Addis Ababa University

Addis Ababa Institute of Technology

School of Graduate Studies

Development and Characterization of Hybrid Flax -Banana Fiber Reinforced Epoxy Composite for Ceiling Fan Blade Application

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfilment of the Requirements Degree of Masters of Science in Mechanical Engineering (Manufacturing Engineering)

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Acknowledgment

First, I would like to thank the almighty God for giving me the strength to finalize this study, beside, I would like to give my deep gratitude to my advisor Dr. Desalegn Wogaso, for his motivational and thoughtful supervision, patience, and his valuable advice from the start to the end of the study.

Special thanks to Addis Ababa University Female Scholarships, for giving me the great opportunity to join the MSc. Program. I would like to thank all of my family and friends for their valuable and prized supports. Foremost, I would like to give great recognition and deepest appreciation to the following governmental organizations for their provision and accomplishment of thisthesis; to Holeta Agricultural Research Center, Ethiopian Textile Industry Development Institute, Ethiopian Environmental and Forest Research Institute, and Ethiopian Defense EngineeringUniversity, for their boundless support.

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Declaration

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This is to certify that the thesis prepared by **Zodiac Simeneh**, entitled **Development and Characterization of Hybrid Flax- Banana Fiber Reinforced Epoxy Composite for Ceiling Fan Blade Application**, do hereby declaring this thesis is my original work and it has not been submitted partially, or in total for a degree in any Institution, which complies with the regulations of the university and meets the accepted standards concerning originality and quality.

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Abstract

A fan blade is the major component of fans, it used for ventilation systems, cooling systems, refrigeration, boilers, and dust collection purposes. The materials used to fabricate ceiling fan blades are fabricated steel, cast or forged aluminum, plastic, fiberglass, or other exotic materials. The present work aims to develop and characterize the mechanical and water absorption properties of hybrid flax-banana fiber reinforced epoxy composite. In addition it examined the suitability of the composite material for ceiling fan blade application. The composite manufacturing process includes fibers extraction, fibers surface treatment, fibers property test, composite plate's fabrication, composite specimen's mechanical and water absorption tests. Based on the experimental test result, the static structural analysis is performed to analyze the induced stress and deformation on the ceiling fan propellers. The fibers are extracted through water retting and manual extraction methods. The flax and banana fibers are treated with 5% and 3% of NaOH solution to increase the interfacial bonding between the fiber and matrix materials. The fibers are hybridized manuallywith 1:1, 3:1, and 1:3 fibers ratio. The composite plates are fabricated with eleven sub-composition of 60/40%, 70/30%, and 80/20% resin to fiber volume fraction. The tensile, flexural,impact, and water absorption property tests are conducted using ASTM D3039, ASTM D790, ASTM D6110, and ASTM D570-99 standards. The ceiling fan blade geometry and static structural analysis performed using Catia.V5 and Ansy's 19.2 software.

Overall, the experimental test results shows that 70/15/15% volume fraction exhibits the highest tensile strength of 68.9MPa and flexural strength of 169.14 MPa respectively. The highest impact strength result was observed on 60/20/20%volume fraction. The highest water penetration resistance was observed on 80/15/5%. Overall, the experimental test results shows 70/15/15% volume fraction has the highest tensile strength of 68.9MPa and flexural strength of 169.14 MPa. On the other hand, the highest impact strength result 10.83J is observed on 60/20/20%. In a water absorption test result, the least water absorption property is obtained on 80/15/5%. In addition, 70/15/15% has presented the second lowest water absorption property. Based on the structural analysis, HFBFREC exhibited the lower Von-misses stress of 2.4MPa and 0.9mm deformation.

Keywords: Flax fiber, Banana fiber, Epoxy, composite, ceiling fan blade.

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List of Abbreviations and Acronyms

L_{fl} length of fiber (mm)

W_f width of fiber (μm)

ρ_c Density of composite (g/cm^3)

ρ_f Density of fiber (g/cm^3)

ρ_m Density of matrix (g/cm^3)

V'_f Volume fraction of fiber (%)

V'_m Volume fraction of matrix (%)

υc Volume of composite (cm^3)

υf Volume of fiber (cm^3)

υm Volume of a matrix (cm^3)

W_C Weight of composite (g)

W_f Weight of fiber (g)

W_m Weight of a matrix (g)

W_{pyc} Weight of Pycnometer (g)

t thickness (mm)

σ Stress (Mpa)

ε Strain (mm/mm)

E Modulus of elasticity (Mpa)

NaOH Sodium hydroxide

ASTM American Society of Testing and Materials

Cfm cubic feet per minute

HFBFEC Hybrid Flax Banana Fibers Epoxy Composite

ETDI Ethiopian Textile Industry Development Institute

EEFRI Ethiopian Environmental and Forest Research Institute

EDUCE Ethiopian Defence University, Colleague of Engineering

Eq Equation

HARC Holeta Agricultural Research Center

m meter

mm millimeter

min minute

m/s meter per second

UTM Universal Testing Machine

Vavg Average air velocity

Chapter One

Introduction

1.1. Background of the study

A composite material is a structural component, it contains two or more constituents that are reinforcement and matrix materials. The two constituents are combined at the macroscopic level and will not be soluble in each other. In history, a composite material fabrication was started by Egyptians and Mesopotamian settlers; they have been using a mixture of mud and straw to make substantial buildings since the 1500s B.C. Mongolians also invented a composite bow from wood, bone, and animal glue for military purposes in 1200A.D. The Mongolian composite bow was a powerful weapon until gunpowder was invented. The modern era of composite started with developing plastics by scientists in the 1900s. The Plastics were vinyl, polystyrene, phenolic, and polyester. In 1935s, the first fiber reinforced polymer composite was produced, it was a glass fiber reinforced with plastic polymer [1].

Composites can be classified based on the geometry of reinforcement, such as particulates, fibers, and flakes. Based on the type of matrix, they can be classified as metal matrix composite (MMC), ceramic matrix (CMC) composite, and polymer matrix composite (PMC). The composite materials can be a combination of metals, nonmetals, organic, and inorganic components such as fibers, matrix, particulates, and stamps[1,2].

The polymer matrix-based composite is a rigid material, it consists plastic polymer as a matrix and fibers as a reinforcing material.

Natural fiber reinforced polymer composite shows great demand in different working sectors due to their acceptable mechanical property, biodegradability, availability, and low cost. However there are also some limitations, such as low stability at a high temperature, high moisture, and water absorption property. To avoid this limitation, a fiber surface modifications can be applied. Natural fiber composites can be used in various industries such as automotive, marine, HAVAC, building bodies, and aerospace[4, 5].

Natural fibers that are used as reinforcement in a polymer matrix composites are, Oil palm, sugar palm, bagasse, date palm, coir, banana, hemp, jute, flax, sisal, kenaf, Roselle, pineapple, rice husk, and cocoa pod. Among the advantages, a natural fiber reinforced composites are low cost, renewable, abundant, lightweight, less abrasive, and suitable for semi or structural engineering components [1, 6].

A fan is a device that uses a power-driven rotating impeller to move the air. The impeller imparting the air to static and kinetic energy [7]. The fan blade is a significant component of fans that used for commercial and industrial applications; such as ventilation systems, cooling systems, refrigeration, boilers, and dust collection purposes. The materials used in industrial propellers or fan blades are fabricated steel, cast or forged aluminum, plastic, fabricated stainless steel, fiberglass, or other exotic metals [8].

There are two primary types of fans that are centrifugal and axial fans; fan types are classified based on the air path. A centrifugal fan can produce high pressure and be able to use in high moisture content, unclean air stream, and elevated temperature area. The axial fans can generate low to medium air pressure, have high rotational speed and high compactness than centrifugal fans. Axial fans can be applicable in a clean air, low pressure, and high air volume application areas and compatible with ducted HVAC installations [7, 9]. Fan blades are subjected to different loads and moments such as aerodynamic loads (lift and drag forces).

Nowadays, natural fiber reinforced composites are applicable in different sectors, such as the automobile industry, marine industry, and aircraft. Synthetic fiber reinforced composite materials should be replaced with a natural fiber reinforced composite materials, because natural fibers have acceptable strength and modulus, are abundant, low cost, lightweight, recyclable, biodegradable, absence of health hazards, and non-abrasive nature [9].

Reinforcements (fibers) hybridization is needed to overcome suitable properties in every manner and used to reduce cost. Flax-Banana fibers hybridization was done because, both fibers have good tensile strength and available. For instance, flax fiber has the highest mechanical property that is almost compatible with glass fiber; on the other hand, banana fiber also has good tensile strength and elongation at break property [10].

1.2. Statement of the problem

Green composites are the primary class of bio-composites that are used in different advanced application areas. They have suitable mechanical properties, low air pollution during fabrication, and sustainable energy. The non-green composites are not biodegradable, have complex manufacturing methods, and expensive. One of the products made from non-green materials are ceiling fan blades. Either large or small propellers are fabricated from metals and synthetic fiber reinforced composites. Materials used to fabricate ceiling fan blades are fabricated steel, aluminum, carbon fiber, aramid fiber, and glass fiber. Metal ceiling fan blades have post-fabrication and machining processes; such as grinding, post-heat treatment, and painting. Metals are not lightweight and need high power consumption to rotate. Synthetic fibers reinforced composites are expensive, not easily available, not degradable and toxic [11,12]. On the other hand, surface treated, natural fiber reinforced composites are being used in advanced structural applications; due to their competitive mechanical properties, lightweight, high corrosion resistance, sufficiently abundant, environmentally friendly, biodegradable, and not costly [6,13]. Due to these reasons, hybrid flax-banana fiber reinforced epoxy composite for ceiling fan blade application is needed to be investigated to full fill the above mentioned gap areas.

1.3. Objective

1.3.1. General objective

The study aims to develop and characterize the hybrid flax-banana fiber reinforced epoxy composite properties and determine the suitability for ceiling fan blade application.

1.3.2. Specific objectives

- ❖ Extraction of flax and banana fibers using water retting and manual extraction method.
- ❖ Fabrication of hybrid flax-banana fiber reinforced epoxy composite with 60/40%, 70/30%, and 80/20% resin to fiber volume fractions using hand lay-up manufacturing technique.
- ❖ Characterization of tensile strength, flexural strength, impact strength, and water absorption properties of different volume fraction of fiber and matrix materials, using ASTM standards.

- ❖ Determination of the water absorption properties of hybrid flax-banana fiber reinforced epoxy composite specimens with their fiber to matrix compositions.
- ❖ Evaluation of the suitability of developed composite material for ceiling fan blade application and compared it with currently used materials.

1.4. Significance of the study

This study has a contribution to expand the utilization of natural fiber composites for different application areas. Since the HFBFREC was developed from organic reinforcements with low density, easy fabrication method, low cost, good mechanical property, biodegradability and availability. In addition it can reduce the power consumption of metal blades, because it is light weight, and avoid oxidation problem. Besides, it will motivate and encourage others to study for further applications, because the HFBFREC characterized with eleven fiber to resin volume fraction compositions. It is a good example to show how to made composite materials from waste banana barks and flax straws for other applications too.

1.5. Scope of the study

The current work contained within fabrication and characterization of hybrid flax-banana fiber reinforced epoxy composite. It examined the suitability of the composite material for ceiling fan blade application. The fabrication process contains fiber extraction, fiber testing (length, width, diameter, density, and elongation), alkaline fiber surface treatment, composite plate fabrication, and test specimen's preparation. Alongside it characterized tensile, flexural,impact, and water absorption properties using ASTM standards. The structural analysis of ceiling fan blade performed using finite element analysis with ansys 19.2 software.

1.6. Limitation of the study

During the thesis progress, some challenging situations was observed, for instance,

- ➢ There was a limitation to get access to epoxy LY-556 and hardener HY-951.
- ➢ The fiber extraction was time taking due to lack of fiber extraction machine.
- ➢ It was challenging to access appropriate experimental setup and testing machines for mechanical tests.

1.7. Research questions

- Is there a substantial effect of volume fraction of fibers and matrix on a composite mechanical and water absorption properties?
- How the fiber surface modification affect the properties of a composite materials?
- Is hybrid flax-banana fiber reinforced epoxy composite suitable for ceiling fan blade application?

1.8. Organization of the thesis

Chapter one: - this section indicates the background of the study including an introduction to composite materials and ceiling fan blades. In addition, it describes the main and specific objectives of the study, problem justification, scope of the study, and limitation of the study.

Chapter two: - describes literatures written on composites, reinforcements, matrix materials, composite manufacturing process, reinforcement's type, fibers surface treatment, and fibers content effect on composites property.

Chapter three: - this section explore materials and methods that used for the composite fabrication and specimen preparations for mechanical and water absorption properties. In addition it shows fiber and matrix collection, fiber extraction, fiber property tests, fiber surface modification, composite manufacturing method, specimen’s mechanical tests, ceiling fan blade geometry, and finite element analysis (FEA).

Chapter four: - explains the result and discussion of experimental and finite element analysis in detail.

Chapter five: - provides a conclusion, recommendations, and future work of the thesis depending on the conducted result.

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Chapter Two

Literature Review

2.1. Composite Materials

These days, composite materials demand is highly growing in manufacturing centers and different application areas. They have competent mechanical properties, high strength-to-weight ratio, simple fabrication method, and low cost. In particular, hybrid reinforced composites are essential due to their acceptable mechanical property, availability, low cost, and low carbon emission during fabrication [14].

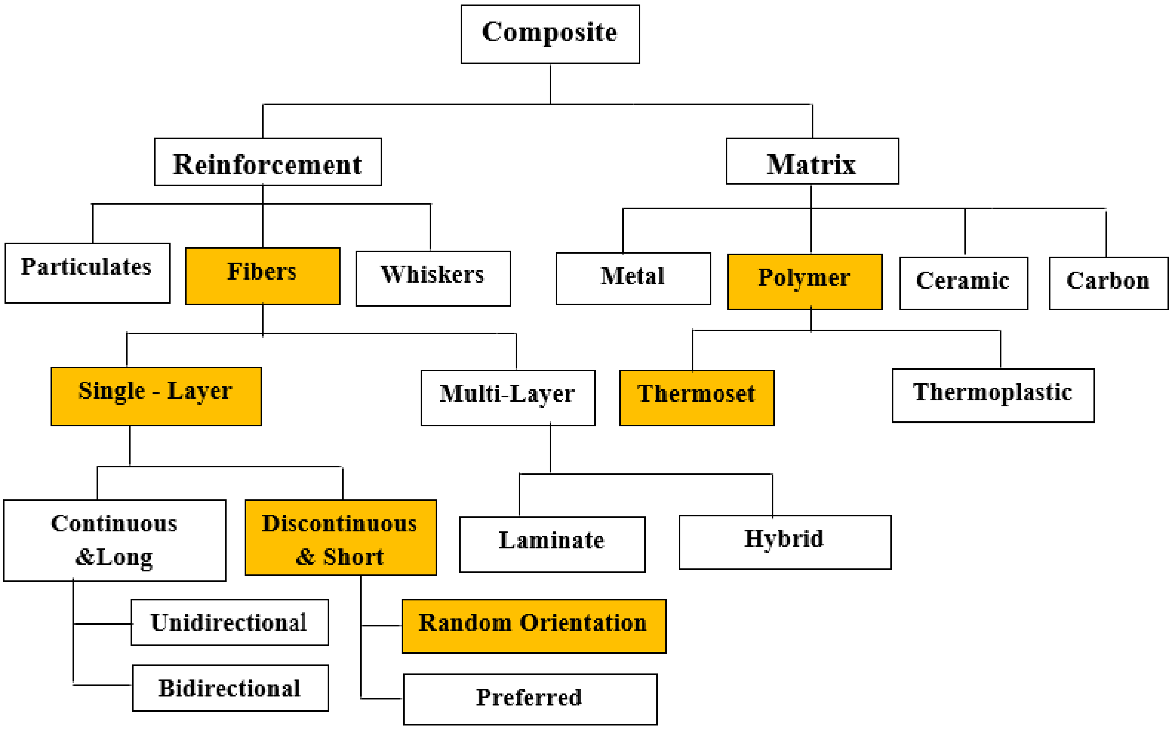


Figure 2. 1. Classification of composites reinforcement, matrix, and orientation type [14].

Composite combines two and more materials, it includes alloys, plastic copolymers, ceramics, wood, and fiber-reinforced polymer composites. Fiber-reinforced polymer composite differs from other composites because the constituents work together but remain in their original form; the constituent materials are different at the molecular structure and separate mechanically [15]. Composites can be classified based on types of reinforcements, fiber orientation, and geometry of fibers, matrix materials, and manufacturing methods.

2.2. Types of composite materials

There are three main categories of composites occurred for instance, metal matrix composite(MMC), ceramic matrix composite(CMC) and polymer matrix composite(PMC) [14].

2.2.1. Polymer matrix composites

Polymer matrix composites are a composition of two or more constituents, such as reinforcing material and matrix material. These kinds of composite materials have low density, high strength-to-weight ratio, low cost, and are simple to manufacture. Matrix materials that used in polymer matrix composites are polymers. The reinforcing materials can be single or hybrid, continuous or discontinuous. The reinforcing materials can be aligned in the form of uni-directional, bidirectional, and random fiber orientation. Polymer matrix composites are applied in different application areas such as aerospace, marine, automotive, and other structural applications [14].

2.2.2. Metal matrix composites

Metal matrix composites (MMCs) are a subsection of composite materials, they contain two or more constituents, such as metal matrices and reinforcements. MMCs have higher temperature capabilities, better radiation resistance, higher electrical and thermal conductivity, and no significant moisture absorption, however, it has complex manufacturing methods and expensive. Based on matrix material, metal matrix composites are classified as, Aluminum based composites, Magnesium based composites, Titanium-based composites, Super alloy composites, and Copper based composites. In metal matrix composite, commonly used reinforcements are fibers (continuous/discontinuous), whiskers, and particles, for example, SiC, Al_2O_3 , Br_4C, C, and Si_3N_4 can be used to achieve good strength, stiffness, and wear resistance of materials [16,17].

2.2.3. Ceramic matrix composites

Ceramic matrix composites (CMCs) are a subgroup of composites, which can be made from a matrix and two or more reinforcing materials, such as silicon carbide matrix composite, oxide matrix composite, and glass matrix composite.

CMCs are consist of ceramic fibers embedded with a ceramic matrix, commonly used materials as reinforcement and matrix are, carbon and carbon fibers such as carbon(C), special silicon carbide (SiC), alumina (Al_2O_3), and mullite (Al_2O_3 –SiO_2) [18]. CMCs being developing to overcome the limitations of monolithic ceramic materials, such as it used to increase fracture toughness, thermal resistivity, elongation, and thermal shock resistanceCMCs have the ability of high-temperature resistance, oxidation resistance, elevated mechanical properties, and radiation protection than single-phase ceramic materials. Reinforcements used in CMCs should have the ability to resist high-temperature, organic, andpolymeric fibers that have less than $500C^0$ melting temperature do not allow to be used as reinforcement. There are different types of CMCs fabrication methods, some of them are polymer infiltration pyrolysis, melt infiltration, slurry impregnation & hot-pressing, chemical vapor infiltration, sintering, electrophoresis, and laser-induced fabrication methods [19, 20].

2.3. Constituents of composite materials

2.3.1. Matrix materials

The matrix material is located on the superior part of composites, It fully covered thereinforcing materials; the main functions of the matrices are binding the fibers and transferringthe load between the fibers. It isolates the fibers individually and that leads the crack propagation to be slow, it provides a good surface finish and resists the fibers from mechanicaldamage, chemical and environmental attacks [21].

i. Polymers

The polymer has a Greek origin meaning 'members'; they can be huge molecules or macromolecules, they are formed by the repeated addition of monomers. These smaller units are termed 'monomers' before converting them into a polymer through the polymerization process. It is classified as addition polymerization and condensation polymerization. Addition polymerization process has the repeating unit that contain the same composition as that of the monomer; the only difference is the change of chemical bonds, which link the monomers. In condensation polymerization, some monomers are lost as condensation compounds, when the monomers react to form the repeating unit of the polymer. Polymer matrixes are classified into two categories, which are thermoplastic polymers and thermoset polymer [21, 22]**.**

a) Thermoplastic polymer matrix

Thermoplastic polymers are linear polymers found either in crystalline or semi-crystalline form, they melted below crystals melting temperature and glass transition temperature, and this leads thermoplastics to be ductile, flexible, reshape, and easily reform with simple heating and cooling. Some limitations of thermoplastics are they have low dimensional stability, thermal stability, and low mechanical properties than thermoset polymers. Examples of thermoplastic polymers are Nylons, Polypropylene (PP), Polyetheretherketone (PEEK), and Polyphenylene Sulfide [22, 23].

b) Thermoset polymer matrix

Thermoset polymers are easy to process either at room temperature or elevated temperature, they have better fiber impregnation, high strength and toughness because during curing they develop three-dimensional molecular structures (they cross-linked each other. In addition, they have high dimensional and thermal stability. some thermoset polymers are epoxy, polyesters, phenolic, vinyl esters, cyanate esters, Polyurethane, Bismaleimide (BMI), and Polyimide[22,24].

❖ Epoxy

Epoxy is a low molecular weight liquid polymer and it has several epoxide groups, as functional group epoxides have a three-membrane ring that contains two carbon atoms with one oxygen atom. Epoxy has better mechanical strength and thermal stability than other thermoset polymers due to its polymer crosslinking structure. During cross-linking, they form covalent bonds alike, vinyl ester and polyesters. Epoxy is not found only in liquid form it is also available in semi-solid and solid forms [24].

Table 2.1. Properties of epoxy matrix [24]

Advantage	Disadvantage
High strength	
Low viscosity and flow rates, which allow good wettability of fibers.	High rigidity
Prevent misalignment of fibers during processing.	
Low volatility during the curing process.	
Low shrinkage rates, reduce the tendency of gaining significant shear stress of the bond between epoxy and the reinforcement.	
Available in more than 20 grades to meet specific property and Processing requirements.	

From the three types of composites, Polymer matrix composite was selected because it is easy to process, low cost, have a competent mechanical property, and lightweight. Based on the information of the above literature, from the thermoset polymer matrix, epoxy LY-556 was used because it has high strength, stiffness, better dimensional and thermal stability.

ii. Metals

a) Aluminum alloy

Aluminum alloys are widely used alloys and have low density, high strength to weight ratio, thermal and electrical conductivity, high corrosion resistance, good forming and joining properties, example of Al alloys are 2XXX series (Al-Cu), 7XXX series (Al-Zn), and Al-Li alloys.

These alloys are mostly reinforced by silicon dioxide, silicon carbide, carbon, boron nitride, and graphite. Have isotropic mechanical properties and low cost. These alloys are mostly used in aerospace, automobile, and structural applications [25].

b) Magnesium alloy

The source of Mg-alloys are natural brines, magnetite, seawater, dolomite, and brucite, this alloy can be extracted through electrolytic method (Dow process and Electron process) and thermal reduction method, but usually produced through gravity and pressure die casting.

These alloys are lightweight, have high castablity, good fluidity, and low susceptibility to hydrogen porosity. It has limited application due to its poor mechanical and corrosion resistance property, however, Mg alloys can be strengthening through grain refinement and precipitation processes. It is mainly used for electronics equipment, gearbox housing and chain saw housing in aerospace applications [25].

c) Titanium alloy

Titanium alloys can resist high temperature, have good corrosion resistance, and excellent strength and strength to weight ratio. The materials are usually used to manufacture aircraft structural materials. In aerospace sectors due to their high thermal and moisture resistance, but Titanium alloys are highly expensive. Titanium alloys are classified into three categories such as α-Ti alloy (have higher creep, corrosion resistance, used to make compressor discs, and blades of aeronautic engines), β-Ti alloy (have higher strength and fatigue resistance, low ductile and need heat treatments, employed to high stressed aircraft materials such as landing gears and springs) and α-β – Ti (exhibit excellent strength, ductility, fracture toughness, and corrosion resistance) [25].

d) Copper alloy

Copper alloys have the ability to be easily cast and formed, have high thermal and electrical conductivity, it has superior wear resistance, and can be applied in electronics application areas. Copper alloys can be reinforced with ceramic particles such as Al_2O_3, and SiC, to overcome good thermo- mechanical properties and to provide semi-conductive materials [25].

iii. Ceramics

a) Silicon Carbide (SiC)

Silicon carbide (SiC) is one of the non-oxide ceramics that can occur in more than250 crystalline forms and are used in different application areas, it contains Silicon (Si) and Carbon(C) as primary elements. It was found naturally as moissanite, but in limited quantity, because of this, it started to produce traditionally through the Acheson process. In this process, the silica sand and petroleum coke are reacted through a solid-state reaction process at a very high temperature (greater than 2500 ^{0}C), which leads to SiC formation. SiC can be found with different colors, transparent, and colorless this is based on the heating process during SiC formation. It has high hardness and strength, high melting point, oxidation resistance, and is stable at high chemical concentration and thermal conditions. Because of this SiC is used in high power and high-temperature electronic devices, it's also used as abrasion and cutting tools. Beyond the Acheson process, SiC can be extracted through physical vapor transport (PVT), chemical vapor deposition (CVD), liquid-phase sintering, sol-gel, and mechanical alloying process [20].

b) Alumina (Al_2O_3)

It is one of oxide ceramic particles, and a chemical compound of aluminum and oxygen, it is commonly known as Corundum, that can occur naturally in many crystal forms such as α-Al_2O_3 (stable at high to low temperature), β- Al_2O_3 (compound of alumina and alkaline solutions) and metastable phases. Alumina is found mainly in Bauxite ore in different forms such as Al (OH), γ- AlO (OH), and α-AlO (OH), this compound contains 65.4 w%, 85w%, and 85w% of Al_2O_3 and the aluminum oxide extracted through the Bayer process. Aluminum oxide has high elastic modulus, strength, oxidation resistance, chemical resistance, and thermal conductivity, however, it has lower fracture toughness and it is mentioned as a limitation to use it in different applications. To overcome this limitation two methods are mostly reported, the first one is by combined alumina with SiC whiskers (Al_2O_3-SiC) and combined it with tetragonal zirconia (Al_2O_3-ZrO_2), through sol-gel processing, colloidal processing, or shear rate blending. Aluminum oxide can be applied as electrical insulators, electro-chemical machining fixtures, extrusion dies, cutting tools, and acid pump seal. A common example of composites made from alumina with other materials is Alumina/zirconia (Al_2O_3/ZrO_2), Alumina/ceria (Al_2O_3/CeO_2), Copper/alumina (Cu/Al_2O_3), and Nickel/alumina (Ni/ Al_2O_3) [26].

2.3.2. Reinforcement

Reinforcements are the main constituents of composite materials, the core functions of the reinforcements are to carry the load, to provide strength, stiffness, and thermal stability to composite materials. Some of the reinforcements are particulates, flakes, fibers, and whiskers [4, 21]. The present work used fibers as a reinforcement to achieve good mechanical properties.

i. Particulates

Particulate composites are the combination of particles immersed in matrices, such as alloys and ceramics. They are usually isotropic and the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, and oxidation resistance [1].

ii. Flakes

Flake composites consist of flat reinforcement's materials such as glass, mica, aluminum, and silver. This reinforcement provide advantages of high flexural modulus, and low cost, however, flakes cannot be oriented quickly and only a limited number of materials are available for use [1].

iii. Fibers

Fiber composites can be made up of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are generally anisotropic, they are used as reinforcement materials during composite manufacturing and they can be classified as plant fiber, animal fiber, and mineral fibers [1].

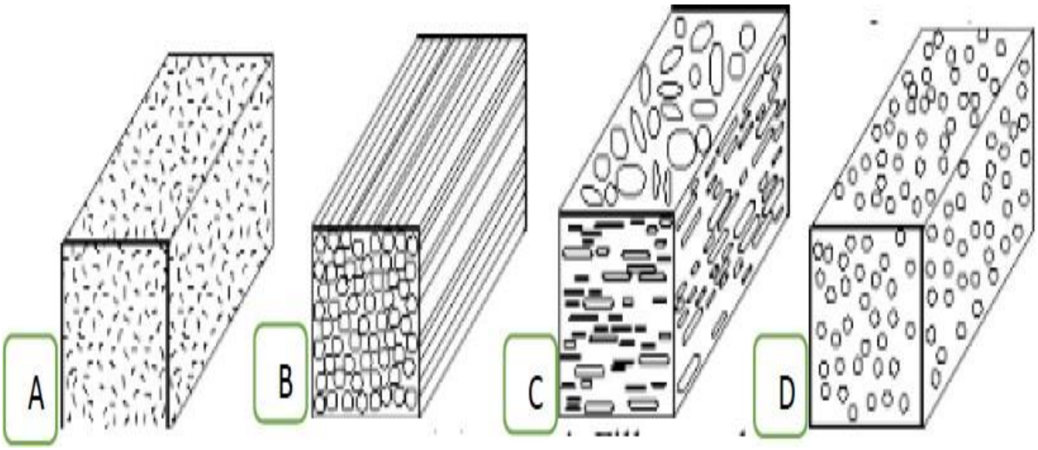


Figure: 2.2.Types of reinforcement's formation and alignments [1]

A) Short fiber (random), B) Long fiber, C) Flakes and D) Particulates

The above figure (2.2) describes different reinforcement alignments in composite materials. Fiber-reinforced composites contain polymer matrix and fibers as a reinforcement and the fibers can be synthetic fibers or natural fibers. Fiber-reinforced polymer composite differs from other composites because the constituents work together but remain at their original form; the constituent materials are different at the molecular structure and separate mechanically [1].

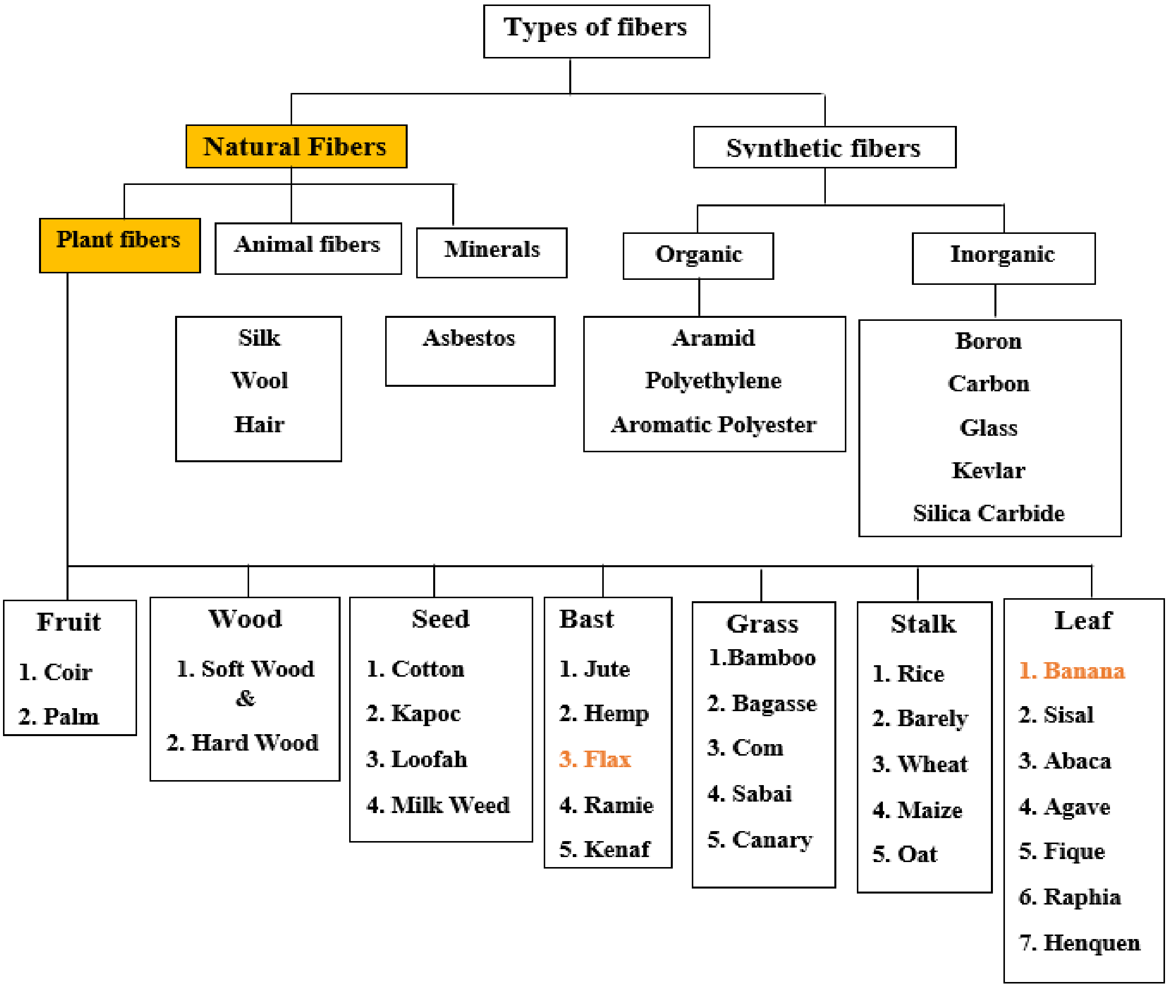


Figure: 2.2.Types and sources of natural and synthetic fibers [27].

a) Natural fiber's reinforced composites

Natural fibers are essential to replace synthetic fibers due to their availability, low cost, high strength, and lightweight and high corrosion resistance. They can be classified based on their sources, such as plant fiber, animal fiber, and mineral fiber.

Cellulosic fibers are extracted from plants and they are categorized as primary and secondary plants, Primary plants are cultivated directly for fibers; in secondary plants, the fibers are extracted from the waste or unutilized part of the plant. However, their properties are dependent on different factors such as growing environment, soil type, plant species, and harvesting methods [11].

The chemical composition of plant fibers includes cellulose, hemicellulose, lignin, and wax, cellulose is the stiffest and the strongest organic constituent of plant fiber, it is a semi-crystalline part of the plant fibers, besides it is highly stiff and strongest than other constituents. The second main part of plant fibers is hemicellulose, which is located around the cellulose part of the fiber, besides its fully amorphous and slightly soluble in water; because of this natural fiber Reinforced composites are water and moisture absorbent. Lignin and pectin are somehow used as binders [28].

Some drawbacks of natural fibers are high moisture absorption, high water absorption, high flammability, and difficulty of processing at elevated temperatures. This limitation of natural fibers can be reduced by exposing the fibers to chemical or physical surface treatments [29]. Natural fiber composite properties are dependent on the nature of the fiber, polymer matrix, fiber surface treatment, fiber extraction method and composite manufacturing method for instance applied pressure, temperature, and time duration. They can be used for different application areas such as the automotive industry, marine industry, aerospace industry, and structural application [5, 30].

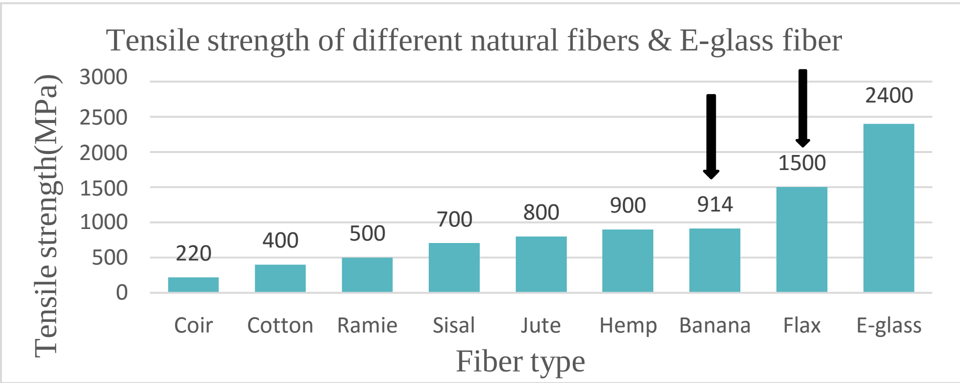


Figure 2.4. Tensile strength of fibers [1, 6].

Figure: 2.4. Describes natural fibers' tensile strength properties and E-glass fibers. As per indicated that flax fiber has higher tensile strength and banana fiber also has competitive tensile strength due to this reason both fibers are selected to be hybridized.

i. Flax fiber

Linumusitatissimum is one of the Bast fibers, the specific name for flax within the family Linaceae, which aptly describes its usefulness and versatility. Its tallness varies from 60 cm up to 120 cm depending on the variety of growing environments, soil type, and seeding density. It is cultivated in different areas of Ethiopia such as Arsi, Bale, East Gojam, Shoa, South Wello, and Tigray. In Ethiopia, linseed is the third important oilseed next to Sesame and Noug in terms of annual acreage and total production. A total of 112,760 tons of linseed was harvested from about 117,000 hectares of land. As such, the crop accounts for over 13% of the total cultivated area and over 15% of the total production of oilseeds in the country [31].

The flax fiber is a natural bast fiber obtained from the stem of the plant, it is cultivated in the temperate, humid, sub-tropical region, and the daily temperature does not more than 30^{o}C. The plant growth has four stages such as germination (G), vegetative (Vs), flowering (F), seed fermentation (SF), fiber maturity (FM), seed maturity(SM), and Senesces(S) [32].

Based on different researcher's reports flax fiber diameter and length were shown some variations for instance. **Moudood et.al & Rahman et.al** reported that flax fiber has a higher length to diameter ratio and its diameter was in the range of 12-80 µm. In addition its length range was among 10-100mm. However, the flax plant length found between 80-90cm [32, 28 -30].

Based on the chemical composition of flax fiber, it has cellulose content, hemicellulose content lignin, and pectin content; the report showed 60-81%, 14-20.6%, 2-3%, and 1.8-5%. Itindicated that if the fiber has high cellulose content it has a high degree of crystalline too, whichmakes it stronger and stiffer [33, 34].

ii. Banana Fiber

Banana is one of the oldest cultivated plants globally, it belongs to the Musaceae family and has almost 300 species, a banana plant has a part called pseudo stem that looks like a trunk where the banana fiber can be extracted. Banana fiber is included in leaf fibers and the plantation is vastly found in Ethiopia, which covers almost 68.72% and 37,076.83 hectares from the total fruit production. The greatest banana plantation of Ethiopia is found in Southern

Nation Nationalities and People Regional State, specifically Gamo Gofa, Bench Maji, and Sheka[35,36]. The height of the banana plant can be reached around 7.5m and the width of leafs of the banana plant about 30cm [37], like other cellulosic fibers banana fiber also contains cellulose, hemicellulose, lignin, and pectin content, which are described as 62-65%, 6-19%, 5-10%, and 3-5 % [34],[31-32].

As indicated in (figure: 2.4.) the flax fiber has higher tensile strength and banana fiber also have competitive tensile strength, both fibers are available in Ethiopia, due to this reason they are selected to be hybridized. The fibers were extracted from secondary plant stems because after the flax cereals and banana fruits were harvested the stalks does not use for other applications and were simply thrown away. Both fibers have a good mechanical property and the banana fiber has better elongation therefore it is suitable to be hybridized them and get better property.

b) Synthetic fiber reinforced composite

Synthetic fibers are manmade fibers they did not found naturally, and made of polymers that produced in the workshop. During synthetic fiber manufacturing chemicals are used, some of polymers used to produce synthetic fibers are nylon, polyesters, acrylics and polyurethane, in addition other fibers such as carbon fiber, aramid fiber, glass fiber and Kevlar fibers also include in synthetic fiber category. Synthetic fibers reinforced composite materials are being used in different advanced applications areas such as automotive, marine, and aerospace and construction [15].

2.3.3. Composite fabrication method

Different composite fabrication techniques are available depend on raw materials, part design, the desired manufacturing process, and end-use or application [38].

i. Filament Winding

Filament winding is a continuous fabrication method that can be highly automated and repeatable, with relatively low material costs. A long, cylindrical tool (mandrel) is suspended horizontally between end supports and dry fibers are run through a bath of resin to be wetted [30, 38].

ii. Lay-up

In the lay-up manufacturing process, small to large parts can be manufactured, products quality and production rate depend on labor skills. There are three types of lay-up processes [38, 39].

- Wet lay-up

This process takes place by pouring low viscous resin on dry reinforced materials such as chopped strand fiber, continuous mat fiber, and woven fabric. The reinforced material can be wetted by brushing, spraying, or using rollers. The layers are formed sequentially until the desired thickness is found. Wet lay-up molding is done on an open single-sided tool; the curing process is usually taken at room temperature without a vacuum bag, it's low cost and simple to use [38, 39].

- Spray lay-up

This process uses chopped fibers mixed with the liquid resin in the spray gun; the mixture is sprayed on the prepared open mold, and curing can be attained at room temperature or by using moderate heat application. It is suitable from low to medium production volume products, it's the simple and low cost [38, 39].

iii. Resin Transfer Moulding

Resin transfer molding is one of the commonly used manufacturing techniques, it is mostly used to produce complex shaped materials, the resin is transferred into a closed mold which holds reinforcement before the matrix is ejected and the fibers are wet until it reaches the optimum level [38, 39].

iv. Pultrusion method

In the polutrition manufacturing method, the reinforced fibers are imbued with the polymer matrix and pulled through a heated die to form composite material shape and size. During the polutrition process main parameters should be considered such as, die temperature, fiber volume fraction, resin viscosity, pulling speed, and resin polymerization [39, 38].

v. Compression molding

Compression molding is a matched-die process that can process medium to large products with good surface finishing. The charge is placed between upper and lower dies to form the required shape, heat and pressure applied for curing, high pressure can be applied to thermoplastics and thermosets polymer composite during the manufacturing process [38].

vi. Extrusion

Extrusion is a method of forming metals or plastics which are forced to flow through a die or series of dies, it is a process of forming materials such as metals or plastics within a specific shape and size of materials. The work materials are forced to flow through an opening die to produce the required product. There are two types of the extrusion process, forward extrusion and backward extrusion process [38].

In all composite manufacturing methods, there is four composite processes are followed.

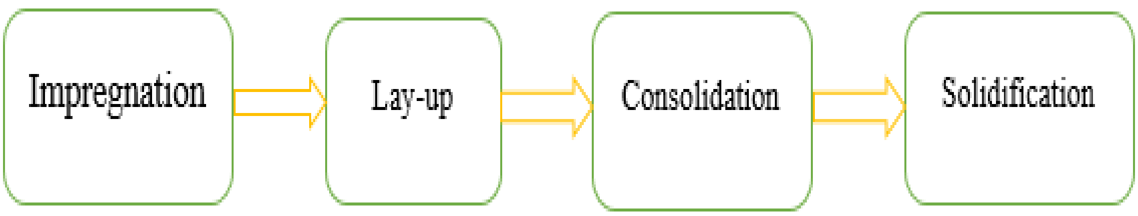


Figure 2.5. Main composite manufacturing process [4].

The above figure (2.5) shows the basic composite manufacturing process, those are discussed below.

a) Impregnation

This process is used to wet the fibers thoroughly with resin or make a mixture of fiber with resin. The main parameters affecting the impregnation process are resin viscosity, surface tension, and passageway action [38].

b) Lay-up

In this process the material is made with the required design; the fiber and resin mixture is placed in the desired specifications of shape, size, and thickness of lamina. The main parameters which affect composite materials during lay-up are fiber distribution and lay-up sequence [38].

c) Consolidation

It makes better contact between the impregnated fiber and each lamina layer, and all the interrupted air will be removed. During consolidation, pressure can be applied, but it should be at the optimum level; if not, the fiber will be elastically deformed, and the resin will flow out from the boundary. This process is necessary to get a good quality product, but the lamina will have voids and dry spots [38].

d) Solidification

It is a process of curing lamina, vacuum or pressure can be applied. In thermoset composites, the solidification rate depends on the resin formulation and cure kinetics, beside the temperature also enlarged for faster solidification. But in thermoplastic composite, the temperature is reduced to make rigid the part [38].

Based on the above literature descriptions, for the current work, to fabricate the composite materials, fiber impregnation, lay-up, consolidation, and solidification process were followed. For impregnation of fibers through epoxy resin and consolidation process specifically wet lay-up manufacturing technique and compression molding methods were applied, because it is suitable application for medium and large materials production purpose, wet lay-up technique is easy to mold the material, in addition, press machine was used for compacting the molded material through applying 50 bar (5Mpa) pressure.

2.4. Factors affecting natural fiber-reinforced composites

2.4.1. Fiber extraction methods

The fiber extraction method is one of the factors, which can affect the quality of fibers and natural fibers can be extracted using different methods some of them are,

- ❖ **Water retting**

Water retting is mainly practiced in a hot climate region, it used to separate fibers from the straw part, during retting the stalk is immersed in slowly running water for 5-15 days, at room temperature. A weighted material placed on the above to avoid extra movement. The plant stem is decomposed due to practiced action of microbes which biologically existed through retting of water.

On the other hand, water retting can be carried out using a water-filled tank; the stem is immersed in water for 2-3 days; during this retting the water is stationary and the fermentation occurs, the stem decomposed through microbial action. In This process, the water temperature and pH values can be 20 -38 C° and 4.5-4.9 during retting. The stalks are exposed for over-retting because the water is stationary and this leads the fiber to have rigid or weak fiber quality, therefore in this process water quality, retting duration, and water temperature should be carefully controlled [40,41].

- ❖ **Chemical retting**

It is a hydrolysis process, the plant bark or stem is immersed in a solution that contains warm water with alkaline substances such as caustic soda ($NaOH$), soda ash ($NaCO_3$), and oxalic soda, the immersion process will take up to 10hrs. After retting, the stem is washed with cold water to discrete the fibers, chemical retting is important to reduce time and to uniform fiber quality [40, 41].

- ❖ **Dew retting**

This method of extraction is taking place in a temperate region where rain and dew are occurred frequently, after harvesting, the plant stem is spread on a grass surface under the natural atmospheric condition which developed micro-organisms. It decomposes the pectin bond between the fiber and woody part through enzymatic reaction [40, 41].

- **Enzyme retting**

The plant straw is immersed in a solution that contains enzymes such as cellulase, hemicellulase, and pectinase. The enzymes are used to separate the fibers from the lignin part of the plant stem [40].

- **Mechanical extraction**

Before the mechanical extraction was introduced, the fibers were separated from the stem using hand scrapers, blunt knives, wooden beater, and hand comber. The mechanical extraction is necessary to overcome good quality and maximize fiber production, it contains mainly breaking, scutching, and hackling. After the plant is harvested it passes through the scutching machine to remove the bark and woody part of the stem, then after its transfer to a hackling machine which combed it lengthwise and removed short fibers, after the hackling process the fiber will be uniform and aligned [40,41].

2.4.2. Chemical composition of fibers

Natural fiber composition is one of the main factors that can affect the physical, mechanical, and chemical properties of the fiber-reinforced composites, some of the elements are fiber cellulose, hemicellulose, lignin, pectin, and wax content. The chemical composition of natural fibers are varies based on the plant growing geographical location, type of soil, extraction method, and environmental condition [41]. **Huang et.al**. Studied and determined the flax fiber composition using Near-Infrared Spectroscopy and compared it with the wet chemical determination method. The study reported that the average value of the compositions was, cellulose 75.884%, hemicellulose 14.398%, and lignin 3.21%, and the near infrared spectrometer (NIR) can provide a simple and fast way to analyze a flax fiber composition [42]. Thermal property of natural fibers also highly related with the fiber chemical composition **Dorez et.al**.conducted the effect of chemical composition on the pyrolysis and combustion property of natural fibers the study intense on Flax, Hemp, Bamboo, Sugar- cane and Coir fibers, the study determined fibers that have a high amount of Lignin content exhibit high burn yield, adequate heat of combustion, and increased activation [43].

2.4.3. Fibers hybridization

Composites, which have two or more reinforced constituents are identified as hybrid composite. During composite manufacturing, fiber hybridization is essential to develop the unique material property which the two reinforcing materials don't have as a single fiber, not only that reinforcement hybridization also reduce materials cost [44]. **Ngoc et al**. have experimented on the tensile property of coir/bamboo polypropylene composite. The volume fractions for hybrid coir/bamboo were 30% and 8% but for single fibers coir/pp 44% and bamboo/pp 45% respectively. The fibers were aligned in monolithic unidirectional (UD) alignment and laminated between two polypropylene layers, it was inserted into a hot press machine at 175C^0, with 10 bar pressure for 15 min. the specimens were prepared and tested, and hybrid coir-bamboo/pp composite was shown optimum strength and failure strain property [45].**Sivasubramanian et al.** examined the effect of hybridization of natural fibers on the mechanical properties of hybrid sisal/banana fiber reinforced polyester composite. The study includes mechanical testing such as flexural, tensile, compression, and wear resistance of sisal, banana, and hybrid sisal/banana fiber reinforced polyester composite. Composite fabrication was carried out using the compression molding method. Based on the report, the Sisal/banana hybrid composite exhibited higher results in all parameters. Besides, banana fiber-reinforced composite show higher tensile and flexural property, on the other hand, sisal fiber-reinforced composite shown better compression and impact load strength [46]. **Ismail et al.** have conducted an experiment on Kenaf /Bamboo fiber reinforced epoxy composite specimens. The main goal of the study was the characterization of void content, tensile strength, vibration, and acoustic property. The two fibers were hybridized in woven mat form, the weight of the fibers ratios were 30/70%, 50/50%, and 70/30% but the fiber surface was not treated. The fiber to resin ratio was constant at 40/60%, composites were fabricated using the hand lay-up method. According to the test result, tensile strength and tensile modulus were increased, especially 50/50 ratio hybrid composite, show significant change. The study concludes that kenaf/bamboo hybrid composite can be used for non-bearing structural and sound absorption applications [47].The current work also showed significant effect of fibers hybridization ratio. When flax and banana fibers were hybridized within 50%/50% the mechanical property of the hybrid composite was higher than other ratios such as 75/25% and 25/75%; it depends also individual fibers property.

2.4.4. Fiber length and volume fraction ratio

Fiber length and fiber content have significant value on the composites properties, **Husna et al.** were conducted an experimental investigation on the outcome of fiber loading and fiber treatment on banana fiber reinforced low-density polyethylene (LDPE) composite. Fiber treatment was conducted with H_2O_2, NaOH, NaSi, $NaCO_3$, and soap in combination. The banana fiber was chopped and mixed with LDPE using a blender; a compression molding was applied with, a load of 50KN and temperature of $105C^0$ for 35 minutes. It reported that tensile strength, flexural rigidity, and modulus of elasticity were increased when the fiber loading increases [48]. **BASIJI et al.** revealed that how the fiber length and fiber loading can affect the mechanical properties of wood pulp /polypropylene composite. To fabricate the composite, wood pulp, chopped Fibers, and maleic anhydride-grafted polypropylene was used. Wood pulp fibers were organized with short ($\leq$1mm), medium (1-2mm), and long (>2mm) fiber lengths. The fiber content was also prepared with 27%, 37%, and 47%, the fiber, resin, and hardener were blended using a twin-screw extruder at a speed of 50rpm and $180C^0$, and composite material was fabricated using injection molding. As the final result is shown when the fiber length and fiber loading were increased, the tensile strength, tensile modulus, and flexural strength also improved, however, impact strength was declined [49].

Idiris et al. studied the mechanical properties of Ethiopian Banana fiber reinforced epoxy composite, the banana fiber was treated with acetone and the fiber to resin ratio was 5/95, 10/90, 15/85, and 20/80%.To fabricate the composite plate hand-layup technique was used and the curing process was conducted at 30°C for 24h. The specimen's mechanical tests and microstructural analysis were performed. According to the test result, 20/80% fiber to resin ratio shows better mechanical property than others. It was reported that, fiber content and composite material of tensile strength, flexural strength, and impact strength linearly increased [50]. **Smita et al.** studied the characterization of jute fiber reinforced polypropylene composite. The fiber loading was 10-45% and the fiber was modified with 1% maleic anhydride (MAPP). The result shows a higher result of tensile strength, impact strength, flexural strength, and fiber-matrix adhesion achieved at 30% fiber content [51]. **Susilowati et al.** examined the effects of fiber loading and fiber length on pineapple leaf fiber epoxy composite mechanical properties. Fiber to matrix ratios was arranged at 10/90, 20/80, 30/70, and 40/60. The fiber length was adjusted at 20mm, 30mm, and 40mm; it was subjected to 5% NaOH treatment, to enhance fiber to matrix interfacial bonding. For composite fabrication, the hand lay-up technique wasapplied. The mechanical properties were increased as the fiber content was increased up to 30%.when the fiber percentage beyond 30%, the tensile strength, flexural rigidity, and impactstrength were decreased. In general 30/70% with 40mm fiber length shows the highestmechanical property; it indicate the fiber content and fiber length have a significant effect on composite materials property [52].

Sathish et al. studied the properties of five different hybridized fibers composite material, which were pineapple/sisal/epoxy, kenaf/sisal/epoxy, pineapple/kenaf/epoxy, and flax/pineapple/epoxy and flax/kenaf/epoxy hybrid composite. For better interfacial linkage, each fiber was treated with 5% NaOH and dried in a hot oven at 60^0 for 4hr. All hybrid composites were prepared from 40/60 fiber to resin ratio. Composite specimens were made with compression molding. Tests such as tensile strength, flexural strength, impact strength, and SEM properties were analyzed. Based on the result flax/kenaf/epoxy composite presented the highest mechanical property and high fiber to resin interfacial bonding [42]. **Mohanty et al.** investigated jute fiber reinforced polypropylene composite, which used 5% of maleic anhydride as a coupling agent, with a fiber loading range of 10-40%. The study reported that impact strength was linearly increased 10- 30% and declined at 40%fiber loading. It's indicated that fiber modification, chemical concentration, and impregnation time significantly affect the mechanical properties of composites [29]. **Agustinus et al.** studied the tensile strength of banana fiber reinforced epoxy composite for prosthetics. Fiber to resin ratios were 10/90%, 20/80, 30/70%, 40/60%, and 50/50 %. The banana, fibers were treated with 90% alcohol for 30 minutes. According to the test result, the 40% fiber volume ratio shows better tensile strength and modulus of elasticity; in addition, this banana fiber composite was found in the middle range compared to other researches [53]. **Araya et al.** examined the fracture toughness property of chopped sisal epoxy composite, the sisal fiber was extracted from the sisal plant leaf and chopped within 2mm and 10 and 15mm. The epoxy to hardener ratio was 10:1 and the number of fiber to resin volume fractions were 15/85, 25/75%, 30/70%, 35/65%, and 40/60% correspondingly. The fiber was impregnated in resin with a hand lay-up technique, and compression molding was applied. The fracture toughness property test was examined, according to the experimental analysis, 30/70 % was shown good fracture toughness and other mechanical properties [54].

Considering the above literature description, fibers composition fiber loading and fiber length have a significant effect on the properties of composite properties. However, the parameters did not affect with in similar manner, because, some of the results were linearly increased and somewhat decreased this indicated that the composite materials property variation depends on the nature of the fibers, manufacturing method, and volume fractions of constituents.

2.4.5. Fiber surface treatment

The main objective of fiber surface treatments is to remove the amorphous and waxy portions of plant fibers, by eliminating hemicellulose, pectin, and lignin parts. The removal of hemicellulose and other impurities increase the roughness surface of the fibers and hydrophobic property by replacing hydrogen bonds with covalent bonds [55].

Natural fiber surface modifications are essential to improve the interfacial bonding between the reinforced fiber and polymer matrix. Plant fibers have high water and moisture absorbency because they are cellulosic fibers and contain water-soluble substances such as hemicellulose. Untreated natural fiber reinforced composites have lack of compatibility with polymer matrixes, moisture sensitivity, and dimensional stability [56].

During the fiber surface treatment process the concentration of chemicals, soaking time and temperature should be considered. If these factors are not controlled the fiber will be degraded and it will be lost its property [34]. The performance of the composite materials are depends on the efficiency of stress transfer between the fiber and matrices; this needs strong linkage between the two constituents. Coupling agents are necessary to make the fiber compatible with the matrix and create a strong linkage between them [57].

According to the fibers surface improvement mechanism, **Zhu et al.** examined and stated the effect of alkali, silane, acetylation, and enzymatic treatments on the surface of a non-woven flax fiber mat. The alkali treatment was taken in 5wt% of NaOH solution for 1 hr and it dried for 12hr at 50°C. In addition, Aminopropyltriethoxysilane (APS) and butane tetra carboxylic acid treatment were also performed. To confirm the flax fiber surface change, Fourier Transformation Infrared Spectroscopy (FTIS) was used. To evaluate the thermal property, thermogravimetric analysis (TGA) was carried out at 23C° - 600C°.The study reported , after all treatments, the FTIS indicate, the NaOH treated fibers shows the highest thermal stability and tensile strength than other treatments [58]. **Yew et al.** studied the outcome of alkali treatment on the surface of coir fiber and compared with untreated one. Specimen tests were performed including thermal stability, water absorption, and structural characterization. NaOH solution was prepared with 5wt% of the coir fiber and 95wt% of water. The fiber soaked in a solution for 24 and 48hr at room temperature and composite material was fabricated. The morphological analysis of fiber-treated composite was done through Scanning Electron Microscopy (SEM) and the chemical structure of treated fiber was also examined using Fourier Transformation Infrared Spectroscopy (FTIR). The study reported that the alkali-treated coir fiber shows good interfacial bonding, and increase fiber hydrophobic property, thermal stability. It suggest to increase concentration of NaOH to remove lignin content [59].

Rakesh et al. were done an overview using various articles which focused on natural fibers (flax, jute, banana, sisal, and pineapple) surface modification methods. According to researches different types of chemical treatments are described some of them are alkaline, silane, acetylation, and peroxide treatments. In addition, natural fibers' chemical composition effects were clarified. The study determined that good surface modification, high fiber to matrix adhesion, and better composite properties are dependent on, the concentration of chemicals, nature of fiber composition, time duration, and temperature used. In conclusion, NaOH treatment was very useful for fiber surface treatment, due to outstanding mechanical and thermal resistance [60].

Arbelaiz et.al were examined the chemical treatments outcome on flax fiber tensile strength property and flax/polypropylene composite shear strength property. The flax fiber was extracted using the water retting method. The chemicals used for treatments were maleic anhydride (MA), vinyltrimethoxy silane (VTMO), and sodium hydroxide (NaOH). The alkaline solution was prepared with 20wt% of the fiber and it socked in a solution for 1 hr. To test the properties of the composite material, optical microscopy (OM) and atomic force microscopy (AFM) were applied. Beside a tensile strength test was also conducted; the study stated that the tensile strength of flax/ polypropylene improved by MAPP and NaOH treatments [61].

Chen et al. conduct the experimental analysis on the wettability and thermal stability of bamboo fiber. The fibers extraction was conducted by chemical retting, and surface modification was performed using NaOH concentration of 6%, 8%, 10%, 15%, and 25 wt% of the fiber. To measure the surface morphology, contact angle, and thermal property of bamboo fiber, atomic force microscopy (AFM) was used. The thermal stability of the fiber also detected by thermo- gravimetric analysis (TGA). In a conclusion, NaOH concentration at 6,8,and 10% improved the thermal stability of the fiber[55]. **Mbeche et al.** studied the effect of alkali treatment on tensile flexural, impact, and thermal conductivity of hybrid sisal/cattail fiber reinforced unsaturated polyester composite. The hybrid composite was fabricated with 20% fiber weight ratio and constant fiber to fiber ratio, which is 75/25. It conclude that higher mechanical and thermal conductivity are shown on treated fiber composites [62]. Fiber surface modifications are necessary for natural fibers, because water-soluble components of the fibers should be removed. Natural fibers high water and moisture absorption properties will affect the composite properties. For current work, alkaline (NaOH) surface treatments were carried out to remove the lignin, hemicellulose, pectin, wax, and other fiber impurities. It used to enhance the interfacial bonding between the fiber and the polymer matrix. However, chemical concentration, temperature, and soaking time should be considered [46-48].

2.4.6. Composite fabrication process

The material fabrication methods have substantial effect on the mechanical properties such as tensile strength, flexural strength, impact strength, fracture toughness and fatigue properties of composite materials. These properties are directly related to the composite defects that caused by following improper composite fabrication method, that cause for catastrophic failure and poor materials property [63]. Some of the defects are void contents, fiber pullout, notch, crack, poor fiber to matrix adhesion, and this leads the material to easily delaminate, to have high rate of crack initiation and propagation. **Ujanto et.al.** Studied and reported the 'effect of fabrication techniques, resin type and fiber combination on the mechanical properties and morphology of glass fiber composite.' the paper examined the tensile modulus, tensile strength and compressive strength of composite materials with two resins (Epoxy &Vinyl ester) and with two fabrication techniques (Vacuum bagging & Vacuum infusion). The result shows the specimens fabricated with vacuum infusion showed high tensile strength than vacuum bagging; beside the composite fabrication method exhibited significant effect on the tensile strength than resin type variation.

The higher compressive strength achieved through epoxy made composite specimens[64].**Maruf.et.al,** also made a review on 'development in manufacturing process and mechanical properties of natural fibers composite.' the study examined ,how the composite fabrication process being grown from hand lay-up to current advanced manufacturing process. It stated that the composite material mechanical property des not only dependent on raw material, resin type, chemical treatment, product size and reinforcement alignments, but it's also affected by the fabrication process and cost. It is suggested that, for long fiber and large product size fabrication, open mold manufacturing process such as hand lay-up and automated tape laying process are preferable. For short fiber, complex geometrical shape and small scale products, injection and compression moulding fabrication methods are suggested [65]. **Rahul.et.al,** reviewed and reported 'the composite material 'history, type, fabrication technique, advantage and application'. The study states that, the composite manufacturing process parameters, such as mold type (open or closed mold), temperature, applied pressure and time have significant effect on the mechanical properties of composite materials [1].

2.4.7. Specimens testing methods

Composite materials specimens' property test results can be affected by the test experimental set-up, the specimen dimensions, amount of applied load, loading rate, displacement rate, and specimen location under loading. **Giovanni et al.** investigated 'the influence of tab types on the tensile strength of E-glass/epoxy fiber reinforced composite'. The tabs were attached to the specimen with bonded and molded type. According to the test result, the tensile strength significantly decreased with in molded and increased with 30^0 bevel angle tabs. It is stated that tab configuration, tab type and gripping pressure have significant effect on the tensile strength of the materials [66]. **Jennifer et al.** studied 'the effects of different test set up on the experimental tensile behavior of basalt fiber reinforced composite,' the study focused on the effect of parameters such as, dimension of the specimen, clamping system, measurement system and the test rate. The study reported the tensile strength shows variation with the same specimen width but in different displacement rate and loading rate. When the width of the specimen was increase, the slippage rate also enlarged. On the other hand, according to the tab type, the leather tab exhibited the peak tensile load resistance than the paper type tab [67]. **Marciano et.al.** Studied the effect of displacement rate on the flexural strength and flexural modulus of glass fiber reinforced polyurethane composite. The specimen test was examined with the same dimensions and with 0.2, 2, 20,100, 200 and 1000 mm/min displacement rate. The report conclude that both ultimate flexural strength and flexural modulus were linearly increased with displacement rate [68]. **Navaranjan et.al** reviewed impact strength of different natural fibers reinforced composites that tested with different impact testing methods. The paper revealed that testing methods have significant effect on the failure mode and energy absorption characteristics of composite materials. Some of the parameters are geometry of test sample, test sample location, load of the striking hammer, notch type, notch face and type of hammer [69].

2.5. Ceiling Fan

Fans are devices which are used to flow air or other vapors through equipment, and exhaust air from the equipment. They are mainly applicable in commercial and industrial areas, for instance, dust collection, cooling, ventilation, and refrigeration purpose. Fans are classified as, axial and centrifugal fans, these two fans are categorized depending on the pathway of the airflow through the fan[8].Centrifugal fans circulate the air radially outward and tangentially away from the tip of propellers. The delivered air stream moves parallel to the blade hub and turns radially toward the blade tip. They can generate high pressure, they can be used in humid regions, in material handling, and high-temperature areas [8].

Axial fans are moving the airstream along the axis or shaft of the fan. The stream is pressurized through the aerodynamic lift which is generated by the fan blades. They are compact, need higher rotational speed, have less rotating mass, sometimes used in place of centrifugal fans. Axial fans are applicable in clean air, low-pressure, and high-volume applications [8].

a) Propeller fans

These types of fans are included in a simple type of fan, which is used on the top of the roof (ceil) for ventilation application, the ceiling fans are included in the propeller fan category. It can achieve maximum efficiency at the lowest delivery pressure, low cost, develop high airflow and low pressure [8].

b) Tube axial fan

Tube axial fans are required in medium pressure supply and high airflow rate application. It can be used in ducted HVAC installation for ventilation, it can supply medium to high pressure and have good working efficiencies [8].

c) Vane axial fans

These kinds of fans can deliver high pressure with good operating efficiencies than propeller-type fans. They have high operating speeds and can be applied in high-pressure required areas for emergency ventilation [8].

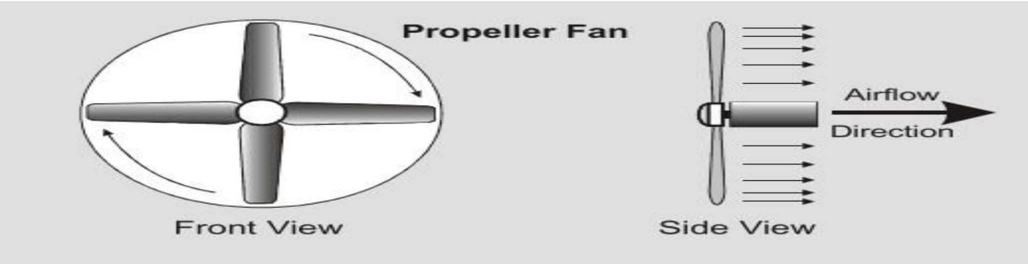


Figure 2.6. Axial Propeller fan [7]

2.5.1. Aerodynamic loads and moments on ceiling fan blades

When a body with arbitrary shape and orientation is immersed in a fluid stream, it will be subjected to different forces and moments. The flow exerts forces and moments on a body along all three coordinate axes. When either the body is stationary and the fluid is moving or the fluid is stationary and the body is moving the fluid induces pressure on a body. Components of net force which are exerted by the fluid are the combined effect of pressure and wall shear forces (skin friction).

Forces and moments which are acted on a body are Drag Force, Lift Force, Side Force and moments are Rolling moment, Yawing moment, and Pitching moment [67, 68].

The drag and lift forces are depending on the density of the fluid, the upstream velocity, and the size, shape, and orientation of the body.

Drag Force: -it is exerted on a body along the direction of the fluid stream and moment on that axis is the rolling moment [70].

Lift Force: - it's a force that Induces on a body which is normal to the fluid flow oncoming flow direction, the moment created along that axis is the yawing moment [70].

Side Force: - it's the third force and neither a gain nor loss, about this axis there is a Pitching moment [70].

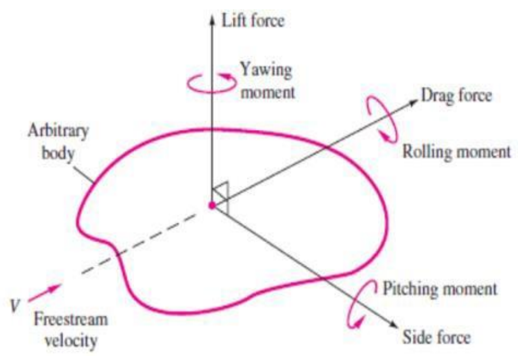


Figure 2.7.Forces and moments on a body immersed in a uniform fluid flow [70]

2.5.2. Performance of ceiling fan

Ceiling fan components are being developed and manufactured from glass, carbon and aramid fiber reinforced composite materials, to overcome the ceiling fan efficiency and to reduce power consumption. **Shih et al**. designed and modified ceiling fan vane structures to reduce the motor load and power consumption without affecting the structural strength of the vane. After the blade plates are formed it is hollowed in the middle. It can be filled with lightweight materials such as cotton, glass fiber or foam. In the end, it improves the overall operation efficiency, it reduced fan motor load and power consumption [72]. The performance of the fan also depends on the number of blades, blade angle, and bending position. **Adeeb et al.** studied the effect of a number of blades on ceiling fan efficiency according to volumetric flow rate, mass flow rate, and torque and energy efficiency. The result shows that an increasing number of blades have a significant effect on the performance of the fan on the above parameters, it concludes six blades exhibited good airflow volume, mass flow rate, and energy efficiency than others [73]. In addition, the rotational speed of the fan also has a significant effect on the air movement and distribution rate. **Chen et al**. were made experimental and numerical investigations of indoor air movement distribution with an office ceiling fan. The main objective of the study was to examine the air movement distribution considering parameters of fan rotational speed, fan geometry, ceiling to fan depth, and ceiling height. To obtain the result numerical analysis and software simulation were used such as computational fluid mechanics analysis. According to the result fan rpm and blade geometry shows a significant effect on increasing air velocity, air volume, and efficiency [74]. Concerning fan blade geometry, **Parker et al.** have modified the design and manufactured a ceiling fan, to increase airflow, for input watt, and to improve uniform airflow distribution through the room. The design objective was to produce airflows with 2 meters/second at a speed of 150 - 200 rpm. The propeller design was selected using numerical analysis. Tapered and twisted blade design was selected for best performance suggestion. The comparative fan performance was measured in both high speed, low speed, using the new developed blade materials. Based on the result prototype CF- 152" and Prototype CF- 164" shows superior and competitive performance in all airflow rates, power, and speed [75]. The fan blade bending position, bending angle, and rake angle have a major role for air delivery rate and distribution. **Muhammad et al.** have improved the efficiency of ceiling fan, considering blade rake angle, bend angle, fan rpm, and bend position. It measured the air delivery rate, power consumption and service value of the fan at different rpm. The blade prototype made from aluminum with a thickness of 1mm, rake angle at 5° and bend angle at 11.8° .The fan geometry contains three blades with a rotary disk hub. The speed range used for experimental testing was 175, 200, 250, 300, 330, 350, and 365rpm. The experimental verification of modified fan blade geometry shows that at 300rpm. The rate of air delivered (RAD), and service value increased by 21% and 22%, in addition, power consumption was reduced by 54% [76].

2.5.3. Fiber reinforced composite for ceiling fan blade application

Currently, fiber-reinforced composites are used in different application areas including wing turbine blades [77]**.** Ceiling fan blades also being made from fiber-reinforced composites**,** such as carbon fiber, glass fiber, aramid fiber, and natural fibers reinforced composites**. Neway et**

al. were fabricated jute reinforced Polylactic acid (PLA) bio-composite, for ceiling fan blades. The fiber surface modification was conducted on the jute fabric surface, and the composite plates were fabricated with 50/50%, 60/40%, and 70/30% volume fraction using compression molding. Tensile strength and shear strength property tests were conducted. The highest result was exhibited at 50/50% and 5 % alkali with 0.5 % silane fabric treatment. Alongside it measured air delivery, air velocity, power consumption, weight, and service value. It compared the new developed composite with "Usha" aluminum alloy- 1050H14 ceiling fan blade. The composite blade shows high air velocity, reduces 20% of power consumption, on the other hand, the air delivery was lower than the aluminum blade due to the lower surface area of the composite blade [78]. Ceiling fan blade started to fabricate using synthetic fibers reinforced composites that have high strength to weight ratio, good strength, stiffness, chemical and moisture resistance, such as carbon, kevlar, aramid, and glass fibers. **Sidhartha et al.** developed aramid fiber-reinforced composite for a ceiling fan blade, the objective of the study was to reduce blade weight, increase efficiency, and reduce power consumption using aramid with volume fraction of 60/40% and a blade thickness of 10mm.The displacement and stress analysis were conducted using Ansys software, it compared with aluminum ceiling fan blade . The report shows the displacement produced on the composite blade was lower than the conventional blade and it reduce 33.42 % cost of the blade. The stress analysis also shows the material can be suitable and safe for ceiling fan blade application [79].

Materials that have low density, high stiffness, and impact strength showed good performance in fan blade application areas. **Prabhakaran et al.** developed ceiling fan blade from glass fiber reinforced composite. The blades prototypes were prepared and compared with the aluminum blade according to weight and cost. The study conclude the glass fiber reinforced epoxy composite was reduced weight, power and cost of the conventional blade by 28%, 34% and 30% [80]. Ceiling fan blades' performance such as air delivery rate, airspeed, and blade rotation capacity are dependent on the blade materials property. **Narayana et al.** analyzed composite material of axial flow fans. It designed and changed the number of blades from 10 to 12 and 8. It increased the efficiency of the ceiling fan using carbon fiber reinforced epoxy composite and compared it with the conventional aluminum alloy 7050-T7651, and mild steel fan blades. The fan design and finite element analysis were done on Ansys software, depending on the airflow

Velocity and air delivery rate the study conclude that carbon-epoxy composite with 8 blades showed better results than aluminum and mild steel blades [81].

Misal et al. investigated the CFD analysis on composite radiator fan with three, four, and six blades, it studied the efficiency of the fan considering the number of blades, blade angle, and rotational speed of the fan. The CFD analysis reported the average airspeed and airflow discharge from the fan exhibited higher air velocity of 3.40 m/s and air delivery of 0.24 m^3/s at 4 blades, 45° blade angle and 1750 rpm [82]. Polymers and polymer matrix composites also being applicable for ceiling fan blade application. **Lowe et al.** was made a design and manufactured extruded ceiling fan blades from thermoplastic (Polystyrene) polymer. The objective of the study was to provide polystyrene extruded ceiling fan blades and to reduce weight and power consumption. In addition it aimed to increase the resistance of heat warp, water, moisture absorption, stability under continuous UV, and avoiding the post-fabrication process. It concludes that polystyrene can be used for ceiling fan blade application [83].

Chiang et al. established methods for manufacturing ceiling fan blades. The study aimed to reduce power consumption using light-weighted materials such as foam layers (originally polystyrene, paper layer, and metal layer). It is also to introduce a simple manufacturing method of the ceiling fan blade. The materials were prepared by inserting a paper layer and metal layers between two foamed polystyrene layers. It exhibited light materials with good strength that can be used for ceiling fan blade application [84].

2.6. Summary of literature review

Polymer matrix composites are now used in a wide range, particularly natural fibers reinforced composites are being used for different applications due to their competent mechanical property, availability, and low cost. However, it is not sufficient [1,4].The literature coverage showed that fiber and polymer matrix selection, fiber extraction, fiber surface modification, fibers and matrix volume fractions, composite manufacturing method, and experimental test setup have a substantial effect on the properties of composite materials.

Natural fiber chemical compositions have a major effect on the properties of composite materials, according to fibers cellulose, hemicellulose, and pectin content, which can directly affect the moisture absorption, water absorption, and mechanical properties of composite materials [32, 82]. Flax fiber has good tensile strength, stiffness, dimensional, and thermal stability properties because, it has a high percentage of cellulose content and most of the fiber parts are crystalline [42]. Banana fiber also has competent tensile strength and good elongation property and it is vastly found in Ethiopia [42]. Natural fibers can be extracted through water retting, chemical retting, dew retting, enzyme retting, and mechanical extraction methods [40]. In the present work, flax fiber was extracted through water retting, manual brushing, and beating, to avoid fiber degradation through applying chemicals and unnecessary cost [41]. On the other hand, the banana fiber was extracted manually from the banana trunk with a blunted knife and other accessories.

Fiber hybridization also has a great contribution to the mechanical, thermal, and physical properties of composite materials, which depends on the type of fibers, fibers volume fractions , and properties of mixed fibers property [45, 47]. For present work flax and banana, fibers were hybridized with eleven sub composition of 60/40%, 70/30%, and 80/20%. These range of composition was used to determine the effect of fiber to matrix volume fraction, fiber hybridization ratio, individual fibers property, and fiber surface modification on composite materials properties. There are different types of fiber surface modification techniques are available which can avoid the amorphous parts and unwanted impurities from cellulosic plants. For the current work, alkaline solution was used for both fiber surface treatment, specifically, for flax and banana fibers 3% NaOH for 1 hr and 5% NaOH for 24 hr, which was recommended by other researchers too [52-55].For both fibers, the NaOH solution concentration and soaking time were varies because, flax fiber has high cellulose amount. It does not need high amount of NaOH concentration and soaking time ,otherwise, the fiber will be degraded ,the strength and stiffness will be reduced [41,42]. The banana, fiber has higher moisture absorption property and it needs more NaOH concentration with a long immersion time to reduce this property [39-42]. Composites can be fabricated with different methods which are classified based on composite fabrication techniques, machine availability, processing time, amount of production, the desired product quality, and cost [39, 40].In this paper composite plates were fabricated through wet hand lay-up with compression molding method, considering its simplicity, can be used from small to large product fabrication and press machine availability. Composite materials are being applied.

in different application areas such as automotive, marine, aerospace, agriculture, and air conditioning system components. Ceiling fan blades are one of the components made by composite materials such as glass fiber, carbon fiber, and aramid fiber-reinforcedcomposites [76, 77, and 83]. The current paper also characterizes the mechanical properties of hybrid flax-banana fiber reinforced epoxy composite properties and examines the suitability for ceiling fan blade application using fluid flow and static structural analysis.

Overall, the fibers property, fiber to matrix volume fraction, fiber surface modification, manufacturing method, testing mechanism have a significant effect on mechanical, thermal, and physical properties of natural fiber-reinforced composites.in addition the composite property depends fibers wettability, fibers uniform distribution, and fiber to matrix adhesion. Natural fibers reinforced composites basic limitation need to be studied to overcome good mechanical, thermal and water absorption properties to use them in advanced manufacturing industries.

❖ Gaps identified on the above literature

From the previous works, the hybrid flax -banana fiber reinforced epoxy composite not adequately studied. The effects of various fiber to resin compositions and hybrid fibers volume fractions on mechanical and water absorption properties of other natural fibers were studied. On the other hand, hybrid flax-banana reinforced composite was not studied according to different parameters. In addition, most of the literature covered how to increase the ceiling fans' efficiency and reducing power consumption. To increase the fan performance different researches have been conducted through modifying the blade angle, rake angle, bending position, rotational speed, and angle of attack of the stream. But it was not consider materials replacement. In addition to that materials, the property has a significant effect on power consumption and increasing the performance of the fan, according to strength to weight ratio however it does not get the desired consideration.

Chapter Three

Research Methods and Materials

3.1. Introduction

In this thesis paper, for better data collection, data analysis, and interpretation both qualitative and quantitative (mixed) data collection methods were used. The data collection includes observation, reviewing articles and online literatures, referring manuals and books, experimental and software analysis. Some of the methods used in the study was fibers harvesting and extraction, fiber surface alkaline treatment, fibers property test, mold preparation, fiber to resin volume fraction preparation, and composite specimen's fabrication. The test specimens prepared for tensile strength, flexural strength, impact strength, and water absorption tests.

Data collection: - to achieve the aim of the thesis, both qualitative and quantitative data collection methods were used. Reviewing articles about composite materials, natural fibers, fiber hybridizations, volume fraction, manufacturing methods, testing methods, and software analysis were some of the data collection methods.

Raw materials collection & preparation: - to fabricate the composite material plates, fiber, epoxy, hardener, wax, mold and other materials were collected and prepared. Theoretical and experimental material preparation methods were followed. It included fiber to matrix volume fraction preparation, fiber extraction, fiber cutting, fiber surface modification, fibers testing, and mold preparation.

HFBFREC fabrication: - composite plates were fabricated based on the rule of mixture analytical equation. It was used to prepare density, volume, and weight of epoxy, fiber, and composites with 60/40%, 70/30%, and 80/20% matrix to fiber volume fraction. The fibers were treated with 3% and 5%alkaline solution (NaOH) and dried. The fibers were chopped and aligned in a random orientation. The chopped fibers were impregnated with epoxy matrix through the hand-layup technique. The consolidation process carried out through the compression molding using a hydraulic press machine. The solidification process carried out at room temperature for 24 hours.

Composite specimen's preparation & tests: - HFBFREC specimens were prepared based on ASTM standards, the mechanical and water absorption property tests were conducted, for instance, tensile strength (ASTM D3039), flexural strength (ASTM D790), Impact strength (ASTM D6110), and Water absorption test (ASTM D570-99) were used.

Ceiling fan blade modeling: - the fan blade geometry has been taken from the previous work, because the study compared different fan rpm and it describes better air flow speed and service value. The ceiling fan blade model was prepared using CatiaV5 software.

Finite Element Analysis: - the ceiling fan blade model was imported into Ansys19.2 software, and static structural analysis was conducted.

Compare the result: - experimental results of HFBFREC's were compared with each other and with other works. Beyond that, static structural analysis results (maximum stress and total deformation) were compared according to materials density and weight.

Figure 3.1. Represents, the research work flow according to theoretical and experimental circumstances; the study methods and materials are discussed below.

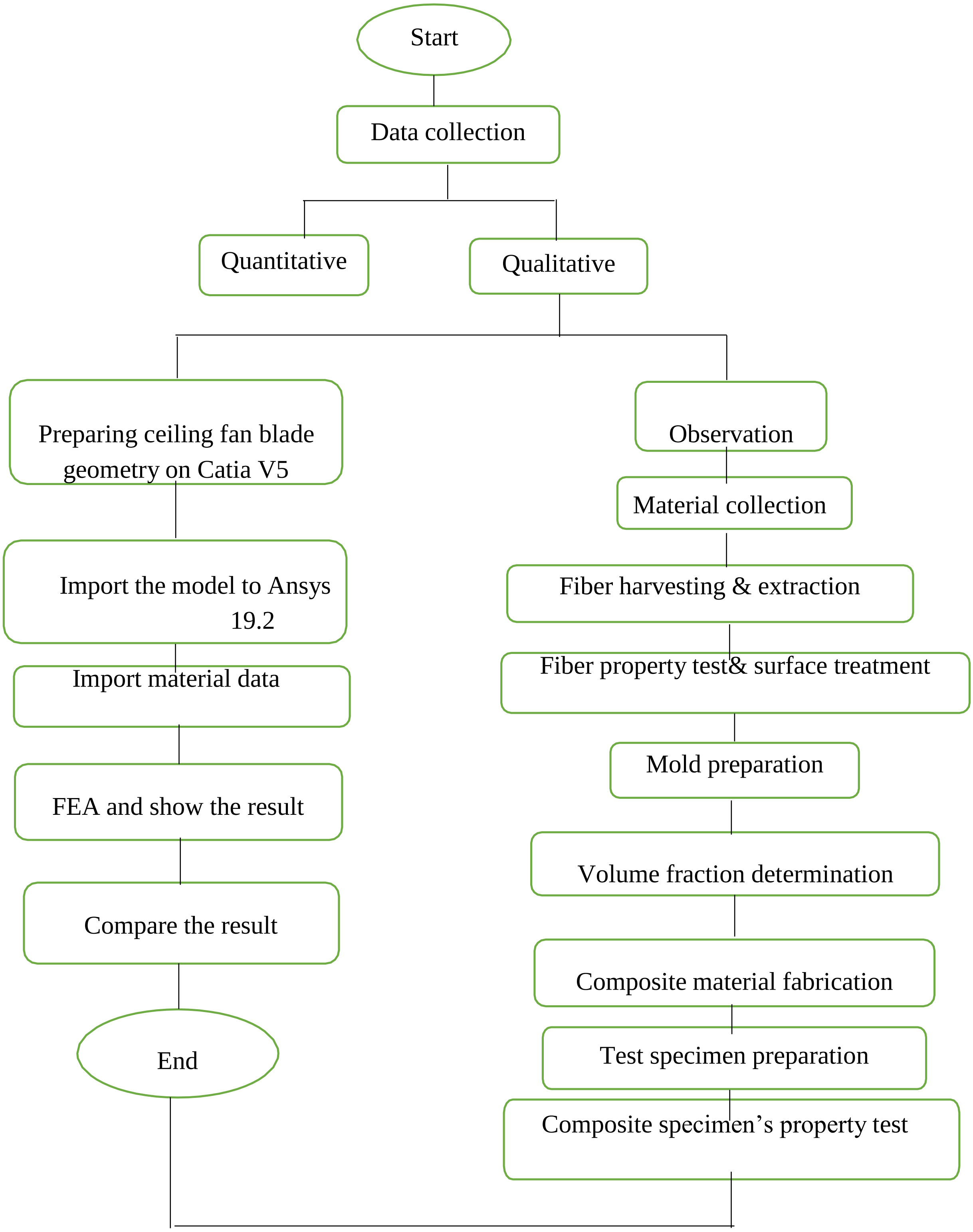


Figure 3.1. Methods and procedure of the study

3.2. Materials used and preparations

3.2.1. Epoxy matrix and hardner

Epoxy matrix resin is highly applicable in composite manufacturing for structural and advanced materials applications. In the present work, epoxy matrix-LY556, hardener-HY951 were brought from India, and other materials such as releasing agent (Wax), mould and sodium hydroxide (NaOH) were collected from the local market.

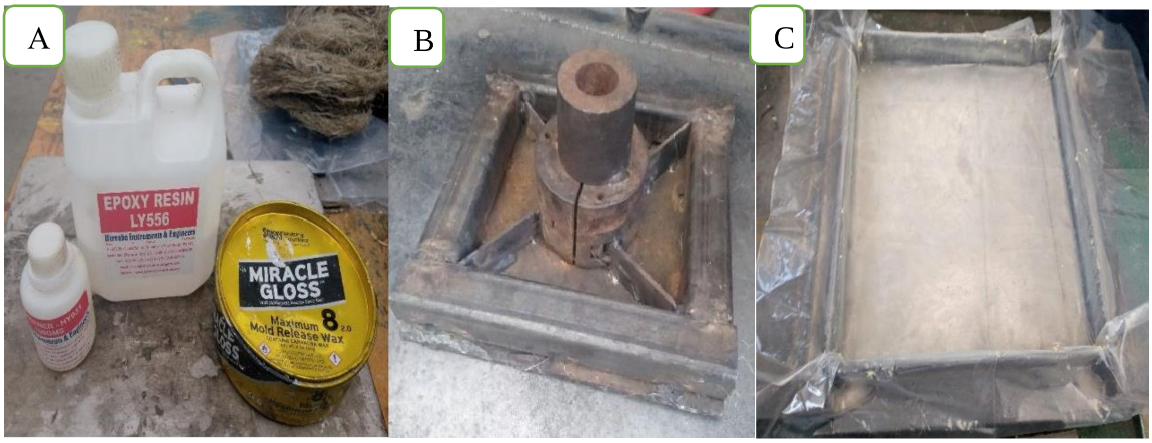


Figure 3.2. Materials used for composite fabrication.

A) Epoxy- LY 556, Hardner -HY951 and Wax, B) Upper plate mold C) Base plate mold

3.2.2. Banana fiber collection and extraction

The banana plant is vastly found in Ethiopia; however, the plantations are used mainly for fruit production purposes. After the plant is harvested, the stems are considered as a waste materials and did not used for other purposes.

For the present work, the banana fiber was collected from the South Ethiopia region, Gurage zone, and Gore woreda.

The fiber was extracted through manual extraction method because,

- ✓ The fiber was not required for the high amount of material production.
- ✓ It was not difficult to separate the fiber from the trunk because it was long and strong enough.
- ✓ There was no advanced or mechanical extraction machine that nearly available.

The banana fiber extraction was carried out through the following process.

- The banana plant was a three years old; it was long, had a circular cross-sectional area, and narrower from the bottom to the top, which differs from a false banana (Enset).
- The banana trunk was covered with a white sheath, it was cut off from the bottom part of the plant using equipment called 'Senda and Tebeche'.
- The trunk has more than four circular layers which aligned together up to the core center, the layers were separated using a blunted knife and prepared for fiber extraction.
- The separated trunk was aligned on the wood plate (sebisa). The white sheath was chopped frequently from the top to the bottom by using wotar (it is made from bamboo and has a little sharpness) and blunted knife. The fiber was extracted through this repeated action.
- After extraction, the fibers were aligned together longitudinally and tied at the top of the fiber to avoid fiber entanglement and degradation.

Figure 3.3. Banana Fiber Extraction process

A) Banana fiber plant harvesting, B) Banana plant trunk and C) Fiber extraction, and D) Extracted fibers

3.2.3. Flax fiber collection and extraction

The flax plant is available at high land and low land of the Ethiopia region. It is cultivated for oilseed production purposes. After the oilseed crops were collected, the plant stems are dropped. Flax plants can be harvested in various stages depending on the climate condition and the required fibers quality, such as green ripe (early stage), yellow ripe (later stages of development), and fully ripe (fully matured) stages. The yellow ripe harvesting stage has better fiber quality (finer and strong) than the green and fully ripe harvesting stages [84, 85]. The flax fiber was took from Oromia Region, Holeta Agricultural Research Center, including fiber extraction process. There are different types of natural fibers extraction methods.

Such as chemical retting, water retting, using microorganisms, and mechanical extraction methods [35].The fiber was extracted through the water retting method because it does not have any chemical degradation effect, it is not expensive and simpler than other extraction methods such as chemical retting, enzyme retting, and mechanical extraction [35].

- ❖ The flax plant was three months aged, and it was at yellow ripe or latter stages of development.
- ❖ The flax straw was harvested using a semicircular blade and immersed in the water for three days using a water tank, but the water was changed per day to reduce over retting.
- ❖ After the water retting process, the fiber was exposed to the sun, and flax fiber was extracted from the stem through brushing and beating with a wood stick, then the fibers were aligned together and tied.

Figure 3.4.Flax fiber extraction process

A) Flax fiber plant and ,B) Harvested fiber stem C) Flax fiber extraction, and D) Extracted flax fiber

3.3. Fibers property test

The fiber properties have significant effect on the composite material properties. It depends on fiber growth environmental condition, soil type, harvesting method, and extraction techniques. Therefore fibers property was examined such as lumen diameter, length, width, cell wall thickness, density, force to break, elongation, and tenacity.

3.3.1. Fibers elongation and tenacity

The fibers test was conducted based on ASTM D2256 test standard at Ethiopian Textile Industry Development Institute (ETDI). The Textechno STATIMAT ME+ automatic tensile tester machine, with USTER5000 brand was used. The automatic tensile tester machine was used at a maximum force of 100N, gauge length of 500mm, and 5mm/min loading speed. The flax and banana fibers elongation, force to break, and tenacity tests were conducted from fifteen individual fibers (based on the ASTM standard), and the mean value was taken as a final result.

Figure 3.5.Flax & Banana fibers prepared for test

A) Banana fiber sample, B) Flax fiber sample, and C) The Textechno STATIMAT ME+ automatic tensile tester machine.

3.3.2. Length and width of the fibers

The banana and flax fibers' cell morphology and anatomical appearance were examined under the optical microscope. The test include fiber length, fiber width, cell wall diameter, and lumen thickness. The test was conducted at Ethiopian Environmental and Forest Research Institute. The fibers used for the tests were extracted from the fibers plant stems using the solvent extraction method. There are different types of extraction methods such as solvent extraction method, sublimation, distillation, and pressing methods. The solvent method is one of the most applicable methods for material extraction.

3.3.3. Sample Preparation for fiber width and length measurement

The fibers were extracted through a chemical retting process (solvent extraction method) for clear and better fiber surface examination for morphological analysis. Mostly known solvent extraction methods are maceration, percolation, and reflux extraction. In the maceration extraction process water, aqueous, and no–aqueous solutions are used as a solvent. It can be done at room temperature and atmospheric pressure; however, it takes a long time during the extraction process [89].For fiber extraction and investigation of the length and width of the fibers, the following procedures were applied. The sample preparation procedure followed based on the ASTM standard.

- ❖ Matchstick size of stems and 50% nitric acid were prepared for maceration processes.
- ❖ The stem samples were immersed in a beaker which has a nitric acid solution and kept at 70°C for 5 to 6 hrs.
- ❖ The solvent was diffused and penetrated the plant stem; the stem outer layers (sheath) were broken and dissolved, the extracted fibers were suspended on the top of the solution.
- ❖ The fiber immersed nitric acid solution was cooled at room temperature, and it was removed.
- ❖ The extracted fibers were washed with distilled water and filtered with Whatman Grade 1 filter paper.

- The fibers dimensions and surface structure test was conducted from 30 individual fibers and measured under Motic BA210 microscope with under 4x magnification scale.

3.3.4. Cell wall diameter and lumen thickness of the banana fiber

Sample preparation for fiber lumen diameter and cell wall thickness test, based on the ASTM standard.

- For cell measurement, slices were cut using a Leica sliding microtome with a thickness of 20μm.
- The slices were immersed into safranin solution (1gram/100ml water) and 25%, 50%, 75% of alcohol concentrations for 1 minute to remove excess safranin solution that may cause invisibility of cells. Besides, slices were immersed into xylene for 1 minute and put on the slide (standard 7.5cm×2.5cm).
- The small amount of Canada balsam was dropped and covered using a slide cover and kept to dry. The sample was examined under Motic BA210 microscope, 30-lumen diameters and cell wall thickness were measured by using the Motic software 2, and then an image was taken.

The current study lumen diameter and cell wall thickness of the banana fibers were taken from 30 areas with various dimensions. It includes from small to large, which examined under Motic BA210 microscope and the result was conducted and test result shown on the table (3.1.).

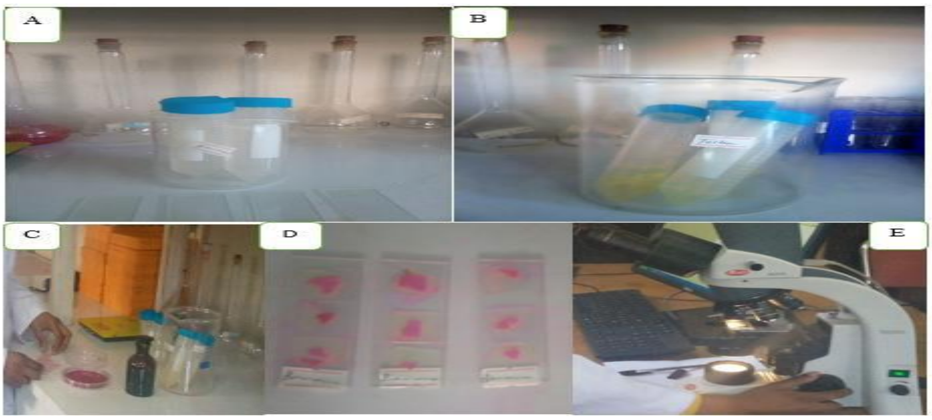


Figure 3.6.Flax & Banana fibers maceration and examination

A) &B) Flax and Banana fibers stems immersed in Nitric acid solution, C) &D) Banana slice preparation, and E) Sample examined under an optical microscope.

The fibers length, width, lumen diameter, and cell wall thickness were examined and the pictures are shown below.

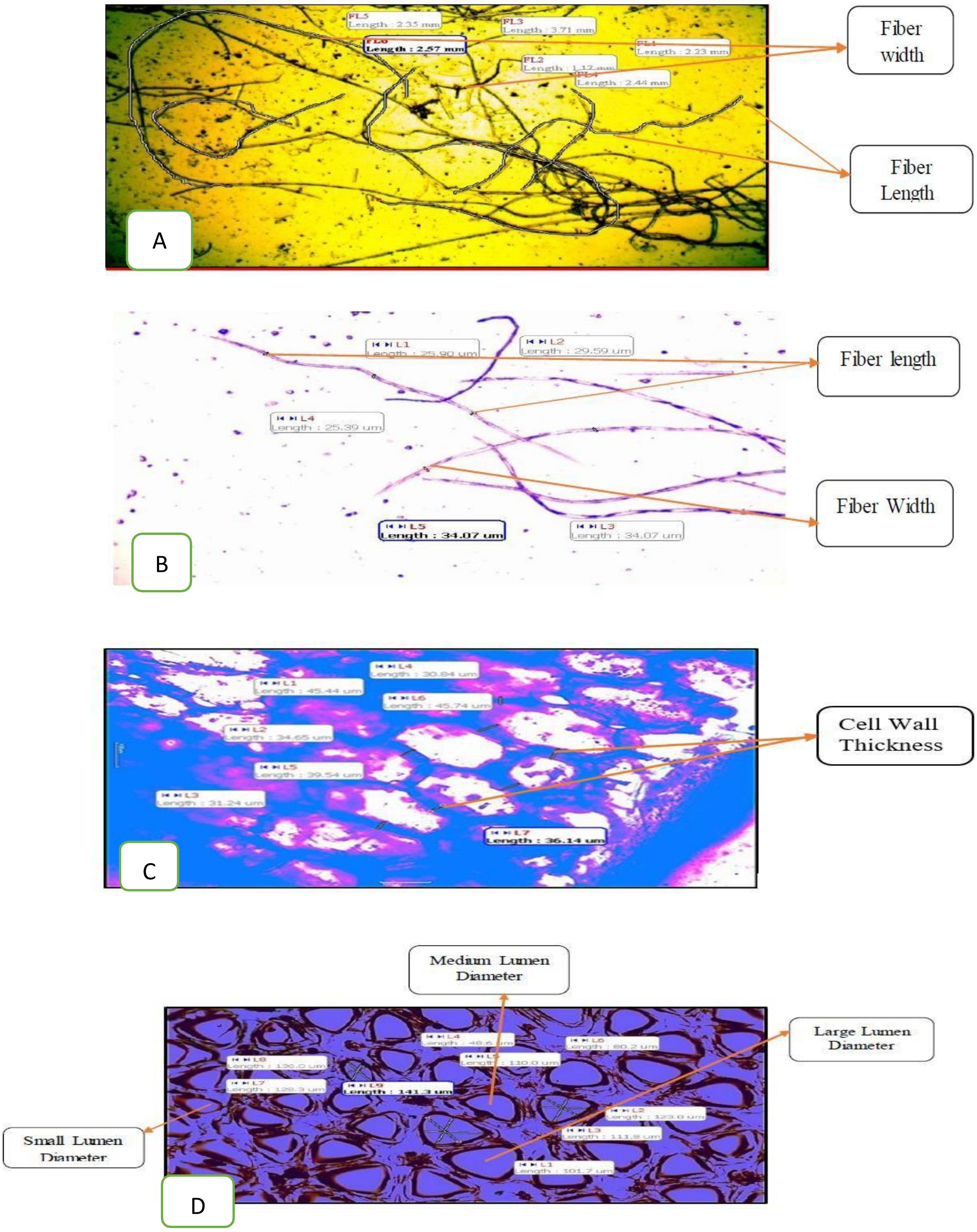


Figure 3.7. Flax &Banana fibers length, width, lumen diameter & cell wall thickness.

A&B) Fibers width and length, C) & D) Banana fiber lumen diameter and cell wall thickness

3.3.5. The density of flax and banana fibers

The flax and banana fibers density were measured based on the solid materials density finding method; during testing, different apparatus were used such as electronic balance scale, Pycnometer, and distilled water, the tests were conducted at room temperature.

i. Pycnometer calibration method

This calibration method was carried on to find out the exact volume of the pycnometer, and this apparatus has a small flask and glass stopper at the top. The following procedures are followed.

- The pycnometer was washed, cleaned, and dried.
- The weight of the Pycnometer was measured without adding water and fibers.
- The distilled water was poured into the pycnometer and measured the total weight.
- The mass of water was calculated by reducing the weight of the pycnometer from the total weight.
- The volume of water was also calculated using mass and density, (take an assumption, the density of water at room temperature can be 0.997g/ml).
- The exact volume of the pycnometer was equaled to the volume of water it holds and it was compared with the volume which wrote on the pycnometer.

W_{pyc} = 16.7g

$W_{pyc} + W_{H2O}$ = 44.5g

$W_{H2O} = (W_{pyc} + W_{H2O}) - Wpyc$ .... Eq (3.1.)

W_{H2O} = 44.5g -16.7g= 27.8g

$$\rho = \frac{m}{V} \quad \text{.......... Eq (3.2.)}$$

$$V_{Pyc} = V_{H2O} \quad \text{.......... Eq (3.3.)}$$

$$V_{H_2O} = \frac{m_{H_2O}}{\rho_{H_2O}} \quad \text{.......... Eq (3.4.)}$$

$V_{pyc} = \frac{27.8g}{0.997g/ml}$ = 27.88ml, it was the exact volume of the pycnometer.

ii. Banana fiber density measurement

The density of banana and flax fibers was measured using the mass and volume calculation method, the measurement steps written below.

- The pycnometer weight was measured.
- The fiber was added to the pycnometer and the total weight was determined.
- Poured the water into the pycnometer which holds the fiber and measured the weight.
- The volume of water and fibers was calculated using a water density of 0.997g/ml at room temperature.

Wpyc = 16.7g

$W_{pyc} + W_{ban} = 17.3g$

$W_{pyc} + W_{ban} + W_{H2O} = 44.44g$

$W_{ban} = (W_{pyc} + W_{ban}) - Wpyc$ .... Eq (3.5)

$W_{ban} = 17.3g - 16.7g = 1.65g$

$W_{H2O} = (W_{pyc} + W_{ban} + W_{H2O}) - (W_{pyc} + W_{ban})$ .... Eq (3.6)

$W_{H2O} = 44.44\ g - 17.3g = 27.14g$

$$V_{H_2O} = \frac{W_{H_2O}}{\rho_{H_2O}}$$ .... Eq (3.7)

$V_{H2O} = \frac{27.14g}{0.997g/ml}$ = 27.41ml , V_{Pyc} = 27.88ml.

V_{Bana}= 27.88ml–27.41ml =0.47ml

$V_{Bana} = V_{Pyc} - V_{H2O}$ .... Eq (3.8)

$\rho_{Ban} = \frac{W_{Ban}}{V_{Ban}}$ .... Eq (3.9)

$\rho_{Ban} = \frac{0.6}{0.47ml} = \underline{1.27g/ml}$

iii. Flax fiber density measurement

$W_{pyc} = \underline{16.7g}$

Measured value of pycnometer with flax fiber,

$W_{pyc} + W_{flax} = \underline{17.4}$

$W_{flax} = (W_{pyc} + W_{flax}) - W_{pyc}$ .... Eq (3.10)

$W_{flax} = 17.4g - 16.7g$

$= \underline{0.7g}$

Measured weight value of flax, water and pycnometer together

$W_{pyc} + W_{flax} + W_{H2O} = \underline{44.49g}$

$W_{H2O} = (W_{pyc} + W_{flax} + W_{H2O}) - (W_{pyc} + W_{flax})$… .... Eq (3.11)

$W_{H2O} = 44.49g - 17.4g$

$W_{H2O} = \underline{27.09g}$

$$V_{H2O} = \frac{27.09g}{0.99802g/ml}$$

$V_{H2O} = \underline{27.37ml}$

$V_{Flax} = V_{Pyc} - V_{H2O}$ .... Eq (3.12)

$V_{Flax} = 27.88g - 27.37 = \underline{0.51ml}$

$\rho_{Flax} = \frac{W_{Flax}}{V_{Flax}}$ …………………………………………………………………….Eq (3.13)

$$\rho_{Flax}=\frac{0.7g}{0.51ml}$$

ρ_{Flax}=1.386 g/ml

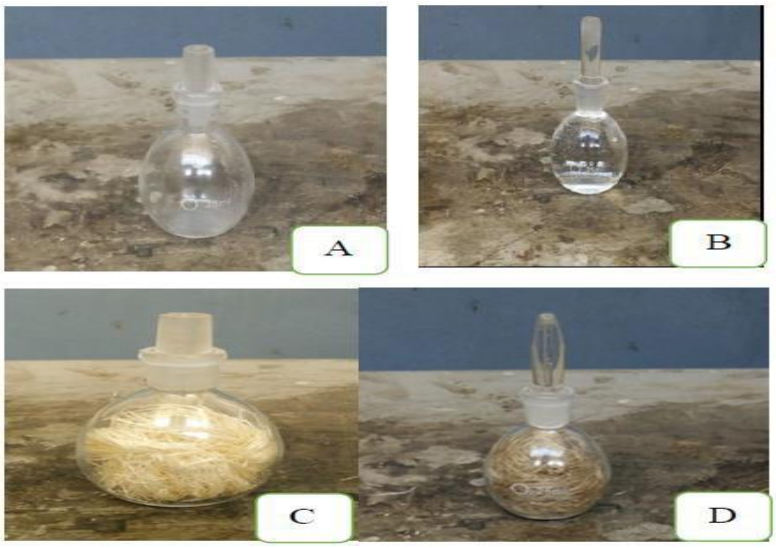


Figure 3.8. Flax and banana fibers density measurement using a pycnometer

A) Empty pycnometer ,B) Water-filled pycnometer ,C) Weight of pycnometer with bananafiber and D) weight of pycnometer with flax fiber

Table (3.1) shown the single fiber morphological and physical properties.

Table 3.1. Fibers properties test result

Fiber	Density (g/ml)	Length (mm)	Width (µm)	Force to break(N)	Elongation (%)	Tenacity (Cn/tex)	Lumen diameter (µm)	Cell wall thickness (µm)
Flax	1.37	3.11	27.35	7.29	0.7	4.94	-	-
Banana	1.27	3.34	29.55	2.96	1.13	15.55	137.01	19.97

3.4. Composite sample fabrication

3.4.1. Fiber surface treatment

Natural fiber surface modification is essential for natural fiber-reinforced composites to reduce the hydrophilic property of fibers, to increase the wettability of fibers with polymer matrix by increasing the interfacial linkage between the constituents. There are different types of fiber modification mechanisms available such as Silane, Acetylation, and Mercerization, Etherification, and Enzymatic treatment. For the current work mercerization (alkaline) type of treatment was selected for better wettability, low fiber surface degradation, no requirements of additional ingredients for PH level neutralization[90].

The fiber surface treatment was needed because,

- ❖ It removes amorphous (water-soluble) contents reduce the hydrophilic properties of natural fibers.
- ❖ Increase the roughness surface of the fibers and wettability of reinforced fibers.
- ❖ It increases the interfacial bonding between the matrix and the fibers
- ❖ To reduce the fiber's moisture and water absorption property.

i. Alkaline (NaOH) solution preparation and fiber soaking procedure

The flax and banana fibers surface treatment were carried with NaOH concentrations of 5% and 3% respectively, on the other hand, the soaking time was also 2hr and 24hr. The fibers surface treatment procedure variation occurred due to the fiber's chemical compositions (cellulose, hemicellulose, lignin, and pectin) and previous researches. The alkaline solution preparation and surface treatment were carried out at room temperature, because it is was simple, not time consuming, and to fibers reduce fibers degradation.

Types of equipment used for fiber surface treatment were beakers, electronic scale balance, stirrer, scissor, plastic pan, and drier. The treatment procedures are written below,

- ➢ The fibers were washed with water to remove dust and other impurities from superficial parts of the fibers (for a better hydrolysis process).
- ➢ The amount of water (solvent) was added to a beaker and measured on the electronic scale balance and poured into the plastic pot.
- ➢ The required amount of NaOH was measured on an electronic scale balance (5% and 3% for banana and flax fibers) and added to the water.
- ➢ The water and NaOH were stirred with a stirrer until a homogeneous solution was formed.

- The fibers were immersed into the solution for the required time (24hr for banana fiber and 2hr for flax fiber).
- After the immersion, the fibers were taken out and washed with water to neutralize the PH from the fiber surface.
- The fibers were inserted into the drier at 40C° for 24hr after the fibers were fully dried it was taken out and chopped through scissor with the length of 20mm.

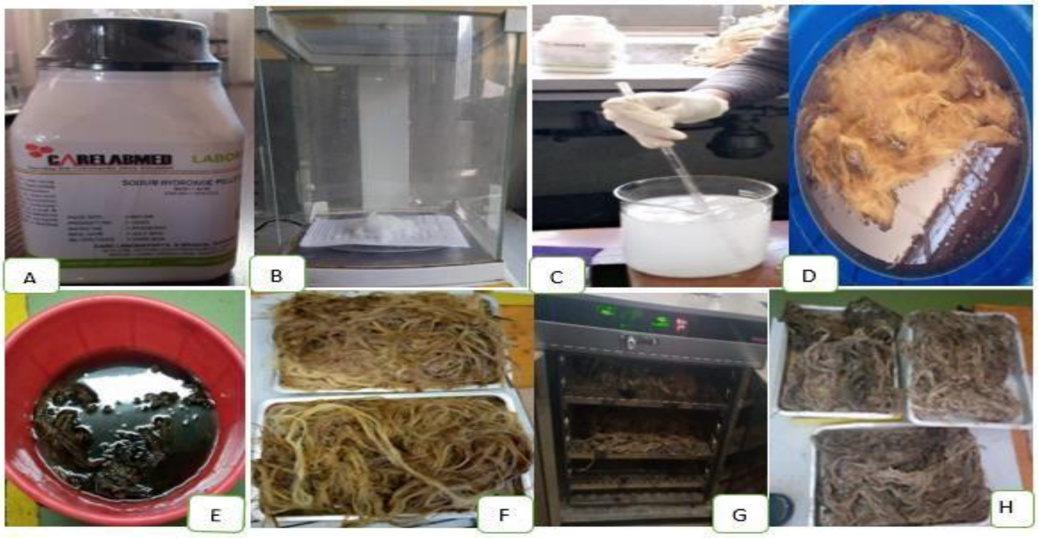


Figure 3.9.Fibers surface treatment with NaOH solution

A) &B) NaOH pellets, C) Alkaline solution preparation, D) &E) Flax and Banana fibers soaking, F) Fibers after treatment, G) Fibers drying in a dryer and H) Dried fibers

3.4.2. Mould preparation

The composite mold was made from metal, the dimension of the mold was decided considering the number and size of test specimens, which was prepared based on ASTM standards including each mechanical and water absorption test. The size of the base plate of the mold was 300mmx300mmx20mm, and the upper plate mold was 295mmx295mmx4mm; the upper and the base plates of the mold were weighted 5Kg and 11.5 Kg respectively.

3.4.3. Volume fraction of fibers and matrix

For the fabrication of the composite plates, fiber to resin volume fractions of compositions were prepared with 60/40%, 70 /30%, and 80%/20%. The compositions were selected for both treated and untreated composites. Most of the researchers were reported that good mechanical properties of composite specimens were achieved on this volume fractions range. The fiber to resin ratios were prepared using the rule of mixture analytical method [4].The composite materials density, fiber volume, fiber weight, matrix volume, and matrix weight were calculated as shown.

i. Fibers and matrix volume preparation

The volume of the composite was calculated based on the prepared mold dimensions (lx w x t), the volume fraction used for an example is the first composition of 70/15/15 %(C1), composite material.

$$V'_f + V'_m = 1 \quad \text{Eq (3.14)}$$

$$V'_f = \frac{vf}{vc} \quad \text{Eq (3.15)}$$

$$V'_m = \frac{vm}{vc} \quad \text{Eq (3. 16)}$$

Example:-

vc = 300mm x300mm x20mm

vc = 270cm^3

The volume of the matrix (v_m) = volume of composite (v_c) * volume fraction of matrix (V'_m)

The volume of the fiber (v_f) = volume of composite (v_c) * volume fraction of matrix (V'_f)

The volume of flax fiber$(v_{fl1}) = v_c * V'_{fl}$ ....Eq (3.17)

$v_{fl\,1}$= 270 g/cm^3 *0.15 = 40.5 g/cm^3

Volume of banana fiber $(v_b) = vc * V'_b$ ....Eq (3.18)

$vb1$= 270 g/cm^3 * 0.15 = 40.5g/cm^3

$$v_m = v_c * V'_m$$

$vm1$ = 270 g/cm^3 * 0.7 = 189g/cm^3

ii. Density of composite

The density of composite materials for all compositions was calculated from volume fraction equations.

The density of composite ($\rho_f v_c$) = density of fiber (ρ_f) * volume of fiber (v_f) + density of matrix (ρ_m) * volume of matrix (v_m)

$$\rho_c v_c = \rho_f v_f + \rho_m v_m \quad \text{Eq (3.19)}$$

$$\rho_c = (v_f/v_c) + (v_m/v_c) \quad \text{Eq (3.20)}$$

$$\rho_c = \rho_f v'_f + \rho_m v'_m \quad \text{Eq (3.21)}$$

$$= \quad V'_m\, \rho_m + V'_{fl}\rho_{fl} + \rho_{ba} V_{ba} \quad \text{Eq (3.22)}$$

Example of calculated density result for composite one (C1)

$\rho fl = 1.386/cm3$, $\rho b = 1.27g/cm3$, and $\rho m = 1.15g/cm3$

$\rho c1$ =1.386g/cm^3*0.15 + 1.27g/cm^3* 0.15 + 1.15g/cm^3* 0.7 =<u>1.2034 g/cm^3</u>

iii. Weight of composite, fiber, and matrix

The weight of the composite, fiber, and matrix was calculated based on the general formula of density, mass per volume Wc, W_f, and W_m are the weight of the composite, matrix, and composite.

$$Wc = \rho c * vc \quad \text{Eq (3.23)}$$

$$W_f = \rho f * vf \quad \text{Eq (3.24)}$$

$$W_m = \rho m * vm \quad \text{Eq (3.25)}$$

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

Example:-

$W_{fl1} = \rho_{f1} * v_{fl}$ .... From Eq (3.24)

= 1.386g/m^3 *40.5g/cm^3 = <u>56.133g</u>

$W_{Bl} = \rho_{B1} * v_{B1}$ .... From Eq (3.24)

= 1.27g/cm^3 *40.5g/cm^3 = <u>51.43g</u>

$W_{m1} = \rho m * vm1$ .... From Eq (3.25)

= 1.15g/cm^3 * 189g/cm^3 = <u>217.35g</u>

$Wc1 = \rho c1 * vc$ .... From Eq (3.23)

Wc_1 =1.2034g/cm^3 * 270cm^3 = <u>324.91 de</u>nsity of composite and Volume of composite, fibers, and matrix. Density, Volume Fraction, and Volume of composite, Epoxy matrix, and fibers.

Table 3.3. Weight of epoxy matrix, flax fiber, banana fiber, and composite

No.Co mposite	Treated/ Untreated	Volume Fraction of Epoxy/Flax/ Banana	Density of Composite (Cm3)	Weight of Compos ite (g)	Weight of Epoxy(g)	Weight of Flax Fiber(g)	Weight of Banana Fiber(g)
C1	Treated	70/15/15	1.203	324.91	217.35	56.13	51.43
C2		70/20/10	1.209	326.48	217.35	74.84	34.29
C3		70/10/20	1.197	323.35	217.35	37.47	68.58
C4		60/20/20	1.221	329.72	186.3	74.84	34.29
C5		60/30/10	1.232	332.85	186.3	112.26	34.29
C6		60/10/30	1.209	326.59	186.3	37.42	102.87
C7		80/10/10	1.185	320.11	248.4	37.42	34.29
C8		80/15/5	1.191	321.67	248.4	56.13	17.14
C9		80/5/15	1.179	318.54	248.4	18.71	51.43
C10	Untreated	UN-70/15/15	1.203	324.91	217.35	56.13	51.43
C11		UN-60/20/20	1.221	329.724	186.3	74.84	68.58

Table 3.4. Volume fractions of flax fiber, banana fiber, and epoxy matrix

No.Composite	Treated/ Untreated	Volume Fraction of Epoxy/Flax/Banana	Density of Composite (Cm3)	Volume of Epoxy (g/cm3)	Volume of Flax Fiber (g/cm3)	Volume of Banana Fiber (g/cm3)
C1	Treated	70/15/15	1.203	189	40.5	40.5
C2		70/20/10	1.209	189	54	27
C3		70/10/20	1.197	189	27	54
C4		60/20/20	1.221	162	54	54
C5		60/30/10	1.232	162	81	27
C6		60/10/30	1.209	162	27	81
C7		80/10/10	1.185	216	27	27
C8		80/15/5	1.191	216	40.5	13.5
C9		80/5/15	1.179	216	13.5	40.5
C10	Untreated	UN-70/15/15	1.203	189	40.5	40.5
C11		UN-60/20/20	1.221	162	54	54

3.4.4. Composite specimens fabrication procedure

Composite plates were fabricated based on the enquired ratio of fiber to matrix and fiber to fiber volume fraction. The composite materials compositions were 60/40%, 70/30%, and 80/20 in both treated and untreated categories. The fiber to fiber volume fractions was prepared with 1:1, 3:1and 1:3 consistently. These volume fraction ratios were selected to examine the effect of matrix and fiber loading, fiber hybridization effect, fiber surface modification effect on the mechanical and water absorption properties of HFBFREC. Composite specimens were fabricated using a hand layup method because it was easy to fabricate. The fibers were aligned in random orientation to resist a three dimensional loads. A compression molding method was used to compact, to increase fiber to matrix adhesion and to remove excess resin. Materials and equipment used in the composite specimen's preparation process were listed in the table (3.4.).

i. Epoxy matrix and hardener preparation

Based on the selected compositions ratio epoxy resin and hardener were measured on the electronic weight scale. The ratio of the polymer matrix to hardner was 10:1, it depended on the materials specification data from the manual. Before the fiber and resin matrix were mixed, epoxy resin and hardener were poured into the beaker and stirred together for 2 minutes for better homogeneity.

ii. Mold cleaning and preparation

Before the resin and hardener were mixed, the mold should be prepared by cleaning and polishing with a releasing agent (wax) for the sake of quickly releasing composite plates after solidification.

Table 3.5. List of materials and equipment's

Epoxy LY-556	The matrix material was used to impregnate and wet the fibers, also it was used to cover and protect the reinforcing materials (fibers).
Hardner HY-951	It is a curing agent, and it was used for composite materials solidification purposes.
Wax	It was used as releasing agent, which was polish on the mold surface and for easy removal of composite materials.
Flax and Banana fibers	Fibers were used as reinforcement with 20mm length.
NaOH	It is an alkaline chemical, which was used for fiber surface modification.
Electronic weight scale	It was used to measure materials' weight during the composite fabrication process.
Scissor	It was used to cut the fibers and change long fibers into chopped form.
Beaker	It was used for preparing the mixture of alkaline solution, epoxy resin, and hardener mixture.
Stirrer	It was used to mix the resin and hardener.
Mould	It was used for holding and molding the materials with specific shapes and sizes of mixed reinforcement and epoxy matrix.
Hydraulic Machine	It was used for the compression molding process and better material compactness.
Drier	It was used to dry and remove the moisture content from the fibers at the required temperature.

iii. Composite specimen's fabrication procedure

The main composite plate fabrication process are listed below.

The weight of flax fiber, banana fiber, epoxy resin and hardner were measured using electronic balance scale.

The flax and banana fibers were mixed until the mixture was uniform.

The releasing agent (wax) was added and the mold polished evenly.

Epoxy resin and Hardner (catalyst) were poured in to beaker and stir red for 1-2minutes.

Small amount of mixed resin added on the mold surface and spread polished uniformly using roller and brush.

Impregnation & Lay-Up

- The mixed chopped fibers were added on the mold and distributed uniformly, mixed resin was poured on the surface of the fibers until it properly wetted using roller and brush, this procedure was applied frequently until the fiber surface was properly wetted and the mold was closed.

Consolidation at room temperature

- The molded material was taken in to the press machine and inserted between the upper and lower dies and compression load was applied for 5hr.

Solidification &Demolding

- After consolidation the material was released and cured for 24 hr, and test specimens were prepared using band saw machine.

Figure 3.10. Composite specimen's fabrication procedure

Through different try and error process the composite plates were fabricated. Since composite materials specimens were made through hand lay-up techniques and shown various surface defects, such as thickness variations, surface openings, fiber pullout, voids, and cracks. However, considering the factors that can affect the property of the composite material, the fabrication process was conducted until the required thickness, uniform fibers distribution and full resin coverage of fibers were achieved.

Figure 3.11. The hybrid composite fabrication process

A) Mould Preparation, B) Fibers before& after hybridization, C) Impregnation & Lay-up and D) Consolidation E) Fabricated hybrid composite

3.4.5. The test specimen's preparation

The test specimen was cut off from the composite plates using a band saw machine. It was prepared according to test standards, such as for tensile strength test ASTM-D3039 (250mmx25mmx3mm), for Flexural strength test ASTM-D790 (125mmx12.7mmx3.2mm), for Impact strength test ASTM-D6110 (127mmx12.7mmx3mm) and Water absorption test ASTM-D570-99(64mmx13mmx3mm) standards were used.

- **Band Saw Machine**

The Band Saw machine was used for cutting composite material plates; the machine was with cutting speed of 500-1000m/min, the blade length was 2560mm, and the maximum work piece height was 230mm.

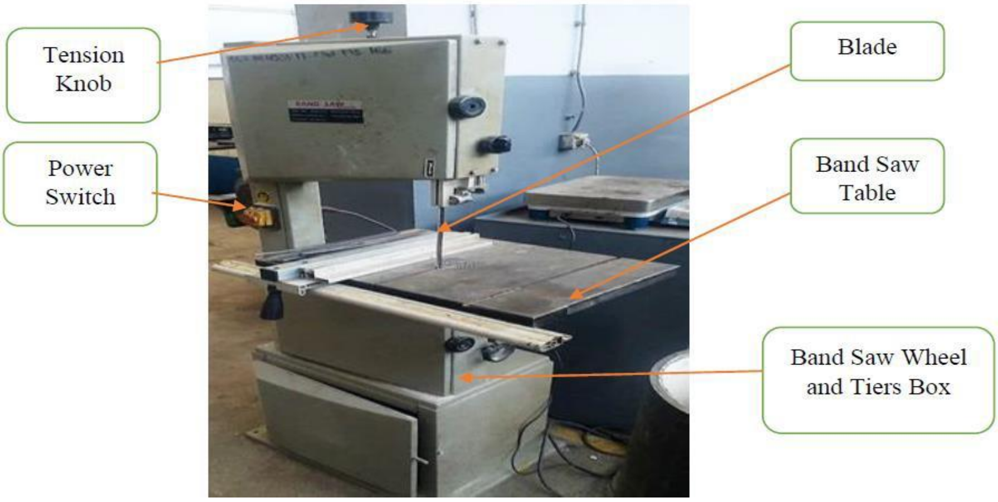


Figure 3.12. The band saw cutting machine

The tensile, flexural, impact, and water absorption test specimens were prepared from each sub composition of 60/40%, 70/30%, and 80/20% composite plates by using the band saw machine. All of the specimens were prepared based on the required ASTM standard methods. It shows on figure: 3.13.

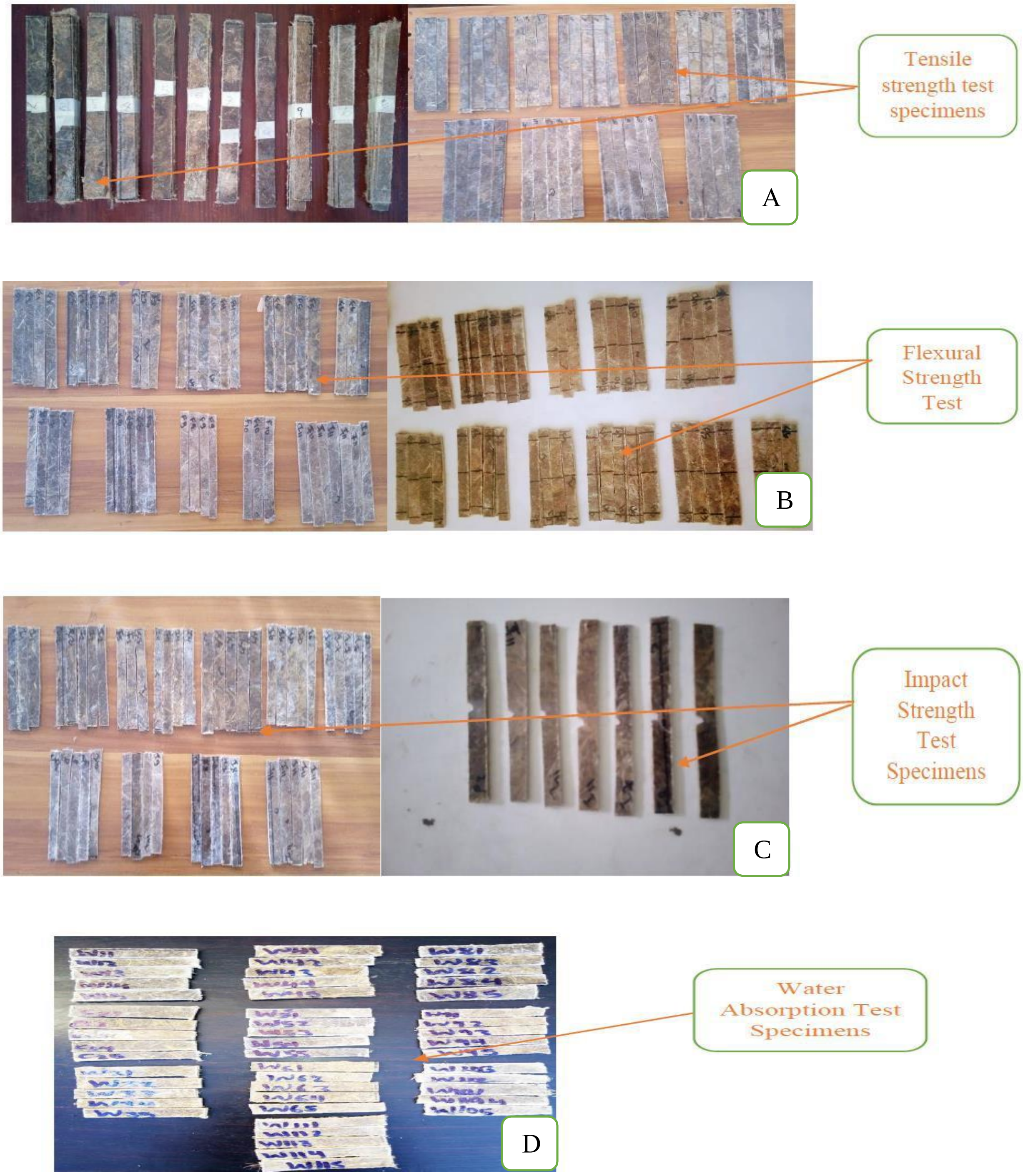


Figure 3.13. Tensile, Flexural, Impact, and water absorption test specimens

A) Test specimens for Tensile strength test, B) Test specimens for Flexural strength test

C) Test specimens for Impact strength test and D) Test specimens for Water absorption test

3.5. Composite specimens property test

On this hybrid flax-banana fiber reinforced epoxy composite characterization, three mechanical property tests were examined. It includes Tensile strength, Flexural (three-point bending), and Impact strength. In addition, the water absorption property test also conducted.

3.5.1 Machines used for mechanical tests

I. Charpy Impact Test Machine

The Charpy Impact test machine used for specimen tests was "Brooks Inspection Equipment, COLCHESTER-ENGLAND", it can be suitable for non-ferrous and low carbon steels as well as plastics. It can be used for materials that can absorb up to 50J impact energy, its division was read as one division equals 0.5J, and the hammer weight used for this impact test method was 18.5Kg.

Figure 3.14.Charpy impact testing machine used for specimens impact strength test

The Charpy impact test machine pendulum was at raised position (at rest) and it has definite potential energy. When it started to swing it changed into kinetic energy. The difference between the height of drop before rupture and the height of rising after fracture indicates the impact energy absorbed by the specimen. The impact energy absorbed by the specimen indicated by the reader. The pendulum achieves maximum kinetic energy at its lowest swing position before it hits the test specimen.

II. Universal Testing Machine (UTM)

A universal testing machine is suitable to test more than four mechanical tests such as tensile, compression, flexural, and shear strength of materials. The UTM machine used for this test has a 6mm/min loading rate and 50KN load cell capacity.

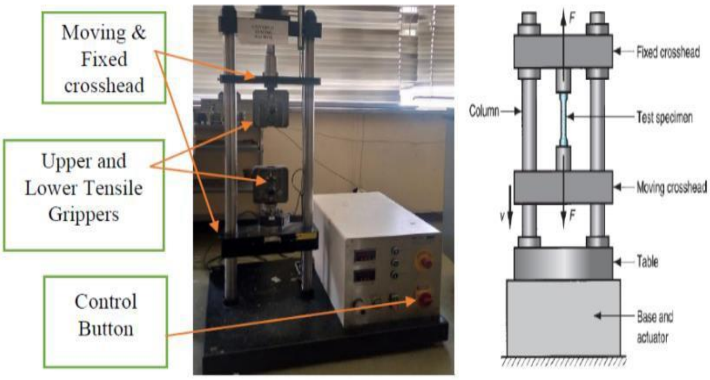


Figure 3.15.Universal testing machine used for tensile and flexural strength test

3.5.2 Tensile strength test

The tensile strength test was aimed to investigate the HFBFEC performance to resist ultimate tensile load, yield force, ultimate tensile stress, ultimate tensile strain, elongation at break, and tensile modulus (toughness).

The tensile test was carried out based on ASTM-D3039. The test method was determined the in-plane tensile properties of polymer matrix reinforced composites. The composite material forms were limited to continuous fiber or discontinuous fiber [51].The composite that has random-discontinuous fiber orientation specimens were examined using universal testing machine (UTM) at a crosshead speed of 6mm/min. For the test, five specimens were taken from each composition. The shape of the specimen was a constant rectangular cross-section with the dimension of 250mmx25mmx2.5mm, with a tolerance of 4% and 1% for the sample'swidth and thickness. The tensile test specimen was located between the fixed and movable jaws; the sample was tapped at the top and bottom of the grippers to avoid specimen slippage and applied force fluctuation of the uniaxial tensile loading. The controlling unit was attachedto the UTM machine and ready to record the required data. The tensile load was applied in a longitudinal direction of the specimen through the movable gripper. The machine was used atthe crosshead speed of 6mm/min, and the result data was recorded.

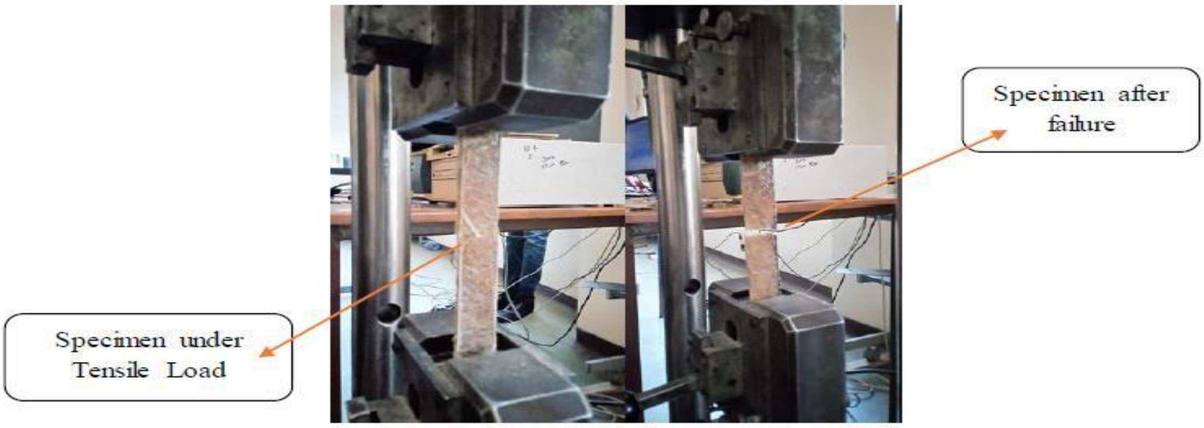


Figure 3.16. Tensile test specimens under examination

3.5.3 Flexural strength test

For the flexural strength test, three-point bending test method was used, the bending test of specimens was examined using a Universal Testing Machine (UTM). The test was conducted through the standard method of ASTM-D790 with a dimension of 125mmx 12. 7mmx3mm. for better result assurance, five specimens were examined for each composition. The rectangular cross-section specimen was placed between the center of two fixed supports and it was subjected to a loading nose on the midpoint. The load was applied at a constant rate, and the specimen started to deflect at the center of the span. The deflection was recorded until the specimen was fractured, this mechanism was applied until the maximum stress, load, and deflection data were recorded.

Figure 3.17. The composite specimen under flexural test examination.

3.5.4 Impact strength test

The Impact strength of natural fiber reinforced composites are different based on a single fiber property such as density, length, fiber extraction method, fibers orientation, alignment, fiber surface modification, and volume fraction of hybridization. The specimen impact energy absorption capacity also dependent on the specimen's preparation method (notched impact (NI) or un-notched impact (UI), and the manufacturing method. For the current study, a notched specimens were prepared, and tested on the Charpy test machine. The test was examined using the ASTM- D6110 standard test method with 127mmx 12.7mmx3mm respectively. In addition five individual specimens were tested from each composition, but the three related results were taken [91]. Before the impact test started with the Charpy impact test machine, it was calibrated by releasing the striking hummer without using the specimen. The reader scale indicates at zero joules, the notched impact test specimen placed on the anvils, the striking hummer released and the absorbed energy was recorded from the scale reader.

Figure 3.18.Impact strength test set up

3.6. Water absorption test

The water absorption test of composite specimen was done to examine the material's ability to resist water penetration. The specimens were tested at room temperature condition (21-23C^{0}).The specimen's test ***s***teps are written below.

- ➢ The weight of each specimen was measured using an electronic scale balance.
- ➢ All of the specimens were immersed in the water for 48 hours.
- ➢ After two days, the specimens were taken out from the water, and their weight was measured.

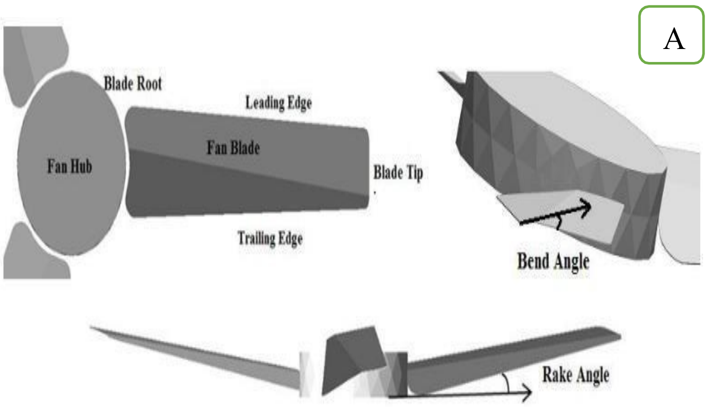
The water absorption property percentage of specimen was calculated depending on the following equation.

$$Water\ Absorp(\%) = \frac{Final\ Weight - Original\ Weight}{Original\ Weight} x100 \text{...Eq (3.30)}$$

Figure 3.19.Specimens immersion in water

3.7. Modeling and Finite Element Analysis

The 3D model and geometry of the ceiling fan blades specifications used for the current work was adopted from **Afaