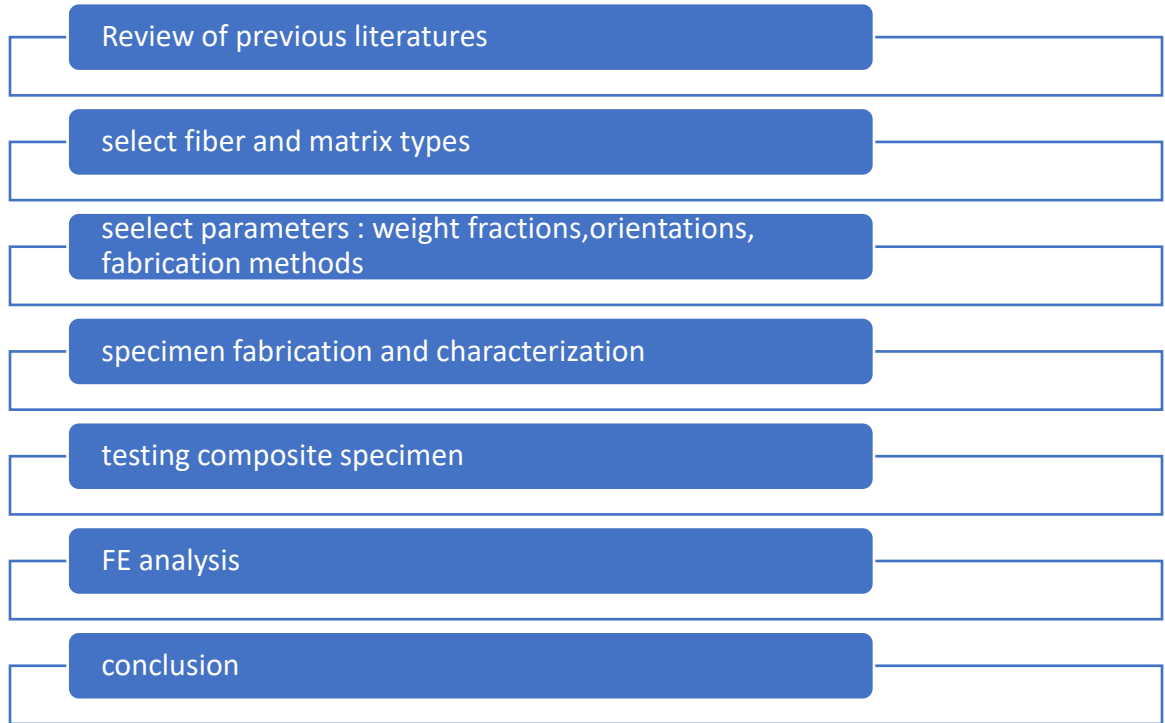
Experimental test setup and Experimentation: five composite specimens fabricated were machined according to the ASTM specimen standards and these specimen samples were tested for tensile, flexural, impact, water absorption and thermal resistance tests. Experimental program was done at Bishoftu Ethiopian Defense University.

Modeling, simulation and analysis of protective laptop casing: after obtaining the result, the composition with superior properties among the five was selected. Protective laptop casing was modeled using CATIA design software and further analyzed using ANSYS 2020 software for analysis. On the software the model was analyzed to obtain maximum principal stress,

deformation and von misses stress. Finally, the result was compared with other materials used for protective laptop casing.

Details of material composition, fiber preparation, testing procedures are presented below.

3.2 Research Methodology



3.3 Materials and equipment used

Better reinforcement and matrix materials were chosen based on different parameters and material’s mechanical properties such as strength and stiffness and physical properties like density and water absorption. In this work materials such as bamboo fibers and Epoxy resin with its hardener were utilized for composite preparation. Epoxy resin with its hardener was obtained from Dr. crafty resin manufacturer from amazon whereas bamboo fiber was extracted from bamboo culms coming from Injibara, North West part of the country, which was procured from African Bamboo Wood and laminate flooring supplier in Addis Ababa.

3.3.1 Reinforcement

The bamboo, which was used in this study was taken from African Bamboo Wood and laminate flooring supplier in Addis Ababa which is lowland bamboo grown in lowland farm yard. The single bamboo timber has an average length, diameter and wall thickness of 10m, 80mm and 30mm, respectively[64]. The bamboo fiber used for this exploration was obtained by manually extracting them at the technology institute campus because processing technique is not yet adopted in the country. The bamboo used in this project is thermally treated at 160⁰ c for 3 hours at African Bamboo Wood and laminate flooring supplier in order to improve composite thermal and dimensional stability while reducing moisture absorption and other properties mentioned in the previous chapter. Below figure 3.1 is bamboo fiber partially extracted and thermally treated at 1600c for 3hr from African bamboo.



Figure 3-1 bamboo fiber partially extracted and thermally treated at 1600c for 3hr from African bamboo

3.3.2 Matrix material

A. Epoxy Resin

The resin that was used for this study was DR. Crafty epoxy resin. It has superior flexural strength, tensile strength, bond strength, adhesive characteristics and fatigue resistance than other types of resins. It is extremely durable and provides a high glistening, water resistant protection for all kinds of projects. It provides an amazing performance, UV stable, transparent, plastic

layer, created to withstand yellowing. Figure 3.2 shows the epoxy and hardener type used for in this experiment.

In general, epoxy resins have the following advantage over the other resin types[38]

- ❖ Better adhesive properties (the ability to bond to the reinforcement or core)
- ❖ Better performance at elevated temperature
- ❖ Superior mechanical properties (particularly strength and stiffness) consistent performance
- ❖ Better electrical properties environmental resistance
- ❖ Improved resistance to fatigue and micro cracking
- ❖ Low shrinkage upon curing and good chemical resistance
- ❖ Reduced degradation from water ingress (diminution of properties due to water penetration)
- ❖ Long pot(shelf) life at room temperature
- ❖ Increased resistance to osmosis (surface degradation due to water permeability) Quantity of resin required



Figure 3-2 Dr. crafty epoxy resin and hardner used as a matrix

Below tables 3.1 and 3.2 shows the physical and thermal property of the matrix used in this experiment.

Table 3-1 Dr. crafty epoxy physical and thermal property table[65]

specification	Dr Crafty
Color	Clear
Viscosity @ 25 ⁰ c	10000-12000 Mpa S
Density @ 25 ⁰ c	1.27g/cc
Working time	30-45 min
Curing time	24-72 hr
Shelf time	2 years

B. Hardener

Epoxy resin was cured by adding a catalyst with a 1:1 resin hardener ratio, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the epoxy resin and monomer ingredient from liquid to a solid state.

Table 3-2 Dr. crafty hardener physical and thermal property table[65]

Resin	Dr Crafty epoxy
Color	Clear
Viscosity @ 25 ⁰ c	8000-10000
Density @ 25 ⁰ c	1.27g/cc
Working time	30-45 min
Curing time	24-72 hr
Shelf time	2 years

3.3.3 Chemicals and release agents

Alkali (NaOH) was used to treat the fiber in order to extract lignin and hemicelluloses, increasing the tensile strength and the elongation at break of the composite. Below figure 3.3 is The Alkali (NaOH) used to treat the fiber order to extract lignin and hemicelluloses.



Figure 3-3 The Alkali (NaOH) used to treat the fiber order to extract lignin and hemicelluloses

Mold release is essential for preventing the epoxy from sticking to the mold when the composite are apart. Even though, 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, and polyethylene plastic for better surface finish of the composite.

3.3.4 Hand tools used

Hand tools and safety equipments were used on each steps of the fabrication process this include:

I. for fiber extraction

- ❖ Soaking tub
- ❖ Rubber hammer
- ❖ Comb

II. For mixing resin and hardener

- ❖ Mixing cups
- ❖ Measuring cups
- ❖ Mixing spatula

III. For impregnation

- ❖ Brushes
- ❖ Roller

IV. For cleaning and cutting

- ❖ Paper towel or any fabric
- ❖ Brushes
- ❖ Scissor and band saw

V. Safety equipments

- ❖ Gloves
- ❖ Safety goggle
- ❖ Safety lab coat and shoes

3.4 Mold preparation

3.4.1 Mold design

The mold was designed based on the standard dimensions the test specimens needed to be cut as presented below:

- ❖ As per ASTM standard dimension of composite sample specimen for tensile test is ASTM D3039
 - ✓ According to this sample specimen dimension is $(l*w*t)$ $(250*25*3)mm^3$
- ❖ As per ASTM standard dimension of composite sample specimen for impact test is ASTM D256
 - ✓ According to this sample specimen dimension is $(l*w*t)$ $(127*12.7*6.4)mm^3$
- ❖ As per ASTM standard dimension of composite sample specimen for flexural test is ASTM D790
 - ✓ According to this sample specimen dimension is $(l*w*t)$ $(125*12.7*1-10)mm^3$
- ❖ As per ASTM standard dimension of composite sample specimen for water absorption test is ASTM D5229
 - ✓ According to this sample specimen dimension is $(100*100*3)mm^3$
- ❖ Therefore, mold dimensions will be
 - ❖ Length = L max + 20 mm (clearance)Eq (3.1)
= 250mm + 20mm

$$= 270\text{mm}$$

$$\text{❖ Width} = W_{\text{total}} * 3(\text{fabricate trice of each sample}) + 100\text{mm (water absorption)} + 10\text{mm (clearance)} \dots\dots\dots\text{Eq (3.2)}$$

$$= [(25 + 12.7 + 12.7) * 3] + 200\text{mm} + 15\text{mm}$$

$$= 450\text{mm}$$

$$\text{❖ Thickness} = t_{\text{max}} + 1\text{mm (clearance)} \dots\dots\dots\text{Eq (3.3)}$$

$$= 6.4\text{mm} + 0.6\text{mm}$$

$$= 7\text{mm}$$

Based on this, below in the figure 3.4 the Catia software mold design (450*270*7)mm³ is given

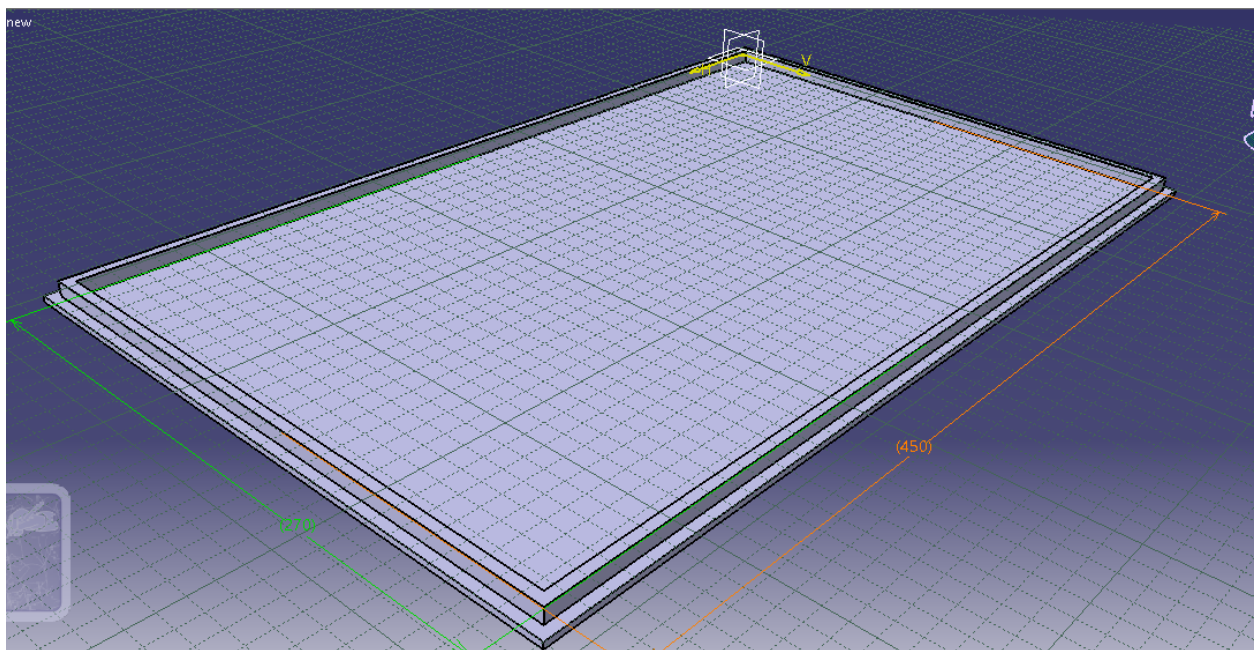


Figure 3-4 Catia software mold design(450*270*7)mm³

❖ As per ASTM standard dimension of composite sample specimen for thermal conduction/resistance test is ASTM D5330-08. According to this sample specimen dimension is 40mm diameter by 65mm length, therefore, the mold had a dimension of 40mm diameter and 20mm length and the pieces were cut at the desired 65mm length.

3.4.2 Mold material

Mold material for the first mold base plate was prepared from sheet metal and the frame was prepared from MDF board. Mold material for the thermal test was a PVC pipe

3.5 Constituent materials preparation

3.5.1 Fiber Preparation

A. Extraction of Bamboo Fiber

Process of extraction is of great importance since the quality, as well as the quantity of extracted, fibers, are strongly influenced by the method of extraction employed. The bamboo o taken is thermally treated bamboo at 160⁰ c for 3 hours. Nodes, most inner parts and very thin layer of exoderm of the lowland bamboo have been removed and remaining parts have cleaved in longitudinal direction. Below in figure 3.5 partially extracted and thermally treated (at1600c for 3 hrs)bamboo fiber from African bamboo is presented.



Figure 3-5 partially extracted and thermally treated (at1600c for 3 hrs)bamboo fiber from African bamboo
As mentioned earlier, the bamboo was partially mechanically extracted then it was soaked in tap water with a sufficient depth for two days in order to soften them and then removed and beaten gently at slow constant impact force using rubber hammer in order to loosen and separate the fiber and combed. The process is repeated until individual fibers are separated.

Below in figure 3.6 and 3.7 bamboo fiber soaked in tap water for 48 hours to soften it for further mechanical extraction and bamboo fiber mechanically extracted after soaked in water and beaten gently at slow constant impact force using rubber hammer in order to loosen and separate the fiber are presented respectively.



Figure 3-6 bamboo fiber soaked in tap water for 48 hours to soften it for further mechanical extraction



Figure 3-7 bamboo fiber mechanically extracted after soaked in water and beaten gently at slow constant impact force using rubber hammer in order to loosen and separate the fiber

B. Alkali treatment process

Alkaline treatment with laboratory grade NaOH, known as mercerization, extracts lignin and hemicelluloses, increasing the tensile strength and the elongation at break of the composite. In this process the fiber was immersed in 6 wt% solution of NaOH with liquor ratio of 1:10 for two hours, followed by continuous washing with distilled water until the PH of the water solution reach neutral and dried in sun light. In general, removal of these fatty-like components from bamboo fiber leads the fibers to:

- ❖ Improve an adhesive property for fibre–matrix interface;
- ❖ Improve fiber’s shear strength;
- ❖ Improve fiber’s rigidity and stiffness;
- ❖ Improve moisture absorption problems;
- ❖ Reduce fiber’s weight; etc.

The alkali treatment process is illustrated in the following figure 3.8.



Figure 3-8 a) Alkali (NaOH) solution b) soaked bamboo fiber to extract lignin & hemicelluloses

3.5.2 Matrix (resin and hardener mix) preparation

Epoxy resin comes in two parts: a resin and a hardener. Mixing the resin and hardener together prompts a chemical reaction between the two, transforming them from a liquid into a solid. Measuring accurately and mixing thoroughly is essential to ensure your epoxy resin cures properly. Resin and hardener ratio is according to the manufacturer's manual which is 1:1 There are 3 simple steps when measuring and mixing epoxy resin and hardener to ensure a perfect pour:

- Determine how much epoxy resin you'll need
- Accurately measure both resin and hardener
- Mix thoroughly for 3 minutes, scraping the sides and bottom as you stir

3.5.3 Fiber and matrix volume fraction of the composite

In design, fabrication and analysis of composite materials, the first and critical task is the determination of ingredient percentages such as fiber and matrix (resin) fraction presence in laminate. These components are microstructural elements of the composite laminate in which composites strength and properties are determined and limited by these values. In general, results obtained from the equations presented below are mandatory for:

- ❖ Composite laminate preparation
- ❖ In order to use ASTM standard. To determine size of laminates that meets the ASTM requirements prior to laminate fabrication, these values are necessary.
- ❖ Finite element analysis purpose. Even though it didn't in this study, but, if anyone who wants to do this task in the future it is possible to take these values as a primary data for analysis.
- ❖ The improvement of fabricated laminate for the future by varying these values.
- ❖ These values can be used as a design manual in collaboration of composite laminate's different experimental results which are fabricated by these contents

Density: The density of sisal fiber was found using pycnometer. Pycnometer is an equipment that uses liquid with well-known density such as; water to identify density. In this thesis, water was used to calculate the density of fibers. Before measuring the density, the pycnometer should be calibrated to find the exact volume of the instrument. Taking the volume on the instrument gives wrong calculation, that is the reason needed for calibration. To do that,

- i. Measure the mass of pycnometer (M_1)

$$M_1 = 28.53\text{g}$$

- ii. Measure Mass of pycnometer with the fiber sample (M_2)

$$M_2 = M_1 + \text{Mass of sample} \dots\dots\dots\text{Eq (3.4)}$$

$$= 30.40\text{g}$$

- iii. Measure Mass of pycnometer with water(deionized distilled water) filled in it (M_3)

$$M_3 = M_2 + \text{Mass of water}$$

$$= 78.95\text{g}$$

$$\gg \text{Mass of water} = M_3 - M_2 \dots\dots\dots\text{Eq (3.5)}$$

$$= 48.54\text{g}$$

- iv. Add Mass of pycnometer and mass of water (M_4)

$$M_4 = M_1 + \text{Mass of water} \dots\dots\dots\text{Eq (3.6)}$$

$$= 28.53 + 48.54$$

$$= 77.07\text{g}$$

Therefore,

$$\text{Density of fiber} = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \dots\dots\dots\text{Eq (3.7)}$$

$$= \frac{30.4 - 28.53}{(30.4 - 28.53) - (78.95 - 77.07)}$$

$$= 1.24\text{g/cc}$$

The equipment used to measure the density of fiber is presented below in figure 3.10.



Figure 3-9 density measurement of bamboo fiber using picnometer

3.6 Composite volume fraction

The natural fiber composite is composed of bamboo as reinforcement and epoxy as the matrix. The reinforcing fiber was cut at a length of 27cm and 45cm and the matrix epoxy was mixed thoroughly with hardener.

The fabrication of the composite includes calculation of mass needed for the reinforcement and matrix under each compositions. Hand-layup method is used to manufacture all the composites. Each composite constituent is mixed according to their composition and mass.

$$V'_f + V'_m = 1 \dots\dots\dots \text{Eq (3.8)}$$

$$V'_f = \frac{v_f}{v_c} \dots\dots\dots \text{Eq (3.9)}$$

$$V'_m = \frac{v_m}{v_c} \dots\dots\dots \text{Eq (3.10)}$$

Example: -volume of composite is calculated based on the mold dimensions, which is $L \times w \times t$

$$v_c = 270\text{mm} \times 450\text{mm} \times 7\text{mm}$$

$$v_c = 850.5\text{cm}^3$$

$$v_f = v_c * V'_{fl} \dots\dots\dots \text{Eq (3.11)}$$

$$v_f = 850.5 \text{ g/cm}^3 * 0.3 = \underline{255.15 \text{ g/cm}^3}$$

Volume of matrix (v_m) = volume of composite (v_c) * volume fraction of fiber (v_m)

$$v_m = v_c * V'_m$$

$$vm1 = 850.5 \text{ g/cm}^3 * 0.7 = \underline{595.35\text{g/cm}^3}$$

Density of composite

Density of materials are derived from volume fraction methods using weight of materials

$$\rho_f v_c = \rho_f v_f + \rho_m v_m \dots \dots \dots \text{Eq (3.12)}$$

$$\rho_c = \rho_f (v_f/v_c) + \rho_m (v_m/v_c) \dots \dots \dots \text{Eq (3.13)}$$

$$\rho_c = \rho_f v_f + \rho_m v_m \dots \dots \dots \text{Eq (3.14)}$$

$$\rho_c = V_m \rho_{f1} V_{f1} + \rho_{Ba} V_{Ba} + \rho_m \dots \dots \dots \text{Eq (3.15)}$$

Weight composite, Fiber and Resin

weight of composite, fiber, and matrix is calculate based on the general formula of density, mass and volume W_c , W_f , and W_m are weight of composite, matrix and composite.

$$W_c = \rho_c * v_c \dots \dots \dots \text{Eq (3.16)}$$

$$W_f = \rho_f * v_f \dots \dots \dots \text{Eq (3.17)}$$

$$W_m = \rho_m * v_m \dots \dots \dots \text{Eq (3.18)}$$

Based on volume fraction of matrix and fiber, weight of composite, matrix and fibers are calculated.

$$W_{f1} = \rho_f * v_{f1} \dots \dots \dots \text{From Eq (3.19)}$$

$$= 1.27\text{g/m}^3 * 255.15\text{g/cm}^3$$

$$= \underline{324.04\text{g}}$$

$$W_{m1} = \rho_m * v_{m1} \dots \dots \dots \text{From Eq (3.20)}$$

$$= 1.24 \text{ g/cm}^3 * \underline{255.15 \text{ g/cm}^3} = \underline{316.38\text{g}}$$

Designating of composite specimens

Below on the table 3.3 is the composite sample specimen generic assigning for this particular experiment.

Table 3-3 sample specimen designation table

Sample name	Fiber %	Matrix %	Orientation
S20%	20%	80%	0/90
S30%	30%	70%	0/90
S40%	40%	60%	0/90
S50%	50%	50%	0/90
S30⁰	30%	70%	0/30
S45⁰	30%	70%	0/45

3.7 Composite specimen fabrication

3.7.1 Mold cleaning and preparation

Surface quality risk can be mitigated by the correct protection and preparation of the mould prior to its first layer of gelcoat. Before resin and hardener were mixed the mold should be prepared by cleaning and polishing mold with releasing agent (wax) for easily releasing of the composite plate after curing and for better surface finishing.

High glass paste wax for use in open moulding by a composite fabricator that requires a wax mould release agent that can perform in both normal and high exotherm moulding temperatures. Easy to apply and the residual film is durable and resistant to abrasion. Available an economical version for general purpose. Figures 3.11 and 3.12 shows sheet metal mold cleaning and polishing mold with releasing agent (wax) for easily releasing of the composite plate after curing and for better surface finishing & mold preparation based on mold design dimension and catia design respectively.



Figure 3-10 sheet metal mold cleaning and polishing mold with releasing agent (wax) for easily releasing of the composite plate after curing and for better surface finishing



Figure 3-11 mold preparation based on mold design dimension and catia design

3.7.2 Hand lay-up procedure

Hand lay-up process - The simplest method of composite processing. The infrastructural requirements for this method are also minimal. Since it is manual process; it is labor intensive process and the quality of the product depend upon the skill of the molder as well as on the quality of the mold used for fabricating the polymer matrix composites. The production rate is less.

- ❖ Release gel (silicone, polyvinyl alcohol, fluorocarbon, or sometimes, plastic film) is sprayed on the mold surface.
- ❖ Unreinforced surface layer (gel coat) may be deposited for best surface quality.
- ❖ Reinforcement fiber may be in the form of mat is placed on the mold surface.

- ❖ The polymer (resin) is uniformly spread with the help of the brush, (the polymer was added with hardener or catalyst in order to accelerate the rate of polymerization or curing.) and hand roller was used to distribute resin, compact plies and remove entrapped air.
 - ❖ Second layer of fiber is then placed on the polymer surface, and the roller is rolled over the surface to remove any air trapped as well as the excess polymer present.
 - ❖ Finally, it is left for curing. The curing can also be done at an elevated temperature, but mostly in hand lay-up process, curing is done at the room temperature.
 - ❖ After curing, the part is taken form the mold and may be go for further processing.
- In order to get the desired orientation precisely, a nail was hammered and string was knotted around the frame to guide the orientation. Figure 3.1 comosite sample preparation at different orientations.



Figure 3-12 different comosite sample preparation at different orientations

The four volume fractions and three orientations factors give a seven samples but one parameter (30% VF at $0^0/30^0$ orientation) repeats itself so six samples were prepared by the above process. The six samples each will go through three (Tensile strength (TS), Flexural strength (FS), Impact strength (IS)) mechanical and thermal performance and two physical (water absorption) tests. Diagrammatic fiber orientation is shown on figure 3.14 below

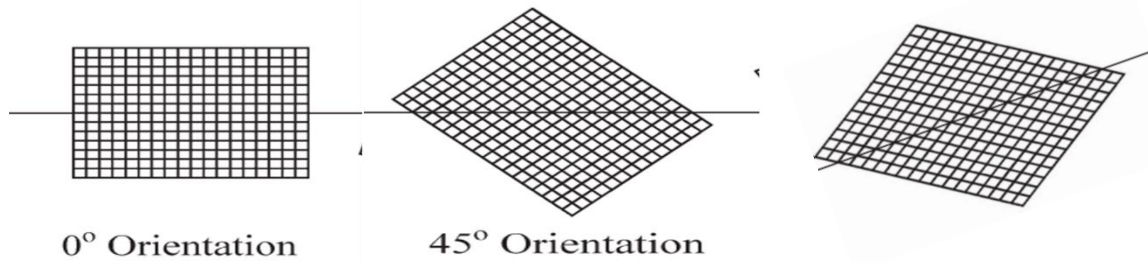


Figure 3-13 fiber orientation diagrammatic representation

3.7.3 Curing and De-molding

According to the specifications and manual of the resin usage, the resin can cure in 24 hours but for better product it is recommended to let it cure for 72 hours therefore the samples were left to cure for 3 days at room temperature. The wax pasted on the mold prior let the sample to de-mold easily.

3.8 Mechanical and physical properties testing of specimens

3.8.1 Tensile test

ASTM D3039 - specimens are rectangular in shape with a constant cross-section. The minimum length of the specimen is equal to the total gripping length + 2 x width + gauge length, but greater lengths are recommended in order to minimize bending stresses. The specimen width and thickness should be representative of the bulk material in respect to quantity of fibers. There are four recommended specimen geometries for 0° unidirectional, 90° unidirectional, balanced, and symmetric and random-discontinuous material types. ASTM D3039 can be used for both continuous and discontinuous fiber reinforcements, but the lay-up of the laminate specimen must be balanced and symmetric with respect to the test direction[66]

Test procedure:

Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and pulled until failure. For ASTM D3039 the test speed can be determined by the material specification or time to failure (1 to 10 minutes). A typical test speed for standard test specimens is 2 mm/min (0.05 in/min). An extensometer or strain gauge is used to determine elongation and

tensile modulus. Depending upon the reinforcement and type, testing in more than one orientation may be necessary.

The most common specimen for ASTM D3039 is a constant rectangular cross section, 25 mm (1 in) wide and 250 mm (10 in) long. Optional tabs can be bonded to the ends of the specimen to prevent gripping damage. Below on figure 3.15 tensile strength test composite specimen prepared based on this are shown

Data:

- i. From tensile test results the following results can be obtained:
- ii. force elongation(strain) graph
- iii. stress elongation(strain) graph
- iv. Tensile strength test report
- v. Force elongation(strain) table
- vi. Stress elongation(strain) table



Figure 3-14 tensile strength test composite specimen

3.8.2 Impact test

ASTM D256 - Notched Izod Impact is a single point test that measures a materials resistance to impact from a swinging pendulum. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. This test can be used as a quick and easy

quality control check to determine if a material meets specific impact properties or to compare materials for general toughness[66].

Test Procedure:

The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs. Since many materials (especially thermoplastics) exhibit lower impact strength at reduced temperatures, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

The standard specimen for ASTM is 64 x 12.7 x 3.2 mm (2½ x ½ x 1/8 inch). The most common specimen thickness is 3.2 mm (0.125 inch), but the preferred thickness is 6.4 mm (0.25 inch) because it is not as likely to bend or crush. The depth under the notch of the specimen is 10.2 mm (0.4 inches). Below on figure 3.16 impact strength test composite specimen prepared based on this are shown

Data:

ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J (or ft-lb) by the thickness of the specimen. The test result is typically the average of 5 specimens.



Figure 3-15 impact strength test composite specimen

3.8.3 Flexural test

ASTM D7264 - composites using a bar of rectangular cross section supported on a beam and deflected at a constant rate. A three-point loading system for center loading test method is designed for polymer matrix composites and uses a standard 32:1 span-to-thickness ratio in comparison to other methods such as ASTM D790, a three-point flexure for plastics, which uses a standard 16:1 span-to-thickness ratio or ASTM D6272 which is a four-point flexure. Fabric-reinforced textile composite materials are also referenced within the ASTM D7264 method[66].

Flexural properties of many materials can vary depending on temperature, rate of strain and specimen thickness.

Test procedure:

Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three-point bending at a specified rate.

Specimen size: Standard specimen thickness is 4 mm (0.16 in), standard specimen width is 13 mm (0.5 in) and standard specimen length is 20% longer than the support span. If the standard specimen is not available, alternative specimen sizes may be used. Below on figure 3.17 flexural strength test composite specimen prepared based on this are shown



Figure 3-16 flexural strength test composite specimen

3.8.4 Water absorption test

The water absorption test followed ASTM standard test method D5229 in which specimen dimensions are 100mm*100mm. Before the measurement, the sample will be dried in an air oven at 50°C for 24 h, and then cooled, and immediately. Then the specimen will be placed in a container of distilled water maintained at a temperature of $23 \pm 1^\circ\text{C}$ for 1 hour, 6 hrs and 24h. At

each hour the specimen is removed from water and water will be wiped off the surface of the sample with a dry cloth; and the sample was immediately weighed, which is designated as M1. For each pet sample, 3 specimens were measured. The water absorption of the sample was calculated as percent weight change (M %) determined as follow

$$MA \text{ of the fiber (\%)} = (w_0 - w_1) / w_0 * 100 [66]$$

W₀ = initial weight of sample

W₁ = final weight of sample

3.8.5 Thermal conductivity test

Thermal conductivity /resistivity test followed ASTM D5334-08 in which Samples can be of any size and shape as long they meet the minimum size requirements. The minimum diameter according to ASTM D5334-08 is 40 mm, the minimum length is the probe length plus 20%. The higher the thermal conductivity, the larger is the necessary sample size. For this test samples were prepared at a dimensions of 40mm diameter and 65mm length according to the testing machine's specification[66].

Theory of thermal conductivity

The theory of thermal conductivity was proposed by Fourier in 1822. According to Fourier, the fundamental heat conduction equation can be stated as “For a homogeneous solid, the local heat flux is proportional to the negative local temperature gradient”. For one dimensional steady state heat transfer, this statement can be represented by Equation 3.21:

$$q'' = -K \frac{dT}{dx} \dots \dots \dots \text{Eq (3.21)}$$

Where q is the heat flux, K is the thermal conductivity of the material, which is a positive 2nd order tensor quantity, dx/dT represents change in temperature across the thickness and negative sign indicates the temperature reduction from hotter surface to cooler surface. According to Equation 3.22, conductivity can be given as (under the assumption, that heat is not lost in its plane)

$$K = (Q/A) / (\Delta T/\Delta L) \dots \dots \dots \text{Eq (3.22)}$$

where K is the thermal conductivity (W /m-K), Q is the Heat Flux (W), A is the cross-sectional area of the specimen (m²), ΔT is the Temperature difference (K), ΔL is the overall distance (m). Thus, the thermal conductivity of a material can be defined as a rate at which heat is transferred by conduction through a given unit area of a given material, when the temperature gradient is normal to the cross-sectional area. The thermal conductivity of a composite material depends on the fiber, resin materials, fiber volume fraction, orientation of the fiber, direction of heat flow and operating temperature[51].

3.9 Geometric model and FEM of Laptop Protective Case

As the laptop is the portable device, carrying it from one place to another should be done with safety and ease. Laptop case is a protective covering case that can be installed upon either the external or if necessary on the appropriate sections of the internal parts of the laptop. The purpose of laptop cases is to add another layer of protection for laptop and it also can help to keep the dust or scratch[4].

Currently, laptop cases are developed by handmade(fabric) and injection molding[4]. This confirms that it can be prepared using another type of fiber which is natural fiber and hand layup method. It delivers protection without sacrificing access to ports, lights, and buttons.

Evidently, all want to get assured the device’s safety, as the laptop is the portable device, carrying it from one place to another should be done with safety and ease. Laptop cases help to look your laptop stylish but most importantly protect it. The laptop cases also make it carrying them safely while you travel to places.

For the analysis of Protective laptop casing, FEM was conducted using the ANSYS 2020 Software package through four distinct steps: building the model on catia modeling software, then exporting it to ANSYS and applying the boundary conditions and load, obtaining the solution, and result review

3.10.1 Modeling Of The Casing On Catia

The model was done on catia 3D modeling software and both the upper and lower casings are presented on the following figures 3.18, 3.19 & 3.20.

The model includes:

- ❖ LIGHTWEIGHT: almost no weight to volume ratio
- ❖ GOOD PROTECTION: without sacrificing access to ports, lights, and buttons
- ❖ NON-SLIP: Rubberized feet to keep the laptop firmly in place without sliding
- ❖ HEAT SINKABLE: Two rows of ventilation on the bottom for safe heat dissipation
- ❖ ACCESSBLE PROTECTION: Fully protects your laptop from accidental drops, hard knocks and scratches, while remaining thin and light

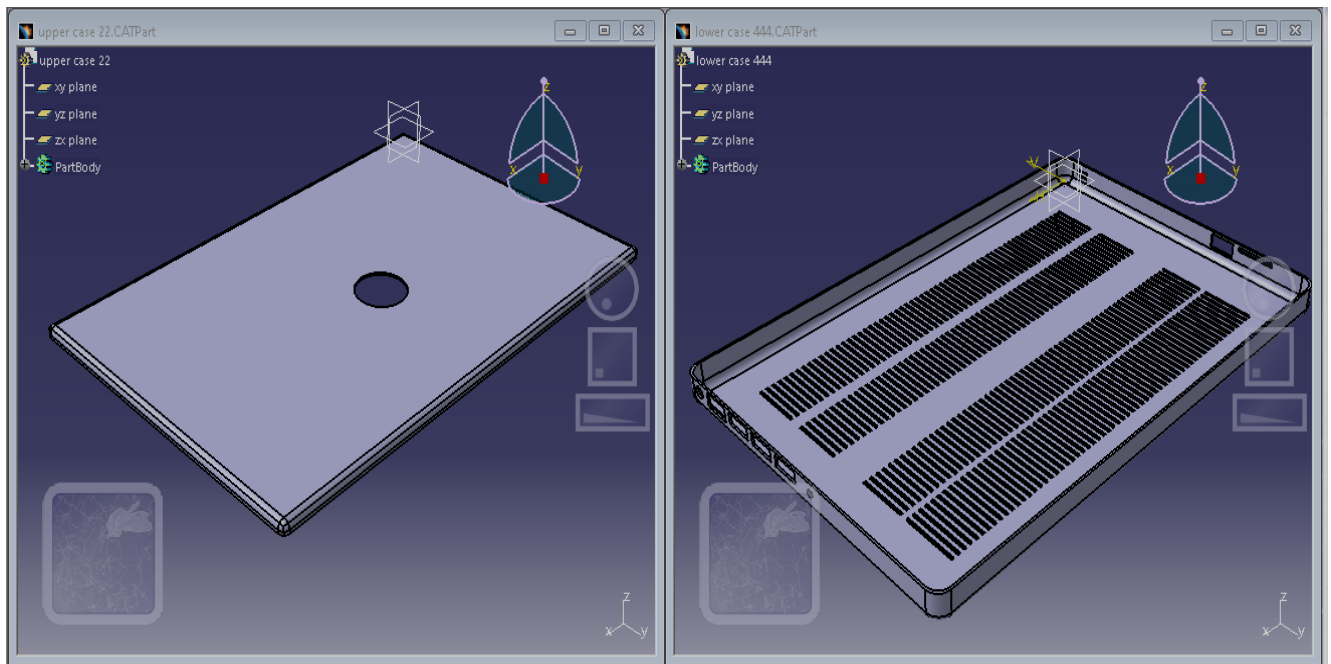


Figure 3-17 catia modeling of both upper and lower casings

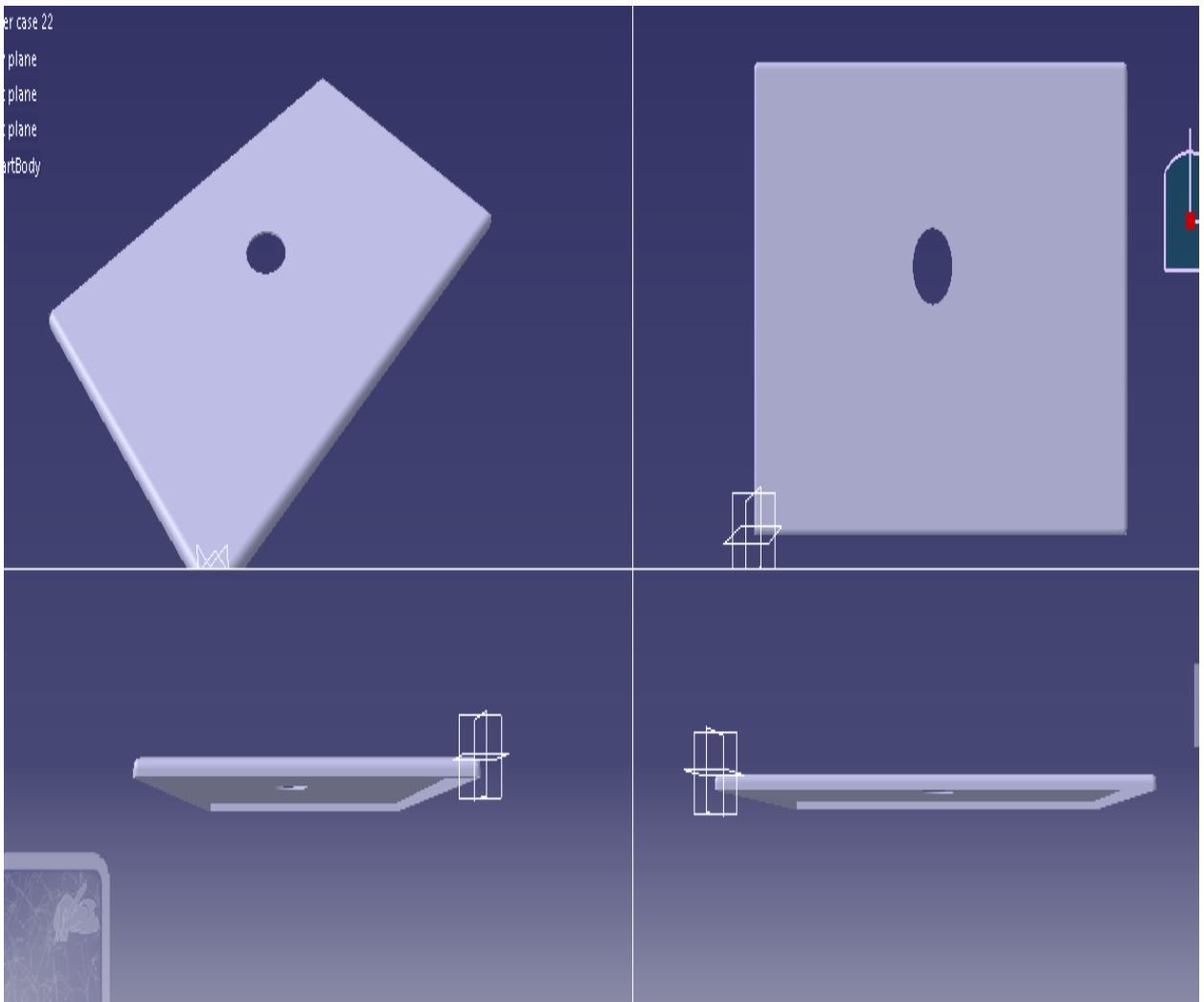
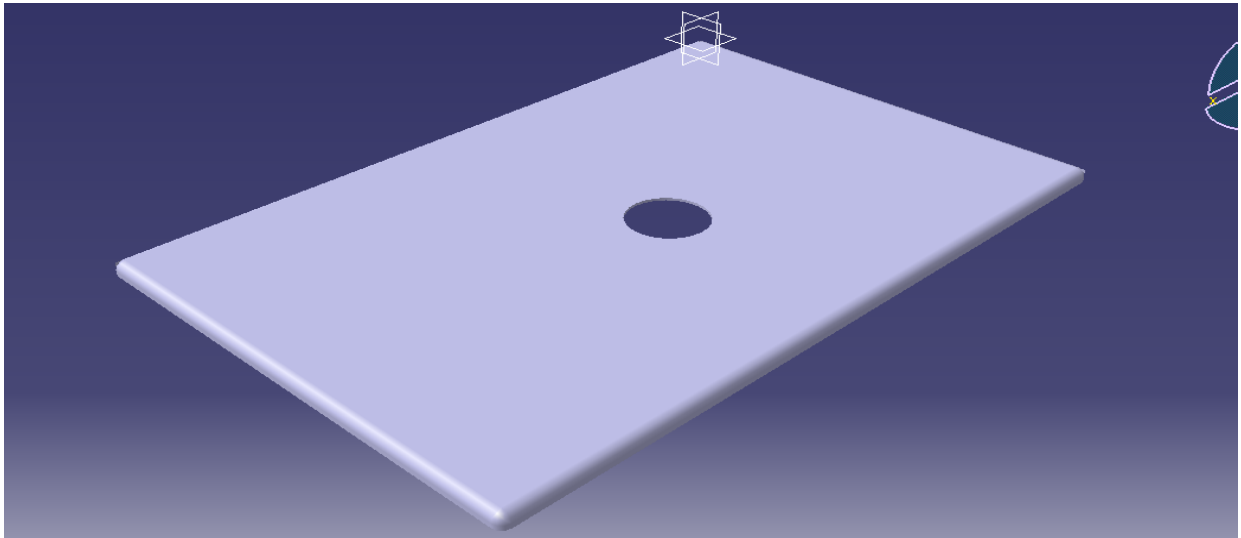


Figure 3-18 hp15-da0012dx laptop upper casing design

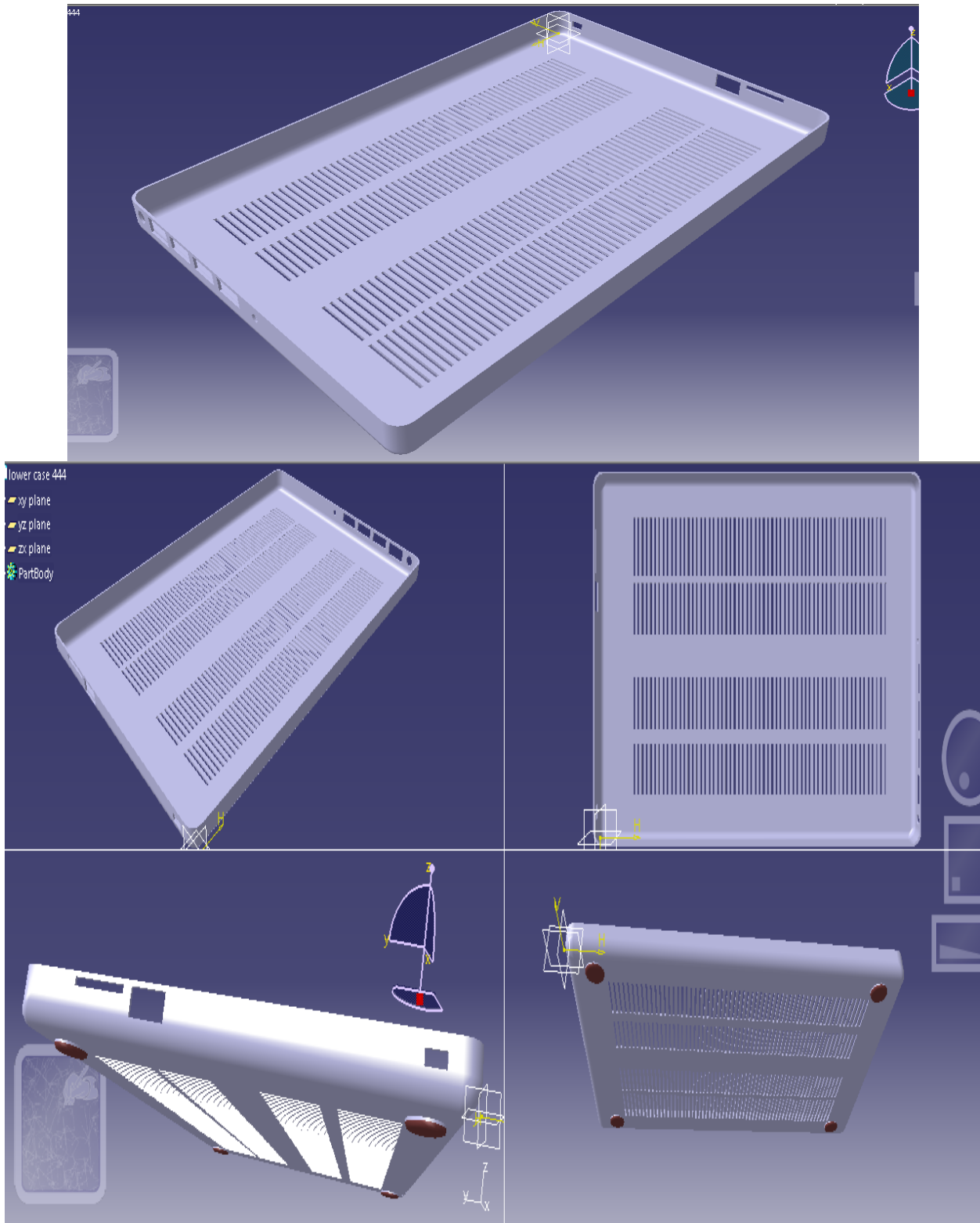


Figure 3-19 hp15-da0012dx laptop lower casing design

In the analysis of Protective laptop casing, steps like modeling, meshing, applying boundaries and loads and analyzing the model was executed. The static analysis was done for maximum principal stress, equivalent stress and deformation. The steps taken in ANSYS analysis are presented below in figure 3.21.



Figure 3-20 steps in ANSYS analysis

Assumptions

The protective casing mat take different shape depending on the type of laptop. This design was done based on my laptop model and dimensions. Therefore, assumptions are needed to make the simulation more practical. So, the following are the assumptions made;

- ✓ The shape of the casing was designed uniform
- ✓ It was assumed that the material is linearly elastic isotropic material by assuming all the fiber and matrix are mixed uniformly.
- ✓ Free of void material
- ✓ Perfect bind between matrix and fiber
- ✓ Homogenous

In this analysis, the selected composite properties were technically epoxy resin properties. Density, tensile yield strength, young's modulus and Poisson's ratio are the properties of epoxy resin.

Density = 1.160g/cm³

Tensile yield strength = 5.4E+7

Young's Modulus = 3.7E+9

Poisson's Ratio = 0.35

Below in figure 3.22 the taken engineering material and datas of the composite are presented.

The figure shows two screenshots from a software application. The top screenshot is titled 'Outline of Schematic A2: Engineering Data' and displays a table with columns A, B, C, D, and E. Row 3 is highlighted, showing 'Resin Epoxy' as the material name, 'Composite_Materials.xml' as the source, and a link to add a new material. The bottom screenshot is titled 'Properties of Outline Row 4: Resin Epoxy' and shows a table of material properties. The properties listed include Density (1160 kg m⁻³), Isotropic Elasticity (with sub-properties for Young's Modulus, Poisson's Ratio, Bulk Modulus, and Shear Modulus), and Tensile Yield Strength (5.46E+07 Pa). The Ply Type is set to Isotropic.

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Resin Epoxy			Composite_Materials.xml	
*	Click here to add a new material				

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1160	kg m ⁻³		
3	Isotropic Elasticity				
4	Derive from	Young's Modu...			
5	Young's Modulus	3.78E+09	Pa		
6	Poisson's Ratio	0.35			
7	Bulk Modulus	4.2E+09	Pa		
8	Shear Modulus	1.4E+09	Pa		
9	Tensile Yield Strength	5.46E+07	Pa		
10	Ply Type				
11	Type	Isotropic			

Figure 3-21 taken engineering material data of the composite

3.10.2 Mesh Generation

It is subdividing of a continuous geometric space into discrete geometric and topological cells. The geometry of the structure is divided into smaller shapes called as, drumroll please, finite elements. Meshing simply means connecting the computations from these finite elements to create a mesh structure.

Here the sizing of meshing was done with fine meshing and default mesh controls are set for the model and is presented below on the figure 3.23.

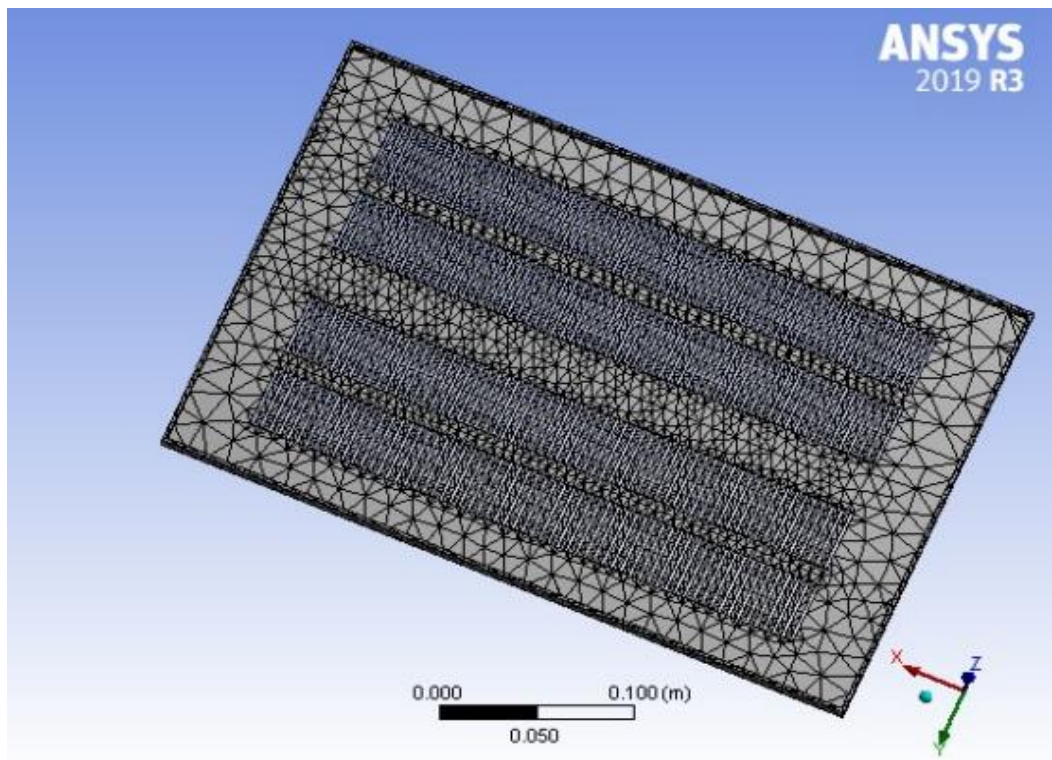
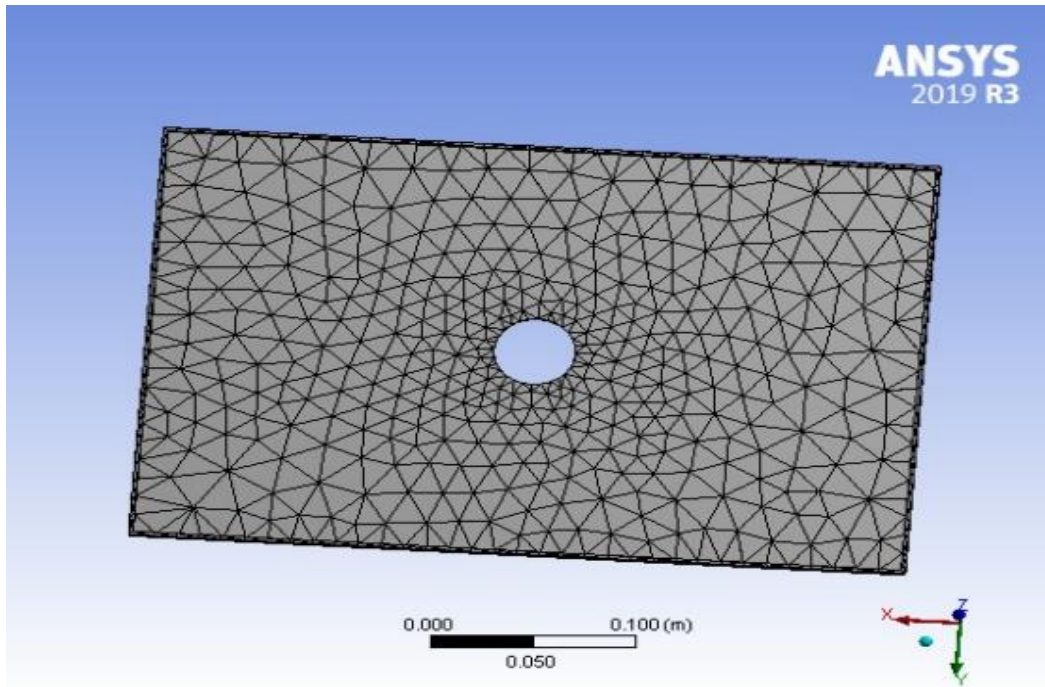


Figure 3-22 meshing details and meshed upper and lower casing Model

Nodal constraint

A node is a coordinate location in space where the degrees of freedom (DOFs) are defined. The DOFs for this point represent the possible movement of this point due to the loading of the structure. The DOFs also represent which forces and moments are transferred from one element to the next.

After the mesh generation, since both impact and uniform strengths were tested, the loadings were also applied as an impact and uniform loadings in which impact load is applied approximately at the center on at the nearest node and uniform loadings are applied at four corners of the casing in order to distribute the loading approximately evenly on the surface at the nodes.

CHAPTER FOUR

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

As stated on objectives, examination of the mechanical properties such as tensile properties, flexural strength and impact strength and physical (water absorption) by varying volume fraction and fiber orientation based on literature reviews was done. Examination of the thermal property was done at the composite specimen volume ratio and fiber orientation that gave the best mechanical and water absorption result on previous test.

As mentioned in the previous section, six composite samples with four different volume fraction and three different orientations were prepared and tested according to ASTM standards. The test results express properties of the Bamboo fiber reinforced Epoxy composites manufactured. All fabricated composites were continuous 270mm and 450mm in fibers length. From each composition, a minimum of 3 and maximum of 6 specimen samples were prepared and tested. Each composite was tested and the result has been discussed below.

Additionally, 3D catia modeling of protective casing for both upper and lower part of the laptop were prepared and finite element method analysis was done on ANSYS software to determine uniform and impact equivalent von mises stress, uniform and impact maximum principal stress and uniform and impact deformation for both the upper and lower casings.

Comparison between previous literatures was also done in this section.

4.1.1 Tensile test result

S20%: is a continuous fiber composite with 20% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.1. and 4.2

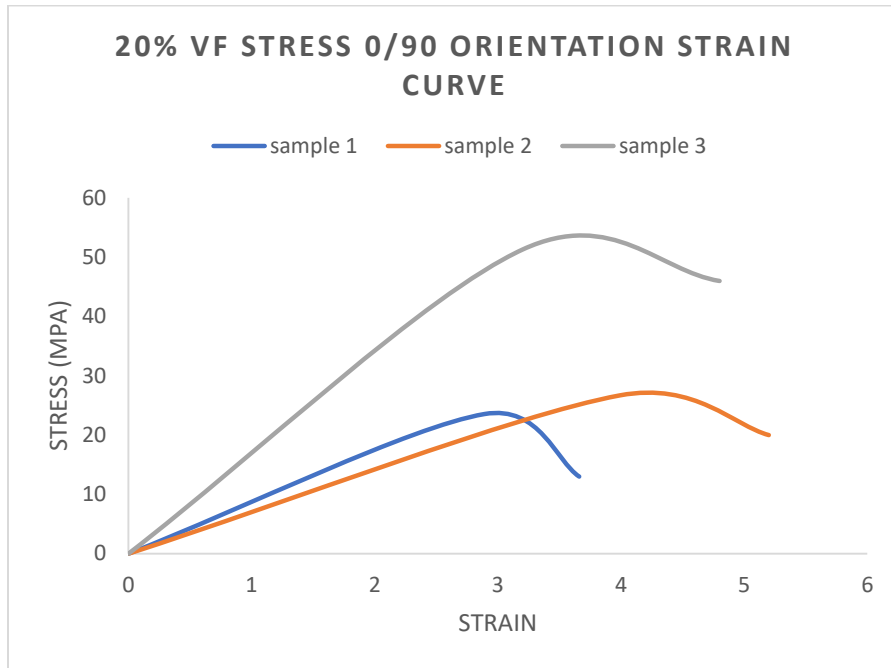


Figure 4-1 stress strain strength test result of three 20% vf sample specimens at 0/90 degree

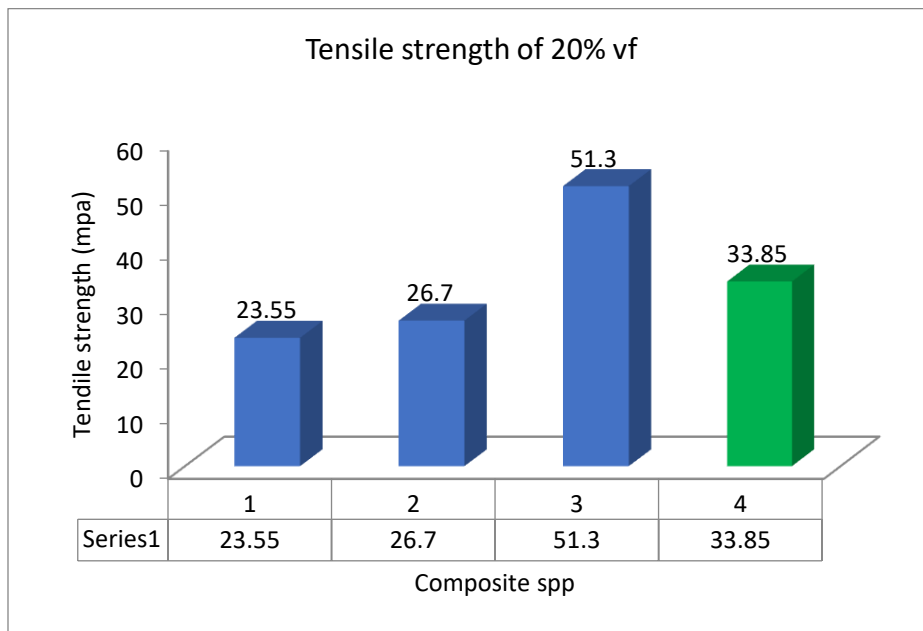


Figure 4-2 tensile strength test result of three 20% vf sample specimens at 0/90 degree

S30%: is a continuous fiber composite with 30% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.3 and 4.4

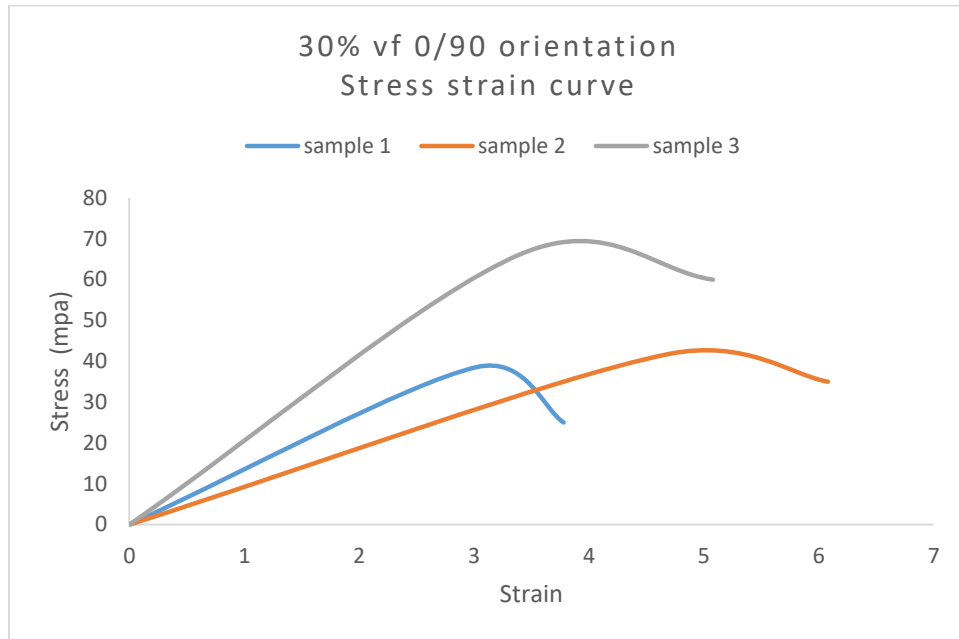


Figure 4-3 stress strain strength test result of three 30% vf sample specimens at 0/90 degree

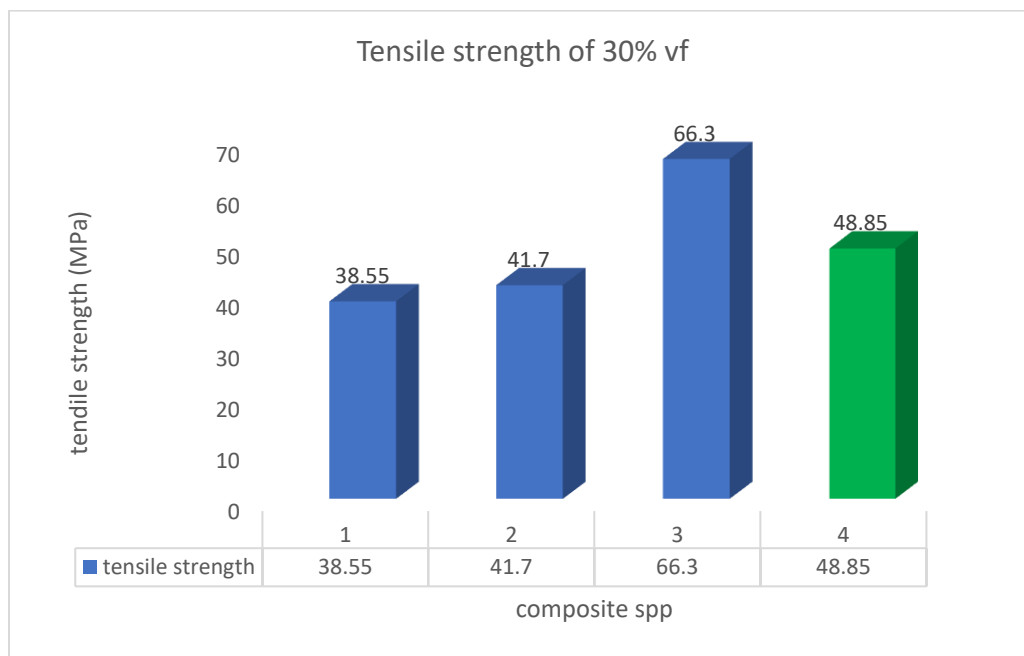


Figure 4-4 tensile strength test result of three 30% vf sample specimens at 0/90 degree

S40% : : is a a continuous fiber composite with 40% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 40% of bamboo fiber and 0/90 degree orientation is shown in figure 4.5 and 4.6

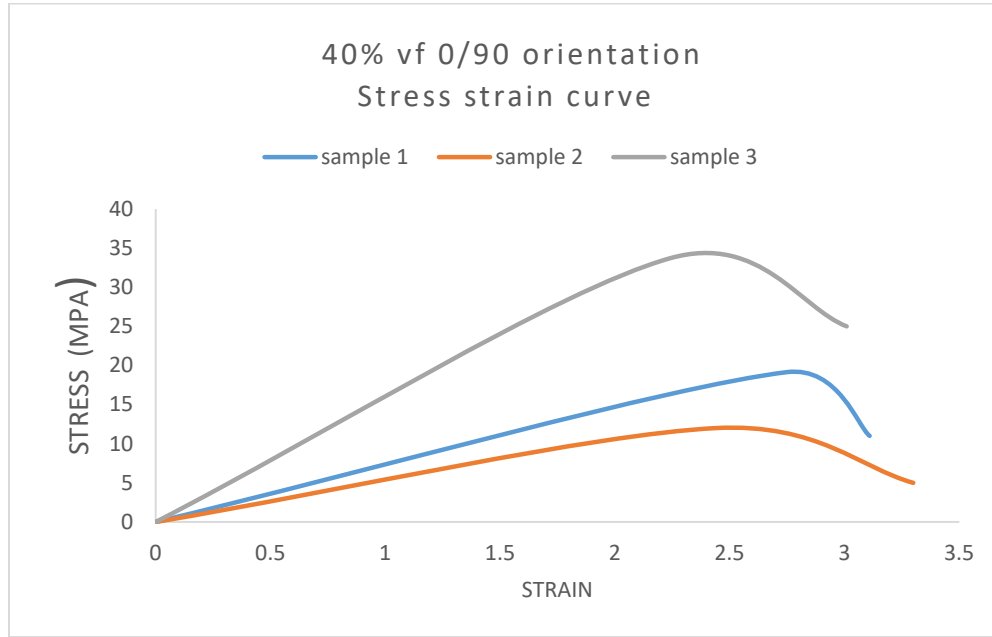


Figure 4-5 stress strain strength test result of three 40% vf sample specimens at 0/90 degree

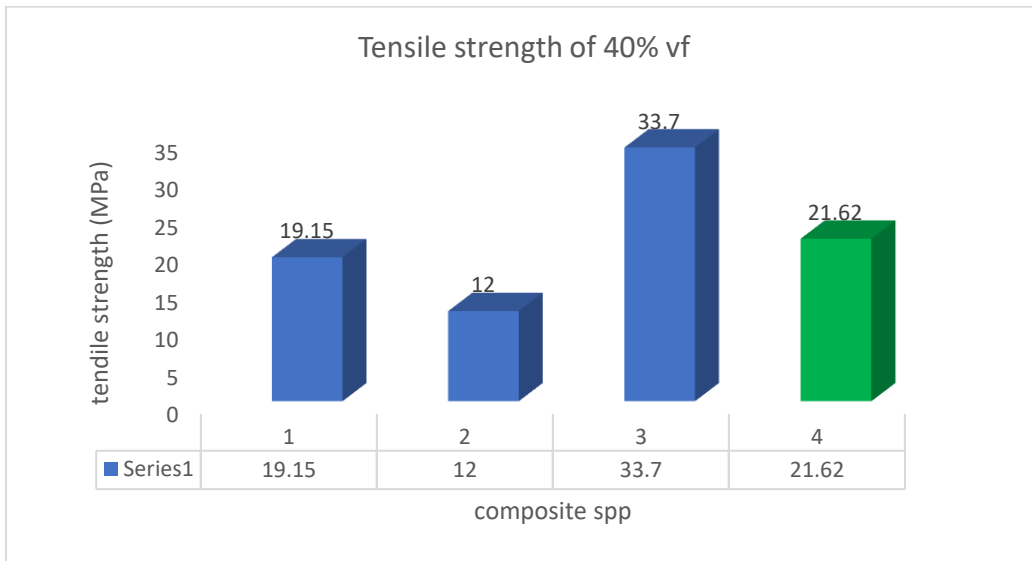


Figure 4-6 tensile strength test result of three 40% vf sample specimens at 0/90 degree

S50%: is a a continuous fiber composite with 50% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 50% of bamboo fiber and 0/90degreorientation is shown in figure 4.7 and 4.8

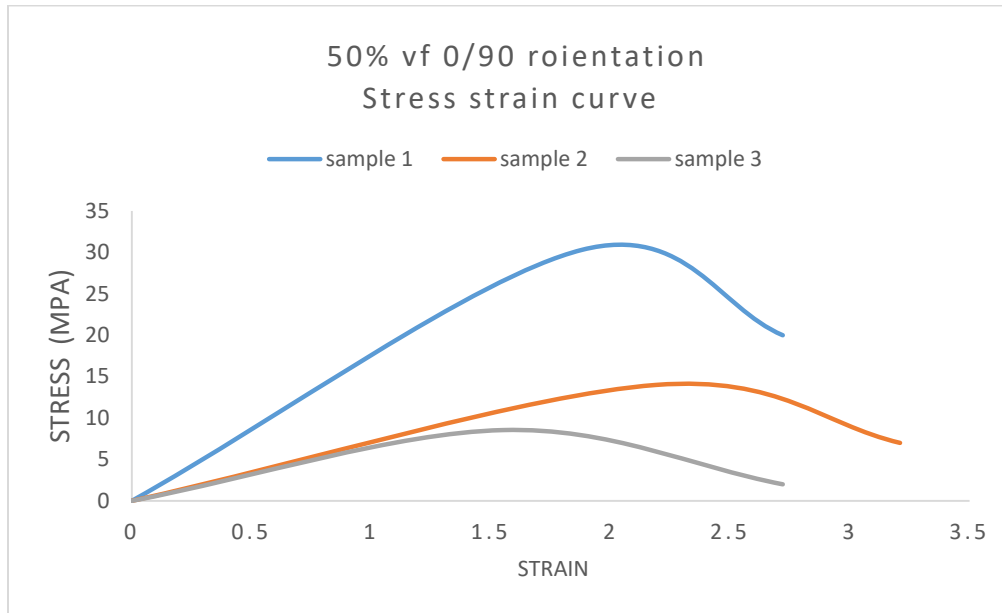


Figure 4-7 stress strain strength test result of three 50% vf sample specimens at 0/90 degree

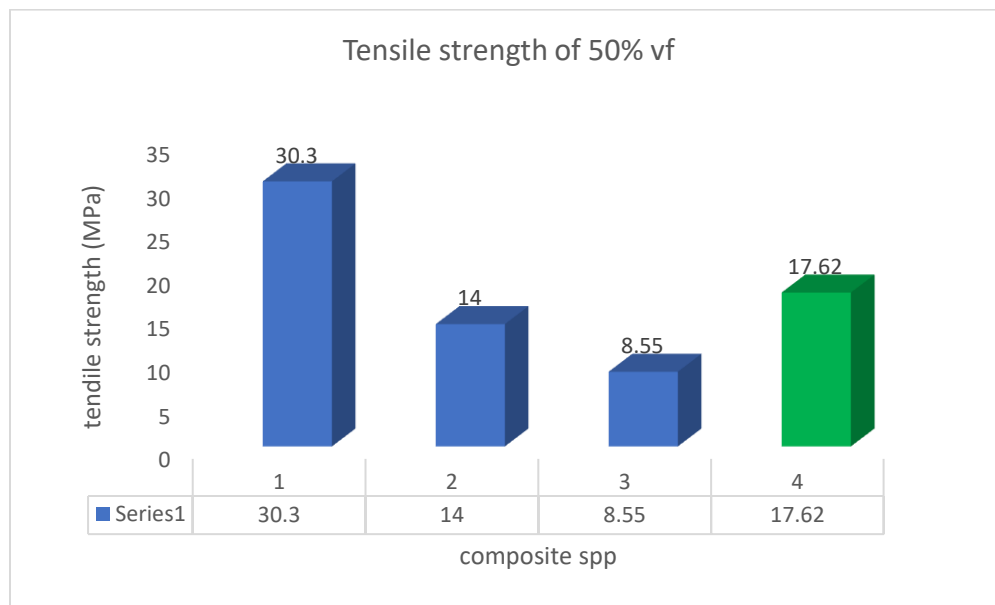


Figure 4-8 tensile strength test result of three 50% vf sample specimens at 0/90 degree

S30⁰ : is a continuous fiber composite with 30% volume fraction and at 0⁰/30⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 30% of bamboo fiber and 0/30 degree orientation is shown in figure 4.9 and 4.10

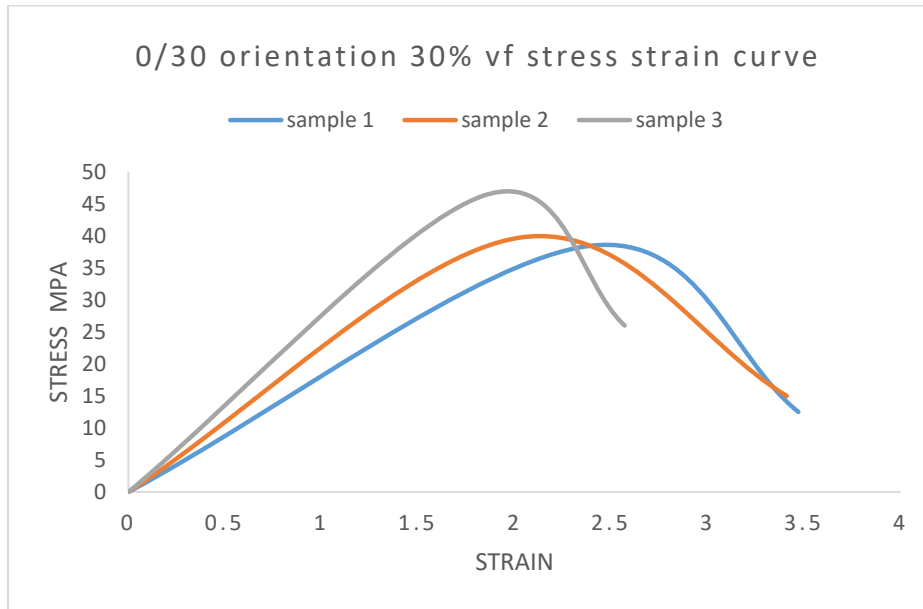


Figure 4-9 stress strain strength test result of three 30% vf sample specimens at 0/30 degree

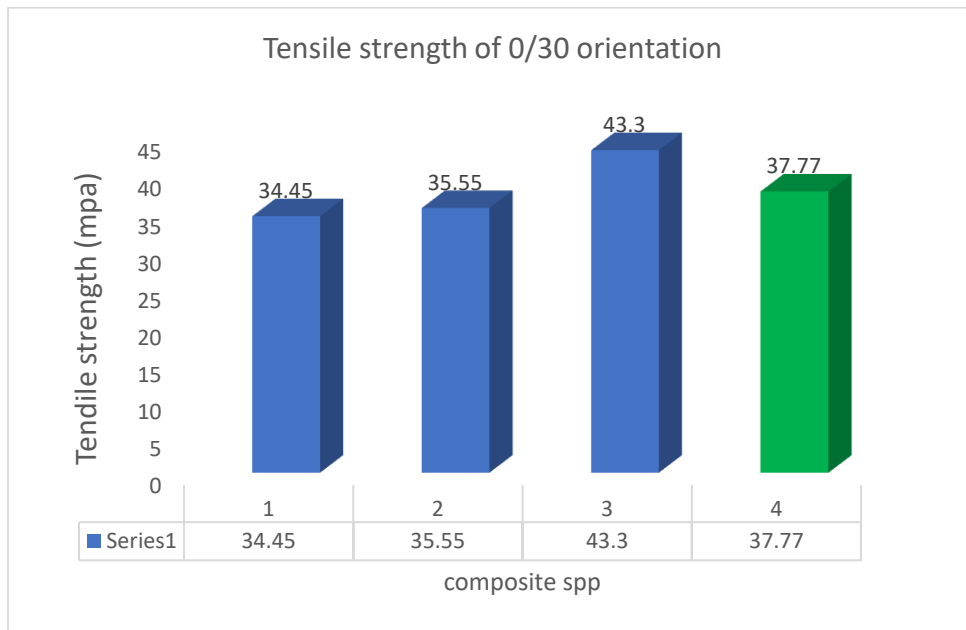


Figure 4-10 tensile strength test result of three 30% vf sample specimens at 0/30 degree

S45⁰ : is a continuous fiber composite with 30% volume fraction and at 0⁰/45⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D3039. The stress-strain curve for the composite with composition 30% of bamboo fiber and 0/45degreeorientation is shown in figure 4.11 and 4.12

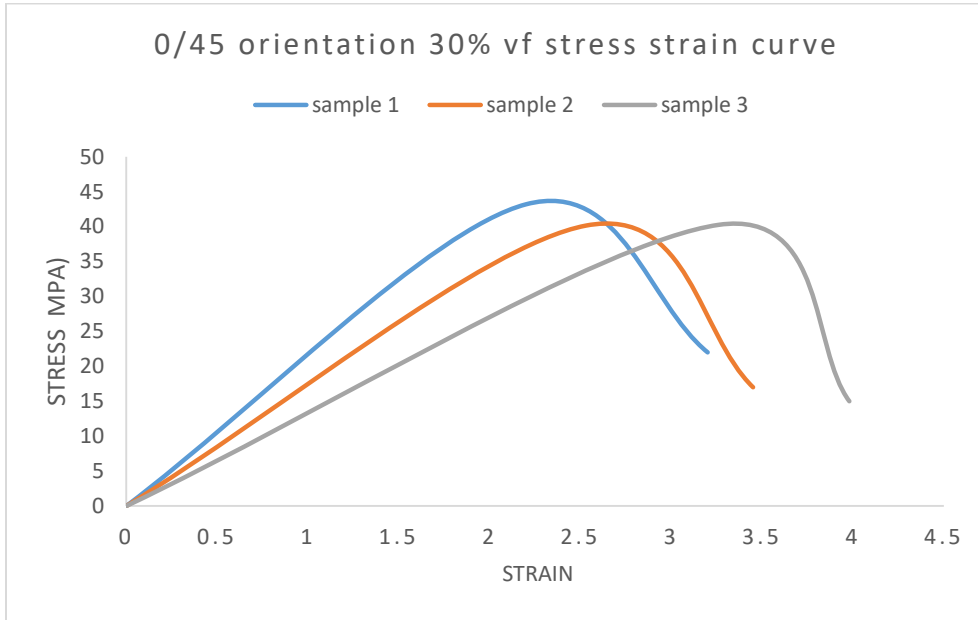


Figure 4-11 stress strain strength test result of three 30% vf sample specimens at 0/45 degree

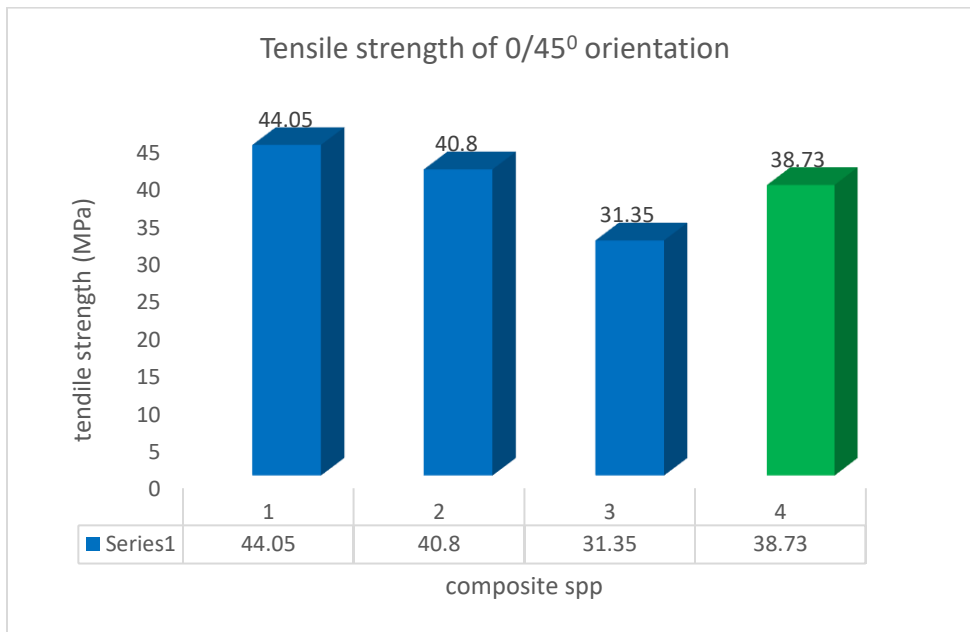


Figure 4-12 tensile strength test result of three 30% vf sample specimens at 0/45 degree

Average stress strain graph and tensile strength is shown in the figure 4.13 and 4.14

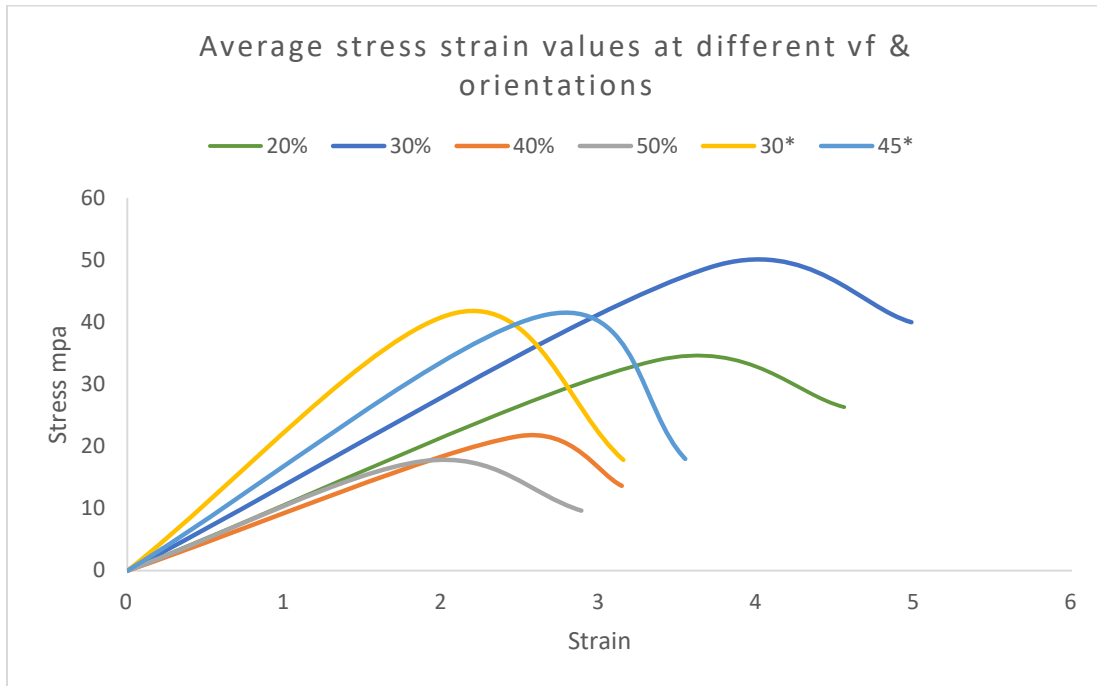


Figure 4-13 average stress strain values at different vf & orientations

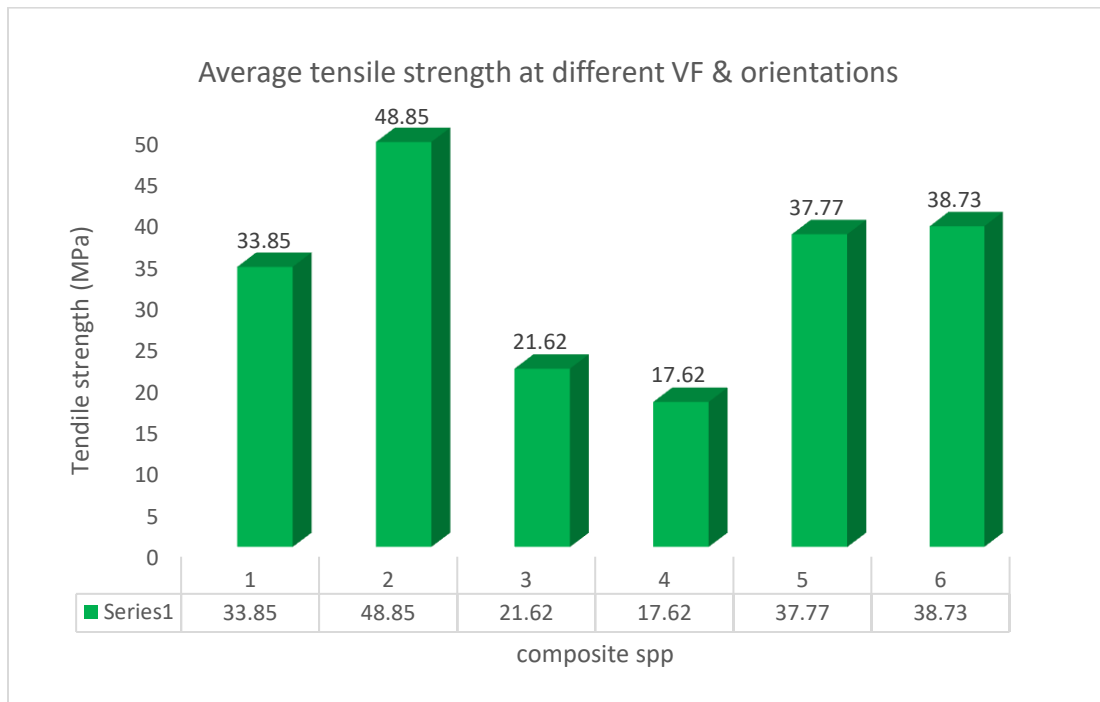


Figure 4-14 average tensile strength of at different vf and orientation

4.1.2 Flexural test result

The flexural test result was obtained from three-point bending test. Result of three specimens were taken. To obtain the flexural strength the machine used, the formula used is equation (4.3).

Section modulus (W_b)

$$W_b = \frac{B \cdot H^2}{6} \dots \dots \dots \text{eq. (4.1)}$$

Maximum bending Moment (M_{bmax})

$$M_{bmax} = \frac{F_{max} \cdot L}{4} \dots \dots \dots \text{eq. (4.2)}$$

From this, Flexural Strength (δ_{bmax}) = $\frac{M_{bmax}}{W_b} \dots \dots \dots \text{eq. (4.3)}$

Where, B = width of specimen

H = Thickness of specimen

Fmax = Maximum Applied Force

L = Span Length

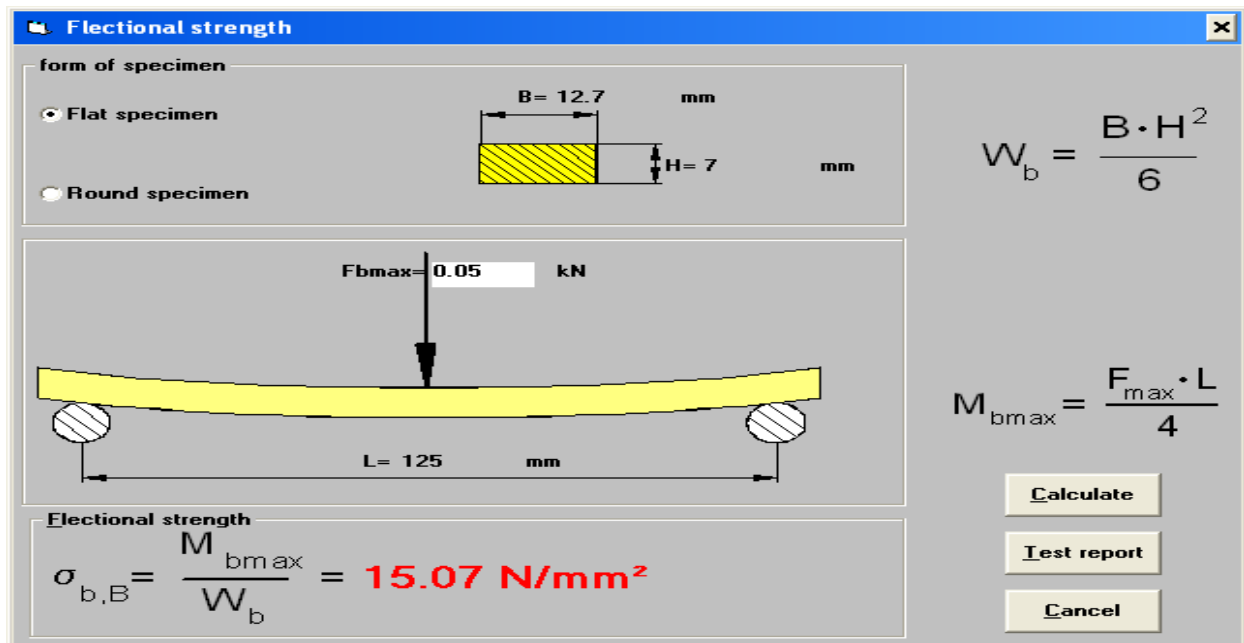


Figure 4-15 computer input and output analysis

S20% : is a a continuous fiber composite with 20% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.16.

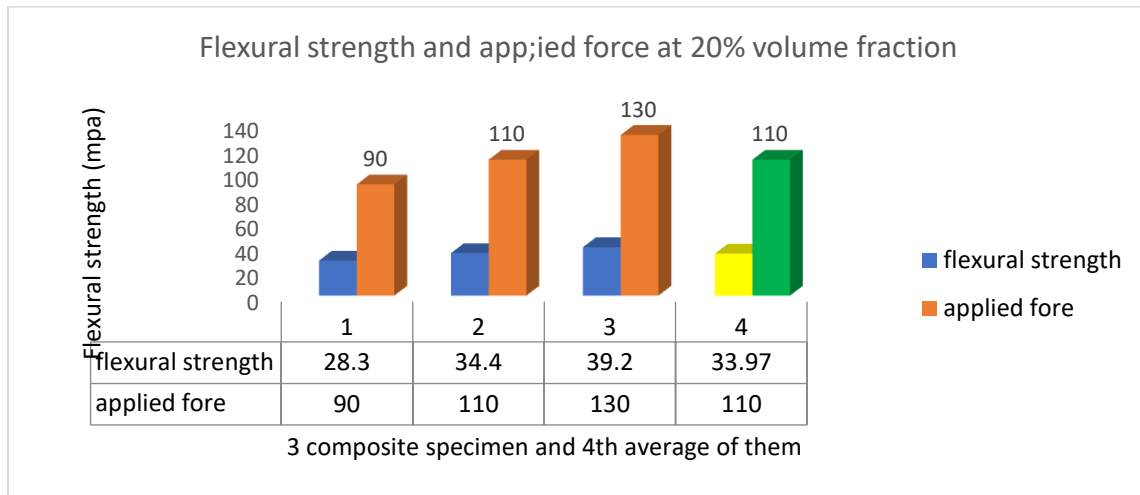


Figure 4-16 flexural strength and applied force test result of three 20% vf sample specimens at 0/90 degree

S30% : is a a continuous fiber composite with 30% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.17.

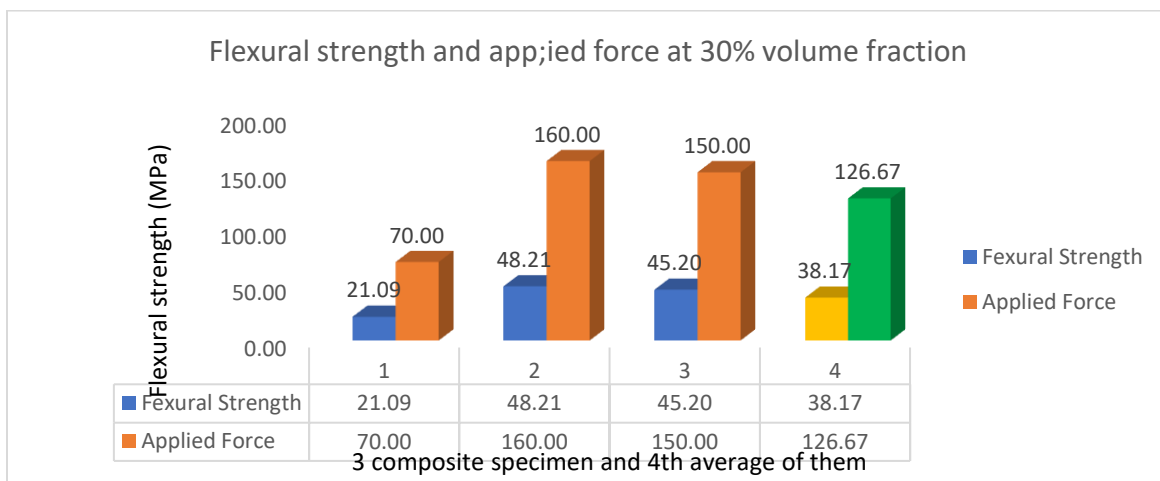


Figure 4-17 flexural strength and applied force test result of three 30% vf sample specimens at 0/90 degree

S40%: is a continuous fiber composite with 40% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 40% of bamboo fiber and $0/90$ degree orientation is shown in figure 4.18.

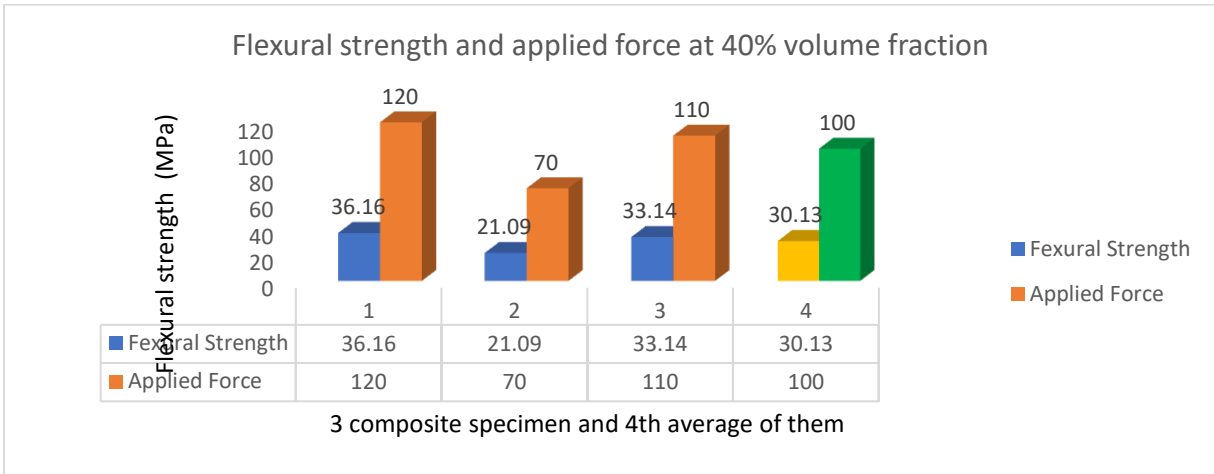


Figure 4-18 flexural strength and applied force test result of three 40% vf sample specimens at $0/90$ degree

S50%: is a continuous fiber composite with 50% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 50% of bamboo fiber and $0/90$ degree orientation is shown in figure 4.19

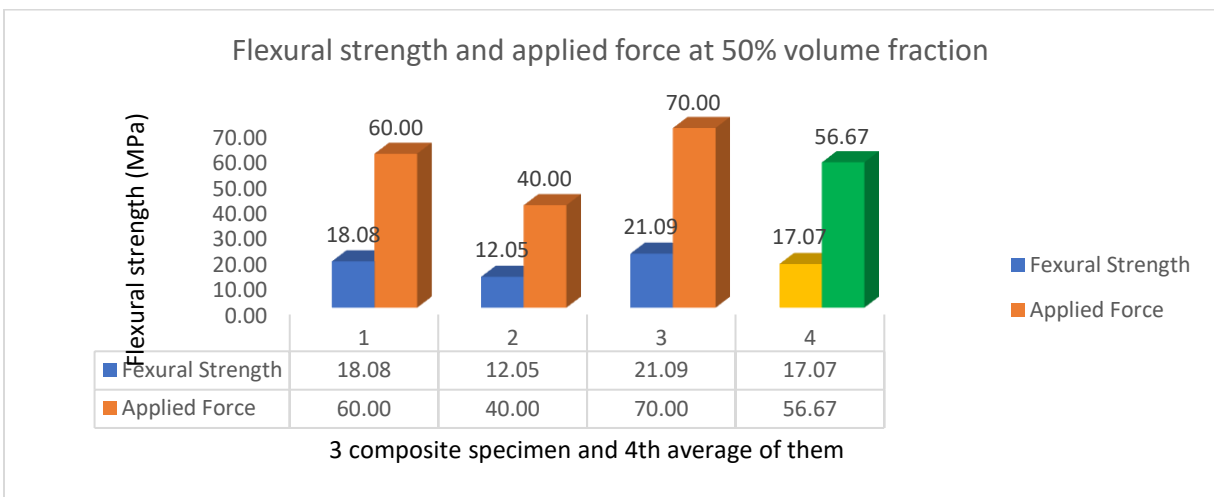


Figure 4-19 flexural strength and applied force test result of three 50% vf sample specimens at $0/90$ degree

S30⁰ : : is a a continuous fiber composite with 30% volume fraction and at 0⁰/30⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 30% of bamboo fiber and 0/30 degree orientation is shown in figure 4.20

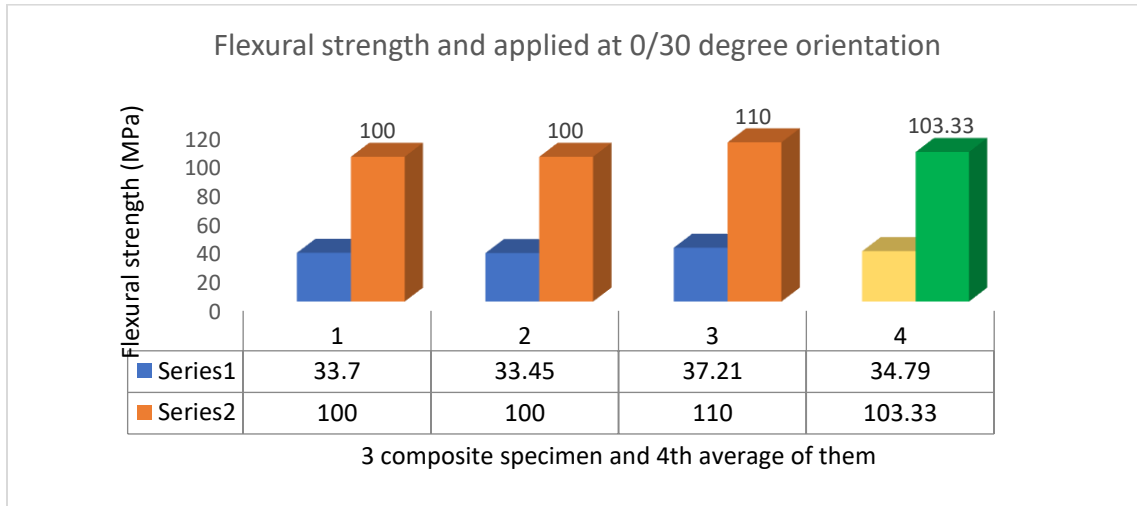


Figure 4-20 flexural strength and applied force test result of three samples at 0/30 degree orientation and 30% vf

S45⁰ : : is a a continuous fiber composite with 30% volume fraction and at 0⁰/45⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D7264. The flexural strength for the composite with composition 30% of bamboo fiber and 0/45 degree orientation is shown in figure 4.21

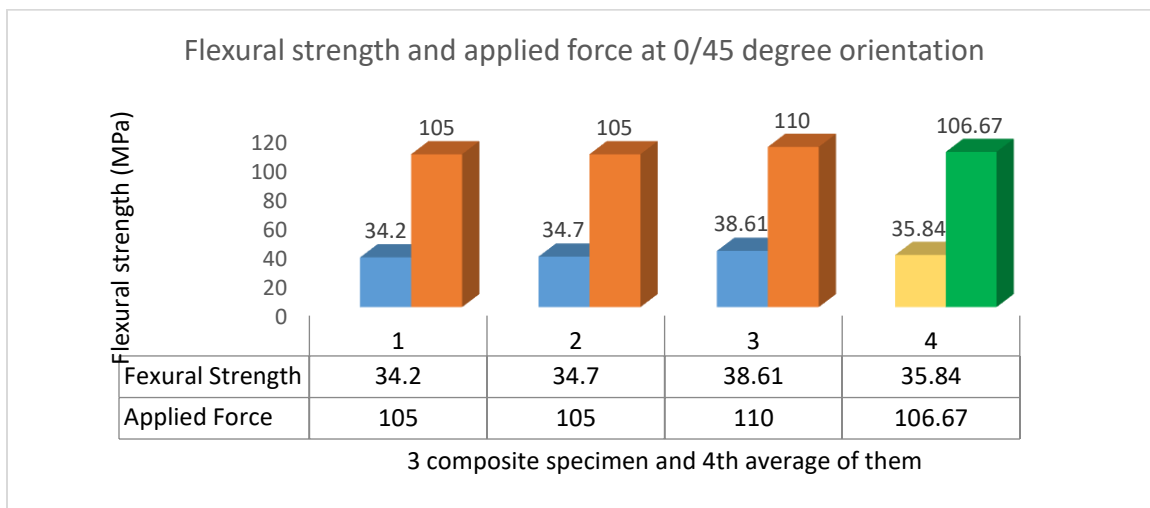


Figure 4-21 flexural strength & applied force test result of three samples at 0/45 degree orientation and 30% vf

Overall, the average Flexural strength and average test forces obtained are shown in the figure 4.22.

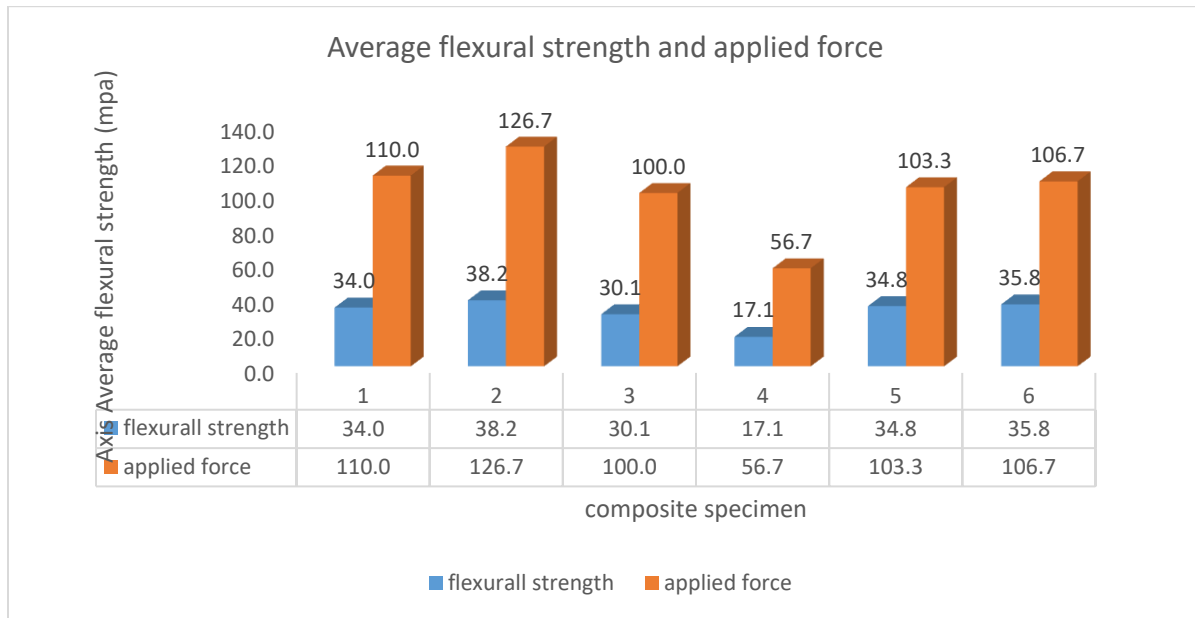


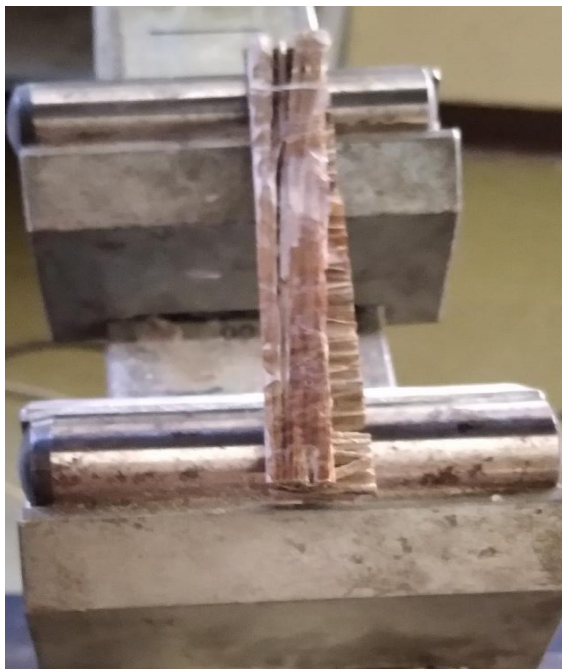
Figure 4-22 average flexural strength and applied force of bamboo fibers at different vf and orientation

From each prepared sample, three-five specimens were tested. Tabular presentation of average flexural strength and applied force of the composite sample specimens at different volume fractions and orientation having the same specimen dimensions is presented in the following table 4.1

Table 4-1 average flexural strength and applied force of bamboo fibers at different vf and orientation

No.	Composite Volume Fraction and Orientation	Specimen dimension(mm)			Average Flexural Strength (MPa)	Average Applied Force(N)
		L	B	H		
1	20% Vf at 0 ⁰ /90 ⁰ orientation	125	12.7	7	33.97	110
2	30% Vf at 0 ⁰ /90 ⁰ orientation	125	12.7	7	38.17	126.7
3	40% Vf at 0 ⁰ /90 ⁰ orientation	125	12.7	7	30.13	100

4	50% Vf at 0°/90° orientation	125	12.7	7	17.07	56.67
5	30% Vf at 0°/30° orientation	125	12.7	7	34.8	103.3
6	30% Vf at 0°/45° orientation	125	12.7	7	35.8	106.7



a)



b)

Figure 4-23 a) flexural strength test specimen prepared for test b) sample after flexural test

4.1.3 Impact test result

Impact strength of the specimens can be calculated using the equation 4.4 mentioned below

$$\text{Impact strength} = \frac{E}{w*t} \dots \dots \dots \text{Eq (4.4)}$$

Where :- E – absorbed energy in in breaking the specimen in joules

w – width of sample

t – thickness of sample

S20% : is a continuous fiber composite with 20% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D256. . The impact strength for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.24.

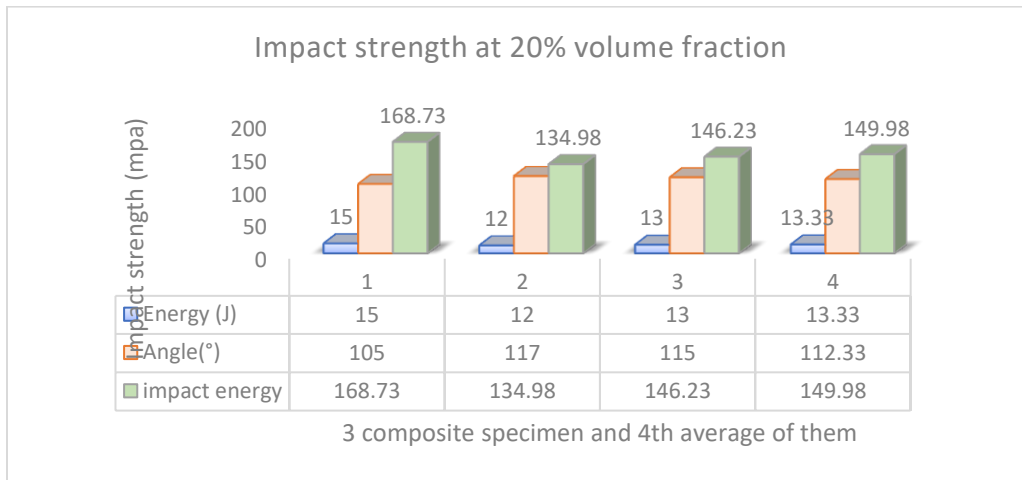


Figure 4-24 impact energy and angle of impact test result of three 20% vf sample specimens at 0/90 degree

S30% : is a continuous fiber composite with 30% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D256. . The impact strength for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.25.

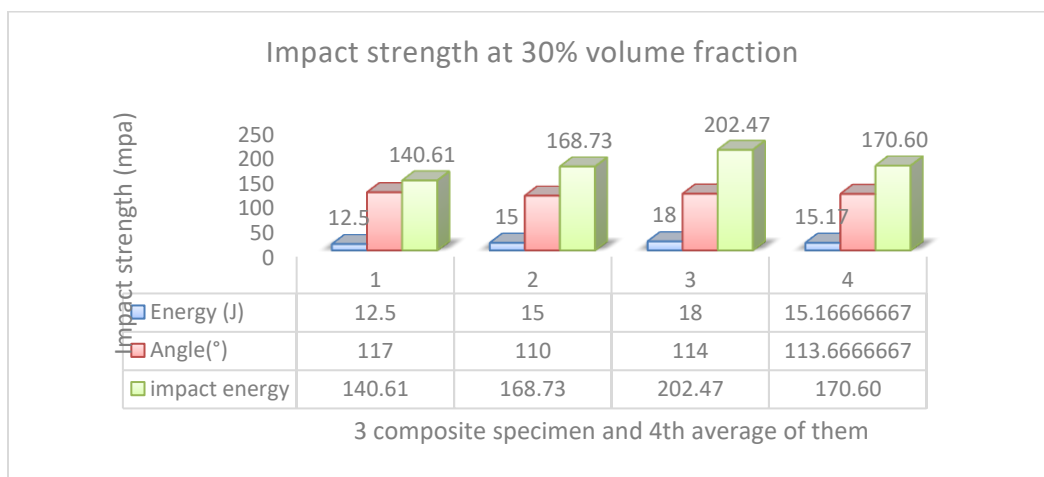


Figure 4-25 impact energy and angle of impact test result of three 30% vf sample specimens at 0/90 degree

S40%: is a continuous fiber composite with 40% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D256. The impact strength for the composite with composition 40% of bamboo fiber and 0/90 degree orientation is shown in figure 4.26.

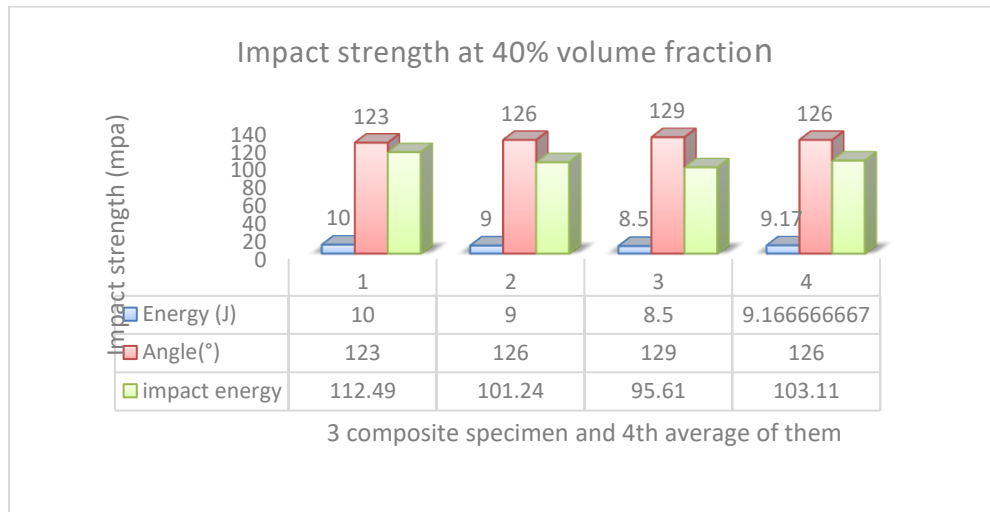


Figure 4-26 impact energy and angle of impact test result of three 40% vf sample specimens at 0/90 degree

S50%: is a continuous fiber composite with 50% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D256. The impact strength for the composite with composition 50% of bamboo fiber and 0/90 degree orientation is shown in figure 4.27

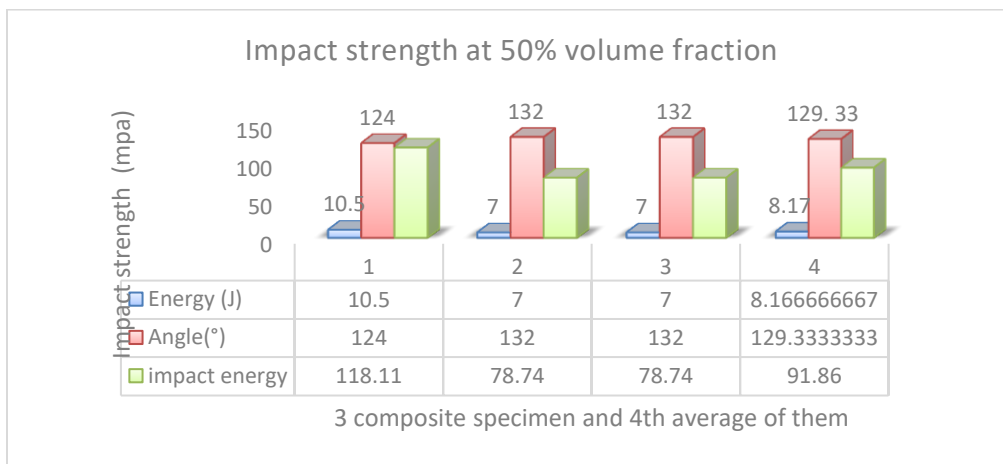


Figure 4-27 impact energy and angle of impact test result of three 50% vf sample specimens at 0/90 degree

S30⁰: is a continuous fiber composite with 30% volume fraction and at 0⁰/30⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D256. The impact strength for the composite with composition 30% of bamboo fiber and 0/30 degree orientation is shown in figure 4.28.

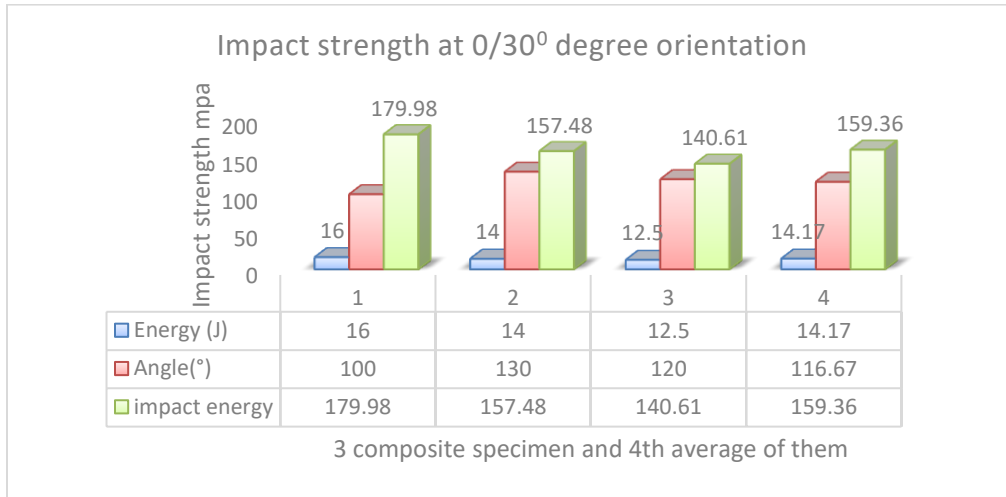


Figure 4-28 impact energy and angle of impact test result of three samples at 0/30 degree orientation and 30% vf

S45⁰: is a continuous fiber composite with 30% volume fraction and at 0⁰/45⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D256. The impact strength for the composite with composition 30% of bamboo fiber and 0/45 degree orientation is shown in figure 4.29.

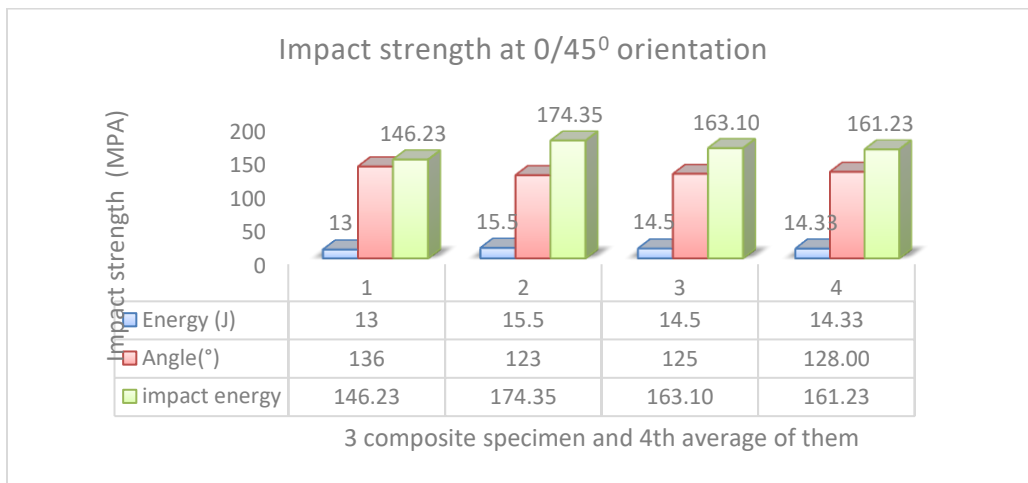


Figure 4-29 impact energy and angle of impact test result of three samples at 0/45 degree orientation and 30% vf

From each prepared sample, three-five specimens were tested. Tabular presentation of average impact strength and of the composite sample specimens at different volume fractions and orientation having the same specimen dimensions is presented in the following table 4.2

Table 4-2 average impact energy and angle of impact of bamboo fibers at different vf and orientation

No	Composite composition	Specimen size(mm)		Impact Energy (J)	Angle of impact	Impact strength (J/m ²)
		B	H			
1	20% Vf at 0 ⁰ /90 ⁰ orientation	12.7	7	15	105	168.73
		12.7	7	12	117	134.98
		12.7	7	13	115	146.23
	Average			13.33	112.33	149.98
2	30% Vf at 0 ⁰ /90 ⁰ orientation	12.7	7	12.5	117	140.61
		12.7	7	15	110	168.73
		12.7	7	18	114	202.47
	Average			15.17	113.67	170.60
3	40% Vf at 0 ⁰ /90 ⁰ orientation	12.7	7	10	123	112.49
		12.7	7	9	126	101.24
		12.7	7	8.5	129	95.61
	Average			9.17	126	103.11
4	50% Vf at 0 ⁰ /90 ⁰ orientation	12.7	7	10.5	124	118.11
		12.7	7	7	132	78.74
		12.7	7	7	132	78.74
	Average			8.17	129.34	91.86
5	30% Vf at 0 ⁰ /30 ⁰ orientation	12.7	7	16	100	179.98
		12.7	7	14	130	157.48
		12.7	7	12.5	120	140.61
	Average			14.17	116.67	159.36
6	30% Vf at 0 ⁰ /45 ⁰ orientation	12.7	7	13	136	146.23
		12.7	7	15.5	123	174.35

		12.7	7	14.5	125	163.10
	Average			14.33	128.00	161.23

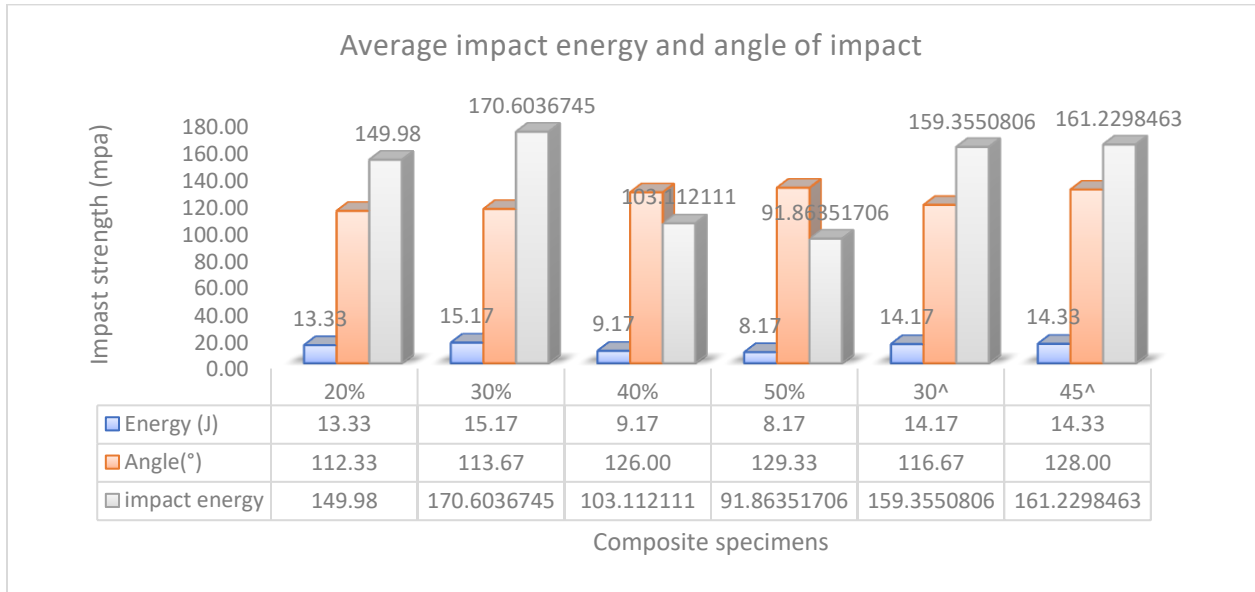


Figure 4-30 average impact energy and angle of impact of bamboo fibers at different vf and orientation



Figure 4-31 a) Charpy impact testing machine

b) tested impact test sample

4.1.4 Water absorption result

The water absorption test followed ASTM standard test method D5229 in which specimen dimensions are 100mm*100mm. Before the measurement, the sample will be dried in an air oven at 50°C for 24 h, and then cooled, and immediately. Then the specimen will be placed in a container of distilled water maintained at a temperature of 23 ± 1°C for 1 hour, 6hrs and 24hrs. At each hours the specimen is removed from water and water will be wiped off the surface of the sample with a dry cloth; and the sample was immediately weighed, which is designated as M1. For each pet sample, 3 specimens were measured. The water absorption of the sample was calculated as percent weight change (M %) determined as follow;

$$MA \text{ of the fiber (\%)} = (w_o - w_1) / w_o * 100 \dots\dots\dots \text{Eq (4.5)}$$

W_o =initial weight of sample

W₁ = final weight of sample

Table 4-3 weight gain result table calculated using equation 4.5

	Initial weight of composite (w _o)		1 hour weight		2-hour weight		6-hour weight		24-hour weight	
20% VF	62.00	58.00	62.50	58.40	62.80	58.70	62.95	58.85	63.05	59.00
30% VF	67.1	57.4	67.60	57.85	68.00	58.25	68.30	58.50	68.40	58.60
40% VF	32.6	38.5	57.30	44.80	57.80	45.30	58.10	45.60	58.20	45.70
50% VF	56.2	43.8	33.60	39.60	34.30	40.20	34.45	40.30	34.55	40.40
30⁰ orientation	61.2	58.2	61.80	58.80	62.30	59.20	62.55	59.40	62.65	59.50
45⁰ orientation	61.4	57.1	61.95	57.60	62.40	58.00	62.55	58.15	62.60	58.20

Therefore, the water absorption weight gain can be calculated using the above equation and tabulated in the following table 4.4 as follows

Table 4-4 mass absorption result table calculated using equation 4.5

	Initial weight of composite (wo)		1 hour water absorption		2-hour water absorption		6-hour water absorption		24-hour water absorption	
20% VF	62.00	58.00	0.81	0.69	1.29	1.21	1.53	1.47	1.69	1.72
30% VF	67.10	57.40	0.75	0.78	1.34	1.48	1.79	1.92	1.94	2.09
40% VF	56.20	43.80	1.96	2.28	2.85	3.42	3.38	4.11	3.56	4.34
50% VF	32.60	38.50	3.07	2.86	5.21	4.42	5.67	4.68	5.98	4.94
30⁰ orientation	61.20	58.20	0.98	1.03	1.80	1.72	2.21	2.06	2.37	2.23
45⁰ orientation	61.40	57.10	0.90	0.88	1.63	1.58	1.87	1.84	1.95	1.93

S20% : is a a continuous fiber composite with 30% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.32.

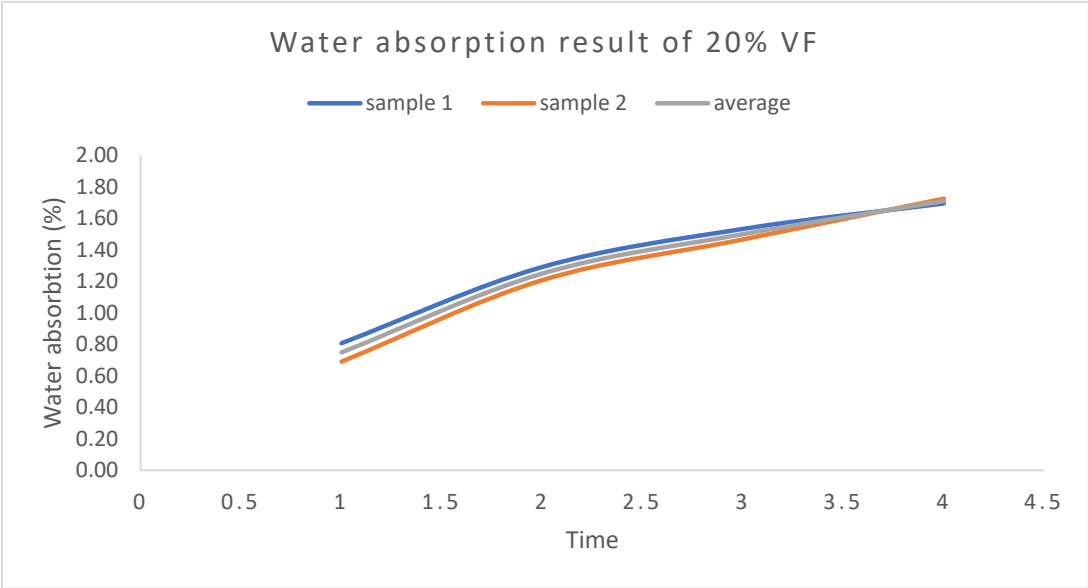


Figure 4-32 water absorption result of 20% VF

S30% : is a a continuous fiber composite with 30% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 30% of bamboo fiber and 0/90 degree orientation is shown in figure 4.33.

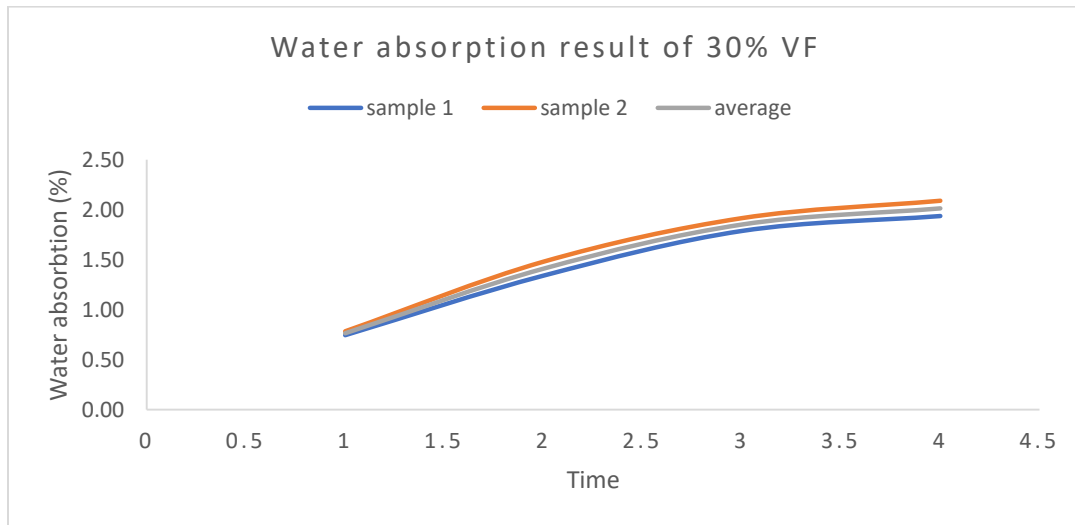


Figure 4-33 water absorption result of 30% VF

S40%: is a continuous fiber composite with 40% volume fraction and at $0^0/90^0$ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 40% of bamboo fiber and 0/90 degree orientation is shown in figure 4.34.

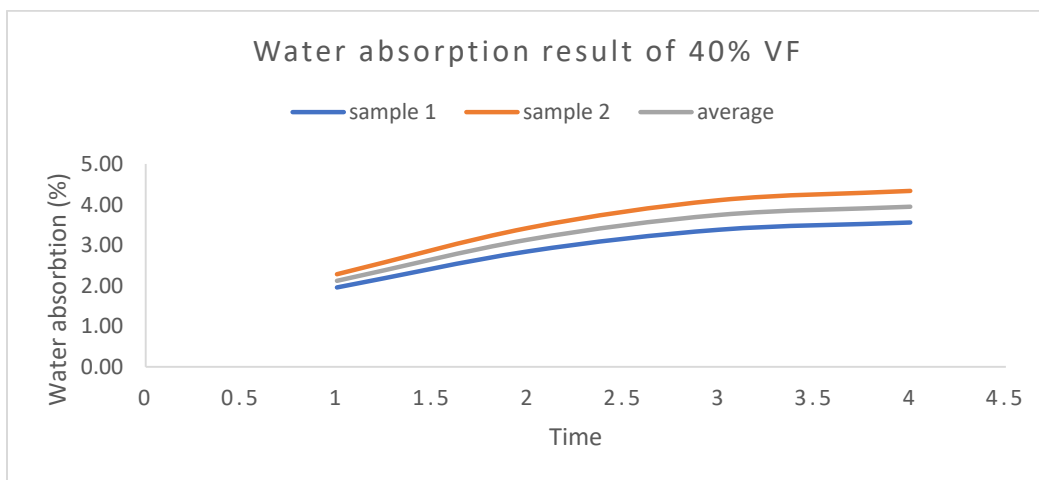


Figure 4-34 water absorption result of 40% VF

S50⁰: is a continuous fiber composite with 50% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 50% of bamboo fiber and 0/90 degree orientation is shown in figure 4.35.

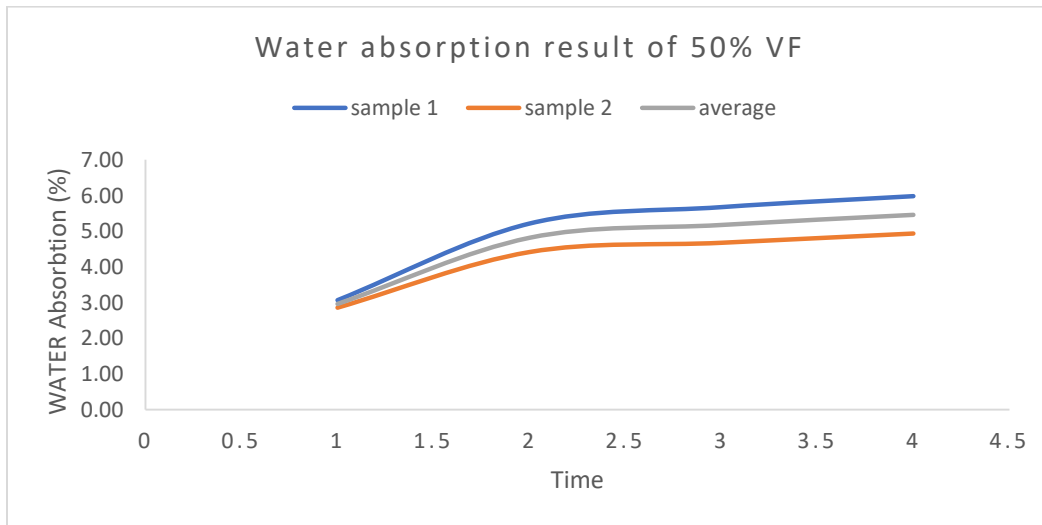


Figure 4-35 water absorption result of 50% VF

S30⁰: is a continuous fiber composite with 30% volume fraction and at 0⁰/30⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 30% of bamboo fiber and 0/30 degree orientation is shown in figure 4.36.

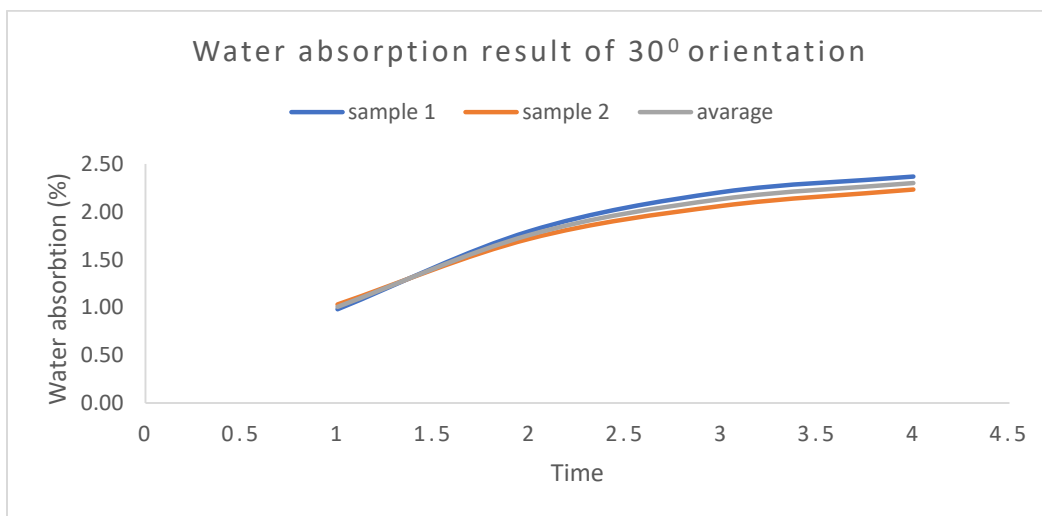


Figure 4-36 water absorption result of 30* orientation at 30% VF

S45⁰: is a continuous fiber composite with 30% volume fraction and at 0⁰/45⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. The water absorption rate for the composite with composition 30% of bamboo fiber and 0/45 degree orientation is shown in figure 4.37.

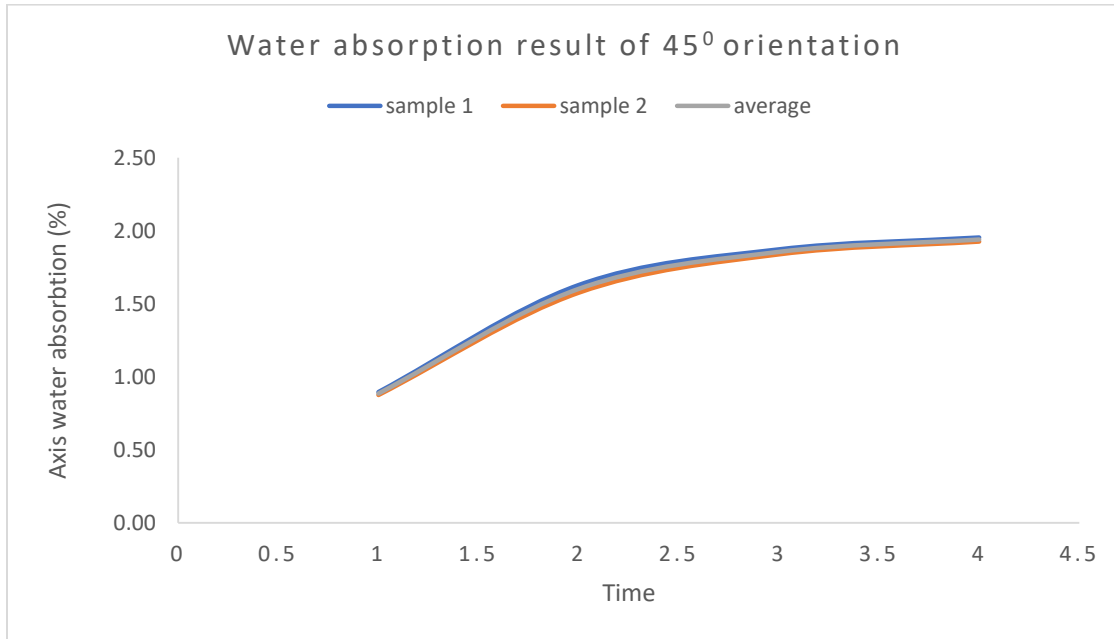


Figure 4-37 water absorption result of 45* orientation at 30% VF

Overall, the average water absorption at different volume fractions and orientations obtained are shown on table 4.5 and graphically on figure 4.38

Table 4-5 the average water absorption at different volume fractions and orientations

	1 hour average water absorption	2-hour average water absorption	6-hour average water absorption	24-hour average water absorption
20% VF	0.75	1.25	1.50	1.71
30% VF	0.76	1.41	1.85	2.01
40% VF	2.12	3.14	3.75	3.95
50% VF	2.96	4.82	5.18	5.46

30° orientation	1.01	1.76	2.13	2.30
45° orientation	0.89	1.60	1.86	1.94

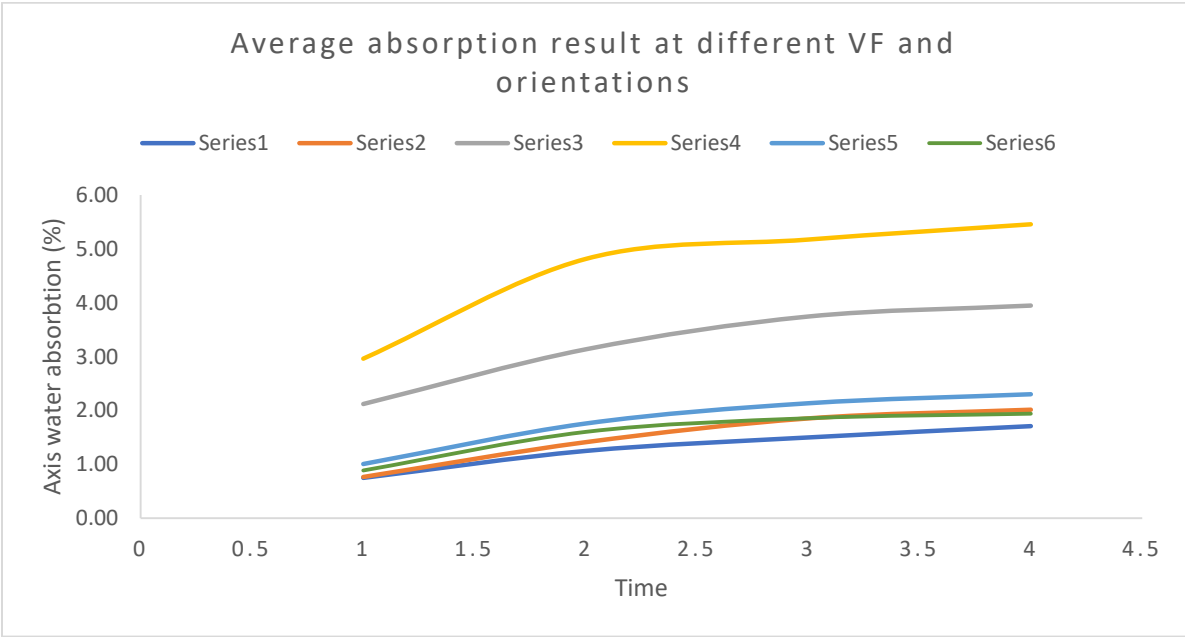


Figure 4-38 water absorption result at different VF and orientations



Figure 4-39 sample soaked in water for water absorption

4.1.5 Thermal resistance test

Sample: from the results obtained from previous tests, 30% VF and 0⁰/90⁰ orientation has better mechanical properties so using this result the prepared sample is a a continuous fiber composite with 30% volume fraction and at 0⁰/90⁰ orientation. For this sample three specimens were prepared and tested according to ASTM D5229. And the results are presented below on table 4.6 and figure 4.35 below.

Measured values: -

- ✓ Temperature 1 (T1)
- ✓ Temperature 2 (T2)
- ✓ Volume of water
- ✓
- ✓ Time of water
- ✓ Area of sample
- ✓ Length of sample

Tabular data: -

- ✓ Heat capacity of water at constant pressure (Cp)

Calculated values: -

- ✓ Change in temperature

$$\Delta T = T2 - T1 \dots\dots\dots Eq(4.6)$$

- ✓ Mass flow rate of water (m)

$$\dot{m} = \text{volume of water} / \text{time} \dots\dots\dots Eq(4.7)$$

- ✓ Rate of heat transfer of water (Qw)

$$Q = (K * \Delta T * A) / L \dots\dots\dots Eq(4.8)$$

- ✓ Thermal conductivity of sample (K)

$$K = (Q/A) / (\Delta T/L) \dots\dots\dots Eq(4.9)$$

Table 4-6 thermal conductivity/resistance test result

sample	T1	T2	ΔT	Cp water	Volume of water(m ³)	Time water(sec)	Length (m)	Area of sample(m ³)	Mass flow rate of water(kg/sec)	Q of water(watt)	K
1	26.9	27.2	0.3	33.44	0.00006	72	0.065	0.0007065	8.33333E-07	8.36E-06	0.002564
2	27.1	27.5	0.4	33.44	0.00006	72	0.065	0.0007065	8.33333E-07	1.11467E-05	0.002564
3	27.4	28	0.6	33.44	0.00006	72	0.065	0.0007065	8.33333E-07	0.00001672	0.002564

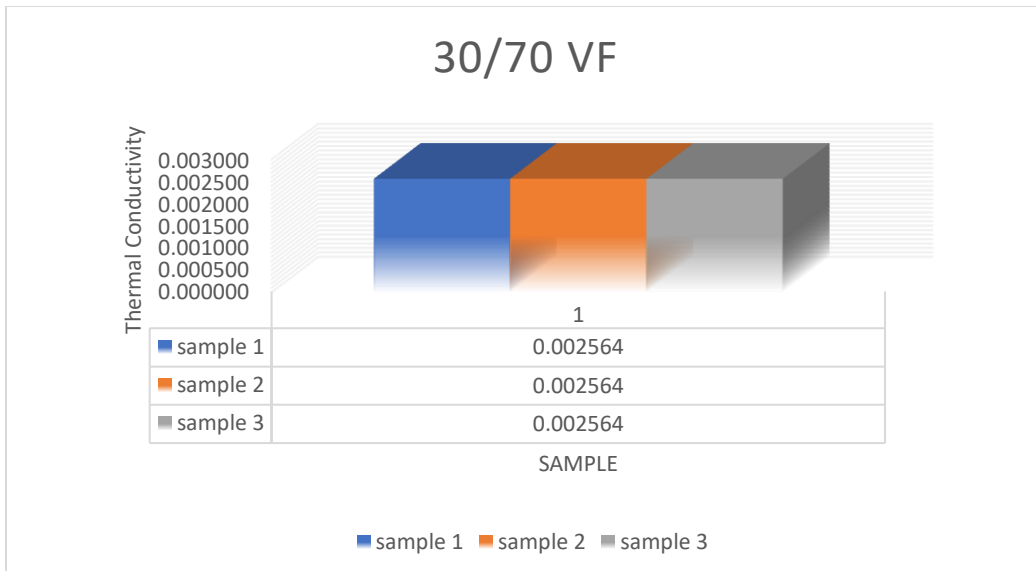


Figure 4-40 thermal conductivity at 30% VF



a.

b)

c)



Figure 4-41 a) thermal test sample

b) thermal test setup

c) thermal test machine

4.2 Discussion of experimental results

4.2.1 The Effect of Volume Fraction And Orientation On Tensile Strength

Results from three specimen samples were obtained and their average value was taken as its tensile strength property for each composite specimen fabricated.

	= highest result
	= second highest result
	= third highest result

Table 4-7 overall average tensile strength result at different parameters

Volume fraction / orientation	20% volume fraction 0/90 ⁰ orientation	30% volume fraction 0/90 ⁰ orientation	40% volume fraction 0/90 ⁰ orientation	50% volume fraction 0/90 ⁰ orientation	30% volume fraction 0 ⁰ /30 ⁰ orientation	30% volume fraction 0 ⁰ /45 ⁰ orientation
Average Tensile strength (MPa)	33.85	48.85	21.62	17.62	37.77	38.73

When comparing the tensile strengths of the sample specimens, the category with 30% fiber VF with 0/90⁰ orientation has the superior tensile strength having 48.85MPa over the other 30% fiber volume fractions with 0/45⁰ & 0/30⁰ orientations having 38.73MPa & 37.77MPa respectively. The higher 40% & 50% fiber VF have the lowest tensile strength compared with the 30% fiber volume fractions

It's seen that that lower ratio of fiber volume fraction 30% has better tensile strength than the other higher fiber volume fractions (20%, 40% & 50% VF), since all the top values recorded are at 30% fiber volume fractions with different fiber orientations which are at 0/90⁰, 0/30⁰ & 0/45⁰ orientations respectively.

And 0/90° orientation has the superior tensile strength having 48.85MPa over the other 0/30° & 0/45° orientations at 30% VF ratio.

4.2.2 The Effect of Volume Fraction and Orientation on Flexural Strength Discussion

In the same way, results from three specimen samples were obtained and their average value were taken as its flexural strength property for each composite specimen were fabricated.

Table 4-8 overall average flexural strength result at different parameters

Volume fraction / orientation	20% volume fraction 0/90° orientation	30% volume fraction 0/90° orientation	40% volume fraction 0/90° orientation	50% volume fraction 0/90° orientation	30% volume fraction 0°/30° orientation	30% volume fraction 0°/45° orientation
Average Flexural strength (MPa)	33.97	38.17	30.13	17.07	34.79	35.84

On this test, the test sample specimen with 30% fiber VF at 0°/90° has the best result. The flexural strength result obtained from treated bamboo with 30% fiber VF and 70% Epoxy composite is 38.17MPa, 34.79MPa and 35.84MPa which is the best composition when compared with the other composite categories fabricated since it holds all the three maximum results . Sample specimen with 20% fiber VF at 0°/90° fiber orientation has superior flexural strength with- a value of 33.13MPa than the sample specimen with 40% and 50% fiber VF at 0/90° fiber orientation.

From the data obtained it can be seen that flexural properties of composite increase with decreased fiber volume fraction which is at 30% (i.e: increased matrix volume fraction), since volume fraction of matrix in both the superior results obtained is 70%, 60% at 0/90° fiber orientation

On the other fiber orientation parameter, superior flexural strength of sample specimens was shown at $0/90^0$ angle orientation implying that $0/90^0$ orientations have better performance than $0/45^0$ & $0/30^0$ orientations.

4.2.3 The Effect of Volume Fraction and Orientation on Impact Strength Discussion

Similarly, here also results from three specimen samples were obtained and their average value were taken as its impact strength property for each composite specimen were fabricated.

Table 4-9 overall average impact strength result at different parameters

Volume fraction / orientation	20% volume fraction $0/90^0$ orientation	30% volume fraction $0/90^0$ orientation	40% volume fraction $0/90^0$ orientation	50% volume fraction $0/90^0$ orientation	30% volume fraction $0^0/30^0$ orientation	30% volume fraction $0^0/45^0$ orientation
Average Impact strength (MPa)	149.98	170.67	103.11	91.86	159.36	161.23

As obtained from the result of Charpy machine the best value is obtained at 30% fiber VF with $0/90$ orientation having 170.67J. The second-best composite composition for impact is the 30% fiber volume fraction specimen with $0/30^0$ orientation having a value of 140.6J. And the third place will be taken by 40% fiber VF with $0/90^0$ fiber orientation with a value of 103.11J.

Still like the previous mechanical properties obtained, the fiber-matrix composition of 30% has the best performance over the other higher volume fractions (40% & 50% fiber volume fractions), since the sample specimen with 30% fiber VF at $0/90^0$ orientation has the leading value.

Also when we come to the orientation parameter, the same pattern happens as the previous ones, which is that the orientation $0/90^0$ have superior performance over the other $0/30^0$ & $0/45^0$ fiber orientations, since the sample specimen with 30% fiber volume fraction at $0/90^0$ orientation takes the greater value.

4.2.4 The Effect of Volume Fraction and Orientation on Water Absorption Discussion

Correspondingly, here also results from three specimen samples were obtained and their average value were taken as its impact strength property for each composite specimen were fabricated.

Table 4-4-10 overall average water absorption result at different parameters

Volume fraction / orientation	20% volume fraction 0/90 ⁰ orientation	30% volume fraction 0/90 ⁰ orientation	40% volume fraction 0/90 ⁰ orientation	50% volume fraction 0/90 ⁰ orientation	30% volume fraction 0 ⁰ /30 ⁰ orientation	30% volume fraction 0 ⁰ /45 ⁰ orientation
Average Water absorption (%)	1.71	2.01	3.95	5.46	2.30	1.94

The lowest water absorption results was observed from the composite sample specimens of 20% fiber volume fraction and at different fiber orientations which are at 0/30⁰, 0/45⁰ & 0/90⁰ orientations having values of 1.79%, 4.09 % & 4.15% water absorption respectively.

4.2.5 The Effect of Volume Fraction and Orientation on Thermal Conduction/Resistance Discussion

Table 4-11 thermal conductivity test result

sample	T1	T2	Δ T	Time water(sec)	Volume of water(m ³)	Mass flow rate of water(kg /sec)	Cp of water	Q of water(watt)	Area(m ²)	Length (m)	K (W/K m)
1	26.9	27.2	0.3	72	0.0006	8.33333E-07	33.44	8.36E-06	0.0007065	0.065	0.002563
2	27	27	0	72	0.0000	8.33333E	33.	1.11467	0.0007	0.065	0.002

	.1	.5	4		6	-07	44	E-05	065		564
3	27	28	0.	72	0.0000	8.33333E	33.	0.00001	0.0007	0.065	0.002
	.4		6		6	-07	44	672	065		565

Result from the three specimen (having 30% VF at 0⁰/90⁰ orientation) samples obtained was almost the same (up to 10⁻⁵ digit) which has an average value of 0.002564 Watt/km which means that it has a very low and/or almost none conductivity (i.e) wood has a conductivity of 0.0001 Watt/km which is taken as non-conductive material. Therefore 30% bamboo fiber reinforced epoxy composite has very high thermal resistivity almost equal with wood, which makes it non-conductive material which is desirable.

4.3 Comparison of Results with Literatures

Even though there are almost no researches concerning bamboo and epoxy fiber composite for protective casing applications, following literature will validate the work executed and result obtained in this research.

Here the experimental test results for the selected material were compared with literatures;

Result of selected composition:

Tensile Strength = 48.85MPa

Flexural Strength = 38.17MPa

Impact Strength = 170.67MPa

Water Absorption = 1.71%

Thermal resistance = 0.002653K

4.3.1 Researches bamboo and bio-fiber composites

B Stanly jones Retnam1 et. al studied on effects of fibre orientation on mechanical properties of hybrid bamboo/glass fibre polymer composites and their result was comparable and suggests that mechanical properties (tensile, flexural and impact strengths) increase as fiber orientation increases[46].

S. Malaiah1 et. al studied on the investigation on effect of fiber and orientation on the properties of bio-fibre reinforced laminates and their result suggested that tensile and flexural strength of 0/90⁰ orientation has 191% and 94.12% times better strength than ±450 orientation.

Implying that mechanical properties (tensile, flexural and impact strengths) increase as fiber orientation increases[22].

Comparatively, here also, 0/90⁰ orientation has the superior tensile strength having 48.85MPa over the other 0/30⁰ & 0/45⁰ orientations at 30% VF ratio over 20%, 40% and 50% VF. In a similar fashion, superior flexural strength of sample specimens was shown at 0⁰/90⁰ angle orientation at 30% fiber volume fraction, implying that 0/90⁰ orientations have better flexural strength than 0/45⁰ & 0/30⁰ orientations.

From this a short conclusion can be drawn that 0/90⁰ is the better fiber orientation correspondingly in like manner as stated on the above literatures that strength increases as orientation increase. Tensile behavior is severely dependent on fiber orientation because if fibers are in line with the load ,then the load is uniformly distributed leading to less fiber failure.

Dheeraj Kumar studied on characterization of tensile properties of treated bamboo natural fiber polymer composite[48].

Table 4-12 tensile strength of bamboo fiber epoxy composite at different volume fraction[43][48]

Dheeraj Kumar results				This BFRC research results			
Designation	Composition	orientation	Tensile strength (MPa)	Designation	Composition	orientation	Tensile strength (MPa)
B	Pure epoxy		18.16	S20%	20% epoxy	0/90 ⁰	33.85
B1	Bamboo Fiber (5%)	Random	26.22	S30%	30% epoxy	0/90 ⁰	48.85
B2	Bamboo Fiber (10%)	Random	37.98	S40%	40% epoxy	0/90 ⁰	21.62
B3	Bamboo Fiber (20%)	Random	45.28	S50%	50% epoxy	0/90 ⁰	17.62
B4	Bamboo	Random	53.61	S30⁰	30% epoxy	0/30 ⁰	37.77

	Fiber (25%)						
				S45 ⁰	30% epoxy	0/45 ⁰	38.73

From Dheeraj Kumar’s results, we can see that the strength increases as the fiber loading (VF) increases from 0% fiber VF (pure epoxy) to 25% VF (25% fiber 75% epoxy matrix) but no way of roving that 25% is the optimum. Stepping from this, on this experiment 20% VF was taken as the minimum VF and proceeded to the higher VFs.

Similarly here on this research, the strength increases as the fiber loading increases and after its optimum volume ration, it starts to decrease which implies that 30% VF has better flexural strength than 20%, 40% and 50% VF. Furthermore, the orientation 0/90⁰ have superior impact strength over the other 0/30⁰ & 0/45⁰ fiber orientations, at 30% fiber volume fraction over 20%, 40% and 50% composite VF.

The lowest water absorption results were observed from the composite sample specimens of lower fiber volume fraction which are 20% and 30% VF having values of 1.71% at 0/90⁰ orientation and 1.94 % at 0/45⁰ orientations respectively.

The thermal conductivity was almost equal to the thermal conductivity of wood implying that it’s a nonconductive material just like its raw constituent materials

4.3.2 Researches on materials for protective casing applications

The currently used mac book apple casings uses ABS plastic which has properties as shown on the table 4.13 below

Table 4-13 comparison of ABS Material Properties with bamboo fiber epoxy composite[67][68]

Property	ABS Material Properties		BFRC	
	Metric	units	Metric	units
General				
Density	1.01e3 - 1.21e3	kg/m ³	8.50e5	kg/m ³
Mechanical				

Yield Strength	1.85e7 - 5.1e7	Pa		
Tensile Strength	13 - 65	MPa	17.62 - 48.5	MPa
Charpy impact	1 - 11	J/cm ²	8.17 - 18	J/cm ²
Hardness (Vickers)	5.49e7 - 1.5e8	Pa		
Fracture Toughness	1.19e6 - 4.29e6	Pa/m ^{0.5}		
Young's Modulus	1.19e9 - 2.9e9	Pa		
Flexural strength	7.5	MPa	17.07 - 38.17	MPa
Thermal				
Max Service Temperature	61.9 - 76.9	°C		
Insulator or Conductor	Insulator		Insulator	
Water absorbtion	1.5 - 3.5	%	1.71 -5.46	%

From this data it can be concluded that bamboo fiber epoxy composite has both mechanical and thermal property superiority over ABS material since its tensile, hardness and fracture strengths are better than ABS's and has the same thermal insulator property, thus can be used as a protective casing for laptops.

4.4 Finite Element Method Analyses

4.4.1 Analysis steps

Finite element analysis is a method of structural analysis that uses mathematical processes. FEA requires you to break down a larger, more complicated object into more manageable sections. As you keep splitting the structure, you get a better idea of how the object will respond to stressors. This method of breaking down a structure for FEA is known as the finite element method (FEM).

The steps (modeling, material defining, load defining, boundary conditions and mesh generations) are explained in chapter three section 3.10 on figures 3.17 – 3.22. The results are presented here in this section

4.4.2 Analysis Results

4.4.2.1 Upper protective casing

- I. **Equivalent uniform von mises stress result :** The Equivalent von mises stress obtained for the upper protective casing material of has maximum value of 6.49MPa as shown in the figure 4.42 below

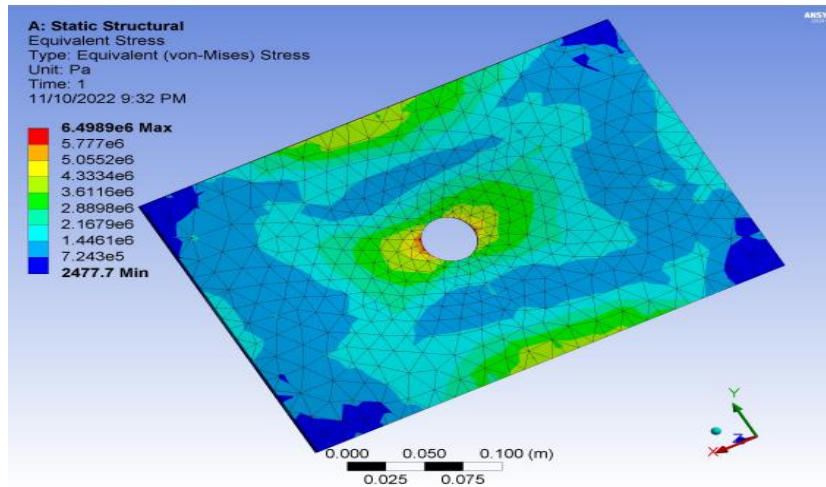


Figure 4-42 Equivalent uniform von mises stress result

- II. **Equivalent impact von mises stress result :** The Equivalent von mises stress obtained for the upper protective casing has maximum value of 4.29MPa. as shown in the figure 4.43 below

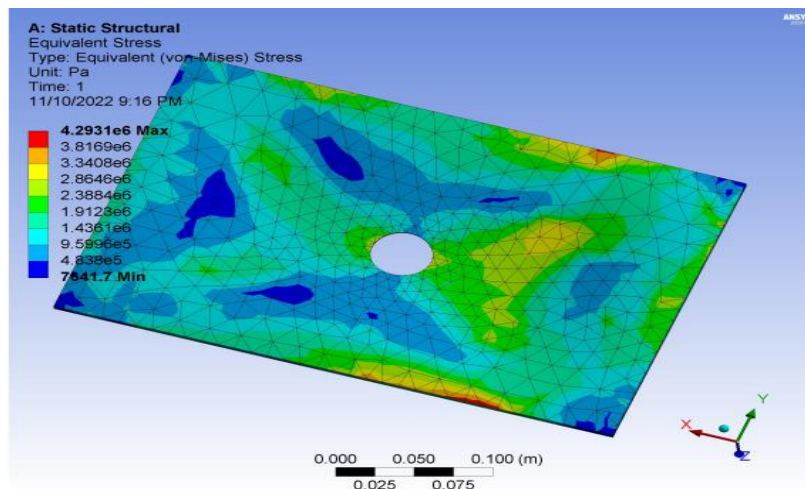


Figure 4-43 Equivalent impact von mises stress result

III. Uniform maximum principal stress result : The Equivalent von mises stress obtained for the upper protective casing has maximum value of 6.61MPa as shown in the figure 4.44 below

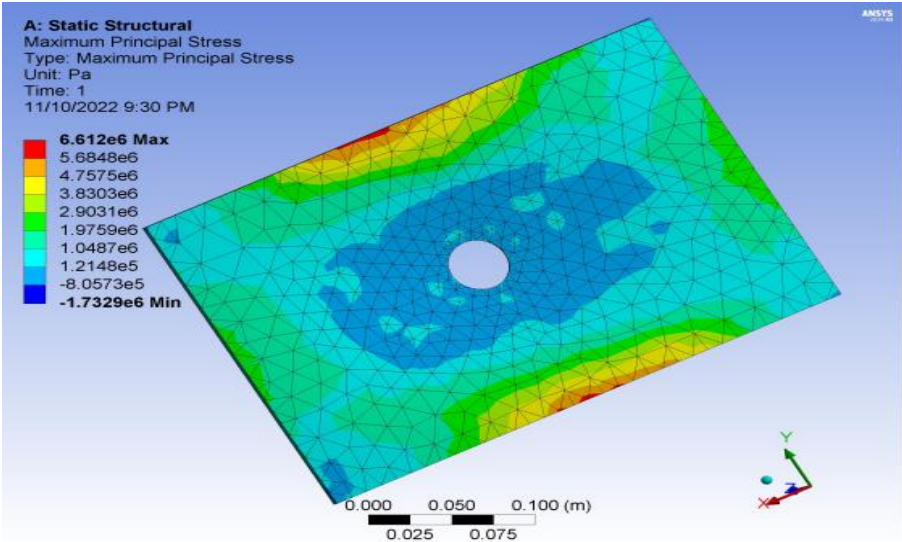


Figure 4-44 Maximum uniform maximum principal stress result

IV. Impact maximum principal stress result : The Equivalent von mises stress obtained for the upper protective casing has maximum value of 5.59MPa. as shown in the figure 4.45 below

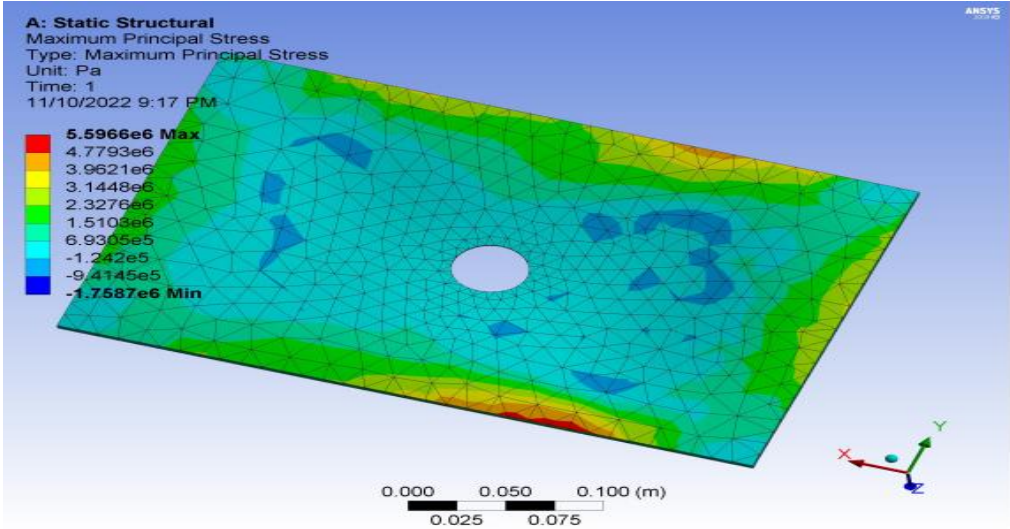


Figure 4-45 Maximum impact maximum principal stress result

V. **Uniform total deformation result** : The Equivalent von mises stress obtained for the upper protective casing has maximum value of 0.0042MPa. as shown in the figure 4.46 below

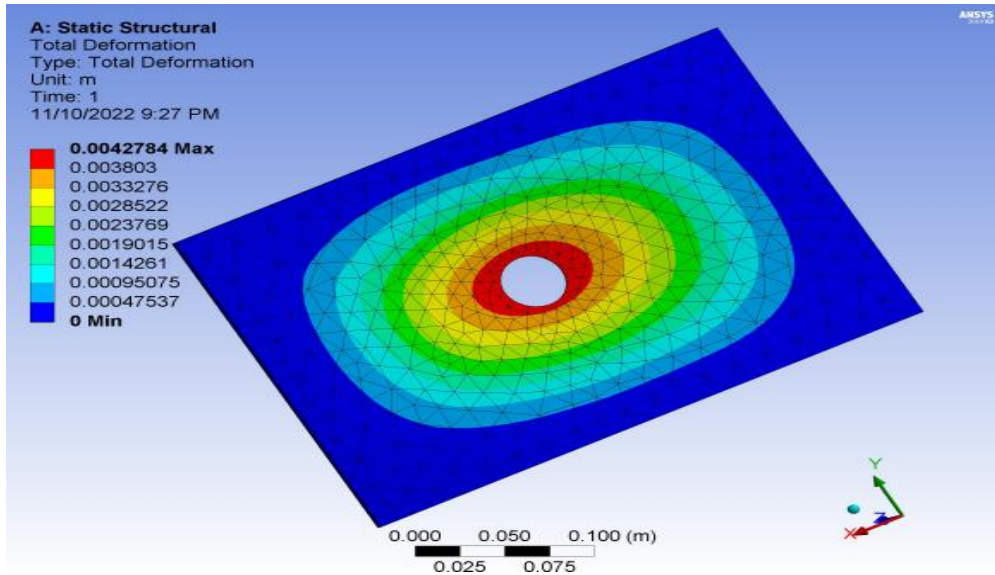


Figure 4-46 Total uniform total deformation result

VI. **Impact total deformation result** : The Equivalent von mises stress obtained for the upper protective casing has maximum value of 0.0026MPa. as shown in the figure 4.47 below

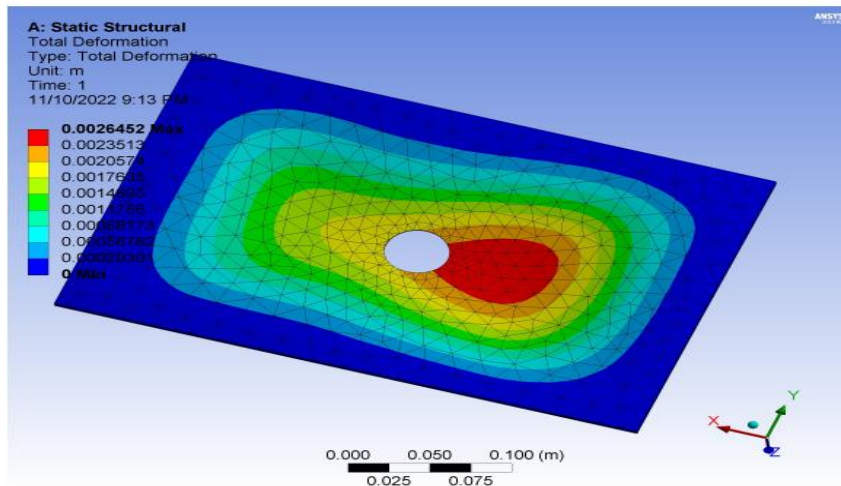


Figure 4-47 Total impact total deformation result

4.4.2.2 Lower protective casing

- I. Equivalent uniform von mises stress result :** The Equivalent von mises stress obtained for the lower protective casing has maximum value of 8.5MPa. as shown in the figure 4.48 below

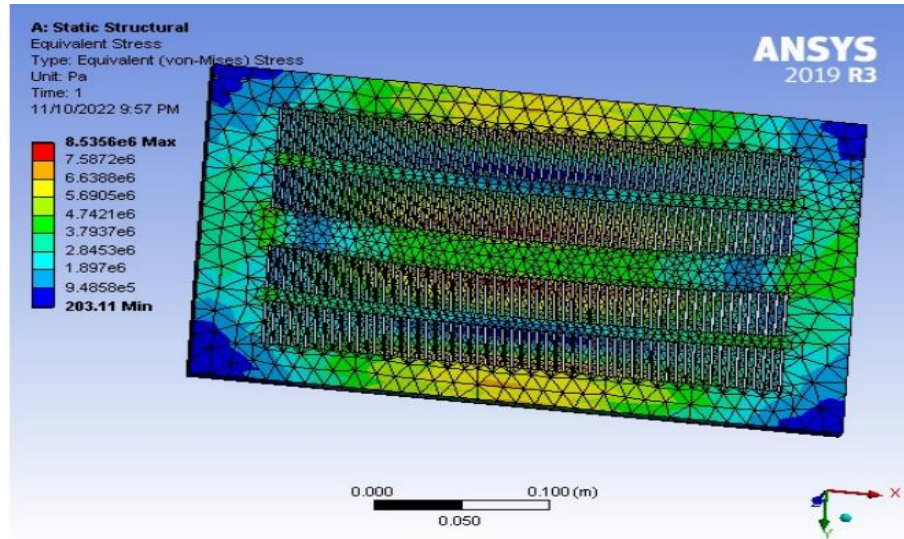


Figure 4-48 Equivalent uniform von mises stress result

- II. Equivalent impact von mises stress result :** The Equivalent von mises stress obtained for the lower protective casing has maximum value of 4.7MPa as shown in the figure 4.49 below

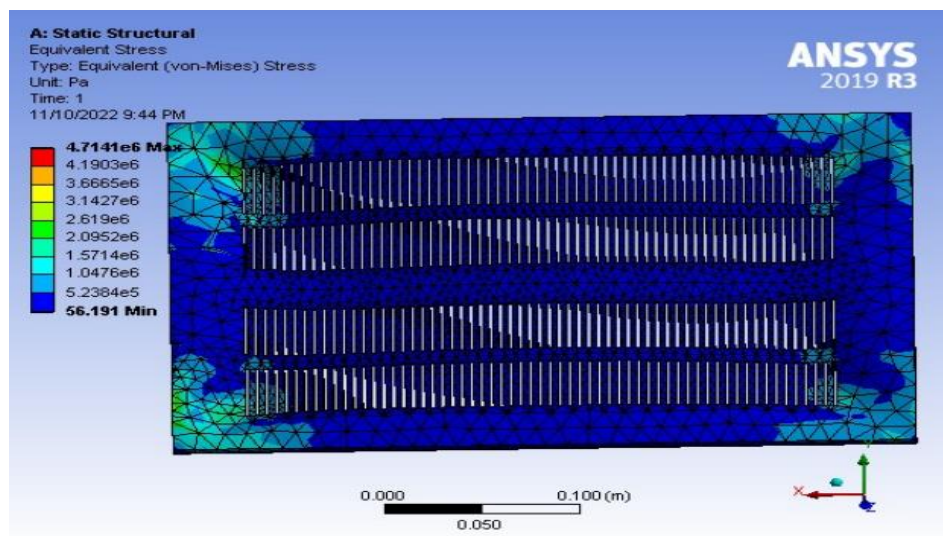


Figure 4-49 Equivalent impact von mises stress result

- III. Uniform maximum principal stress result :** The Equivalent von mises stress obtained for the lower protective casing has maximum value of 8.6MPa. as shown in the figure 4.50 below

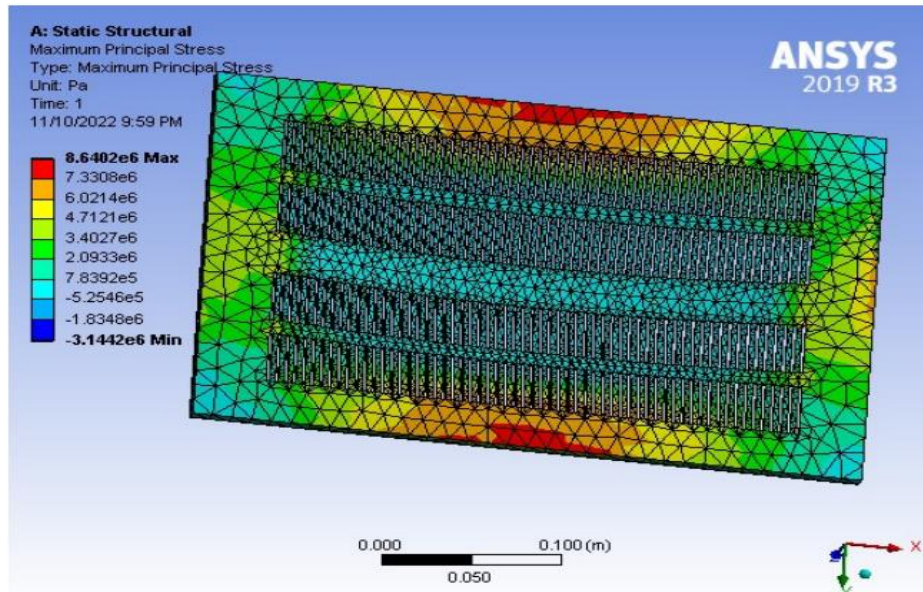


Figure 4-50 Maximum uniform maximum principal stress result

- IV. Impact maximum principal stress result :** The Equivalent von mises stress obtained for the lower protective casing has maximum value of 3.5MPa. as shown in the figure 4.51 below

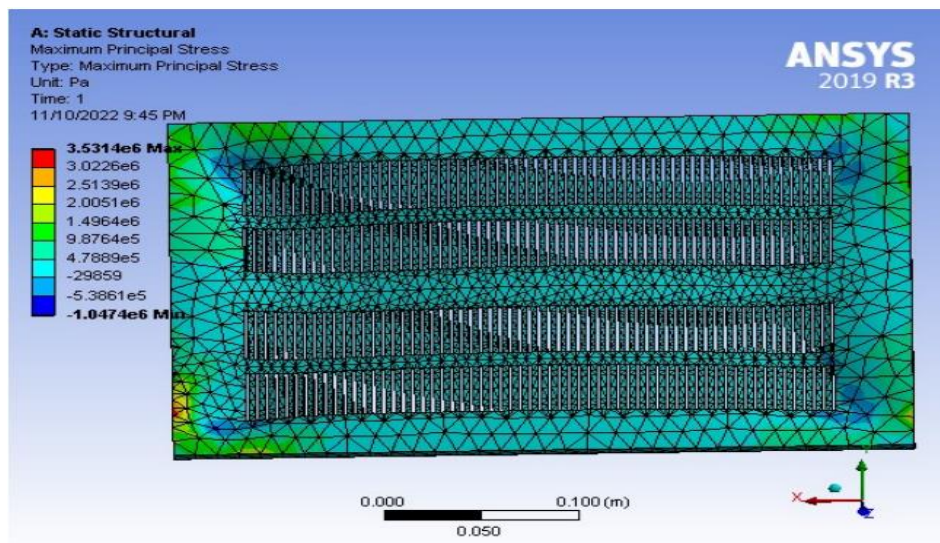


Figure 4-51 Maximum impact maximum principal stress result

- V. **Uniform total deformation result** : The Equivalent von mises stress obtained for the lower protective casing has maximum value of 0.0076MPa. as shown in the figure 4.52 below

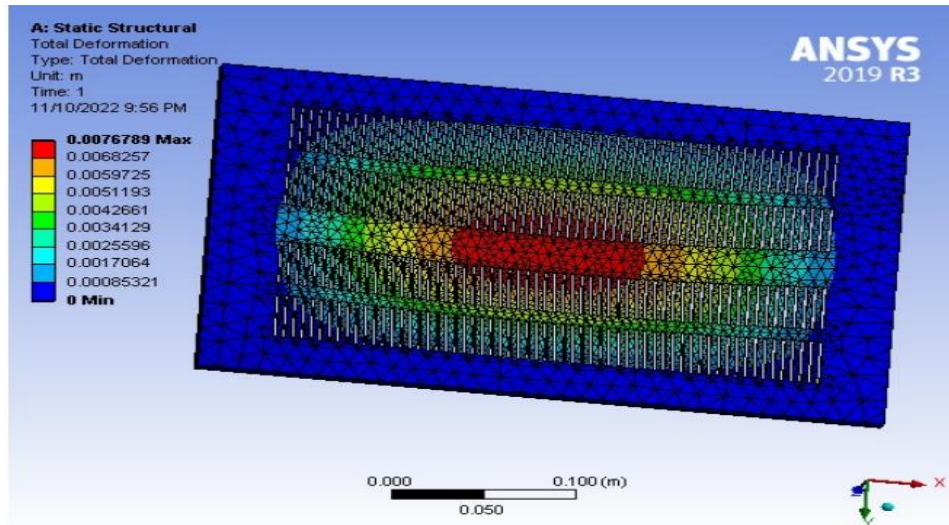


Figure 4-52 Total uniform deformation result

- VI. **Impact total deformation result** : The Equivalent von mises stress obtained for the upper protective casing has maximum value of 0.0022MPa. as shown in the figure 4.53 below

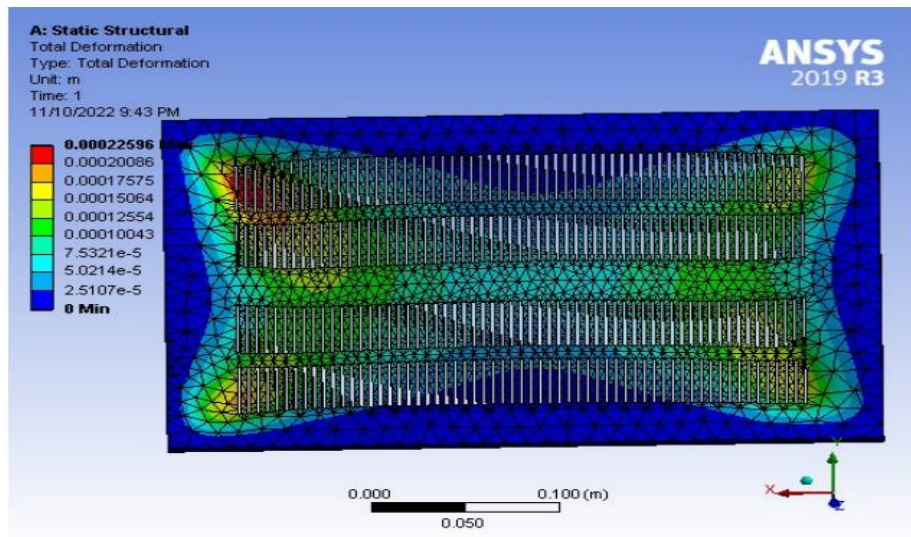


Figure 4-53 Total impact deformation result

4.5 Discussion of FEM analysis

Equivalent von mises stress: both the uniform and impact von mises stress values obtained in both upper and lower cases is slightly higher at the middle but as overall its very low and it indicates that the material is capable of withstanding the load applied. In addition, it shows the composite material can be a good replacement for the conventional material used for manufacturing protective casing.

Maximum principal stress: in this case when uniform load is applied the case has slightly higher stress at the middle sides of the longer side of the case but as over all its very low and it indicates that the material is capable of withstanding the load applied. Since maximum principal stress of ABS plastic is 0.3 – 2MPa[68] and maximum principal stress of BFRC is 3.5 – 6.61MPa is is safe to say that the composite material can be a good replacement for the conventional material used for manufacturing protective casing

Deformation : both the uniform and impact deformation values obtained in both upper and lower cases is slightly higher at the middle where there is a hole for the laptop brand display of the laptop, but as overall its very low and it indicates that the material is capable of withstanding the load applied.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Clearly, the need for protective laptop case is undeniable because of the data and information they carry, their purchasing cost, prone to damage and many other reasons. Especially, in Ethiopia where everybody donot have their office working computer and their personal computer separately so that we have to carry our laptops with us to places where we need them on a daily basis and without any assurance about is safety. Laptop casings for MacBook series laptops are made from hard(thermosetting) plastics and there hasn't been such type of protective casings adopted to the other types of laptops commercially. Therefore, this research not only adopts a protective casing for the other personal computers but also modifies the existing only hard plastic casing type of cases with bamboo fiber reinforced hard plastic composite at its best volume fraction and fiber orientation for better performance.

This study has presented tensile, flexural, impact and water absorption properties of bamboo fiber reinforced epoxy composite with different compositions and orientations. It has also suggested appropriate composition with 30% fiber and 70% epoxy matrix in which fibers are continuous in length and treated with 5% NaOH to be used as an ideal material for an application of protective laptop casing. The conclusion of this work is as follows.

- ❖ Successful fabrication of the natural fiber composite using bamboo fiber reinforced epoxy has been achieved using hand lay-up technique
- ❖ The highest tensile strength was obtained from composite with 30% fiber 70% epoxy matrix composition at $0^0/90^0$ orientation having 48.85MPa.
- ❖ The highest flexural strength was obtained from composite with 30% fiber 70% epoxy matrix composition at $0^0/90^0$ orientation having 38.17MPa.
- ❖ The highest impact strength was obtained from composite with 30% fiber 70% epoxy matrix composition at $0^0/90^0$ orientation having 170.57.

- ❖ The lowest water absorption percentage was obtained from treated composite with 20% fiber 80% epoxy matrix composition at $0^0/90^0$ orientation having 1.71% of absorption.
- ❖ 30% bamboo fiber reinforced epoxy composite has very high thermal resistivity almost equal with wood, which makes it non-conductive material which is desirable.
- ❖ From the seventy three sample specimens of continuous fiber of bamboo and epoxy composite a specimen with 30% fiber VF composition which was heat treated at 160^0c for 3 hours and with 6% NaOH for 2 hours at 1:10 liquor ratio has the superior mechanical and physical properties
- ❖ Suggested composition has tensile strength of 48.85MPa, flexural strength of 38.17MPa, impact strength of 170.57, water absorption percentage of 2.01% and thermal conductivity of 0.002564 Watt/km
- ❖ Finally, it can be concluded that bamboo fiber reinforced epoxy composite with 30% fiber and 70% matrix volume fraction with $0^0/90^0$ orientation can be an ideal material used for laptop protective casing and also can be suggested to other applications too.

5.2 Recommendation

- ❖ Using industrial fiber extraction and manufacturing technique other than manual is absolutely necessary extraction method and gives better mechanical, physical and thermal properties., so it is recommended to moderate the extraction process.
- ❖ Using of injection molding manufacturing technique other than hand layup process.
- ❖ Using of suggested material to replace the current ‘only thermosetting’ material.
- ❖ Investigate bamboo/epoxy with another (lower fiber amount and higher matrix content) composition and orientation.
- ❖ The selected material is recommended to be used for different application areas.

5.3 Future work

From different aspects, working on natural materials as composite have several advantages. From this point of views, regarding BGREC's several things can be made and improved in the future in which this study couldn't addressed. So, the following research areas are recommended for future studies.

- Finding of different bamboo fiber extraction processes.
- Effect of different fabrication techniques on BFRECs
- Design of natural fibers extraction processing machine
- Incorporating slim damping system inside the casing to decrease the transfer of force directly to the laptop.

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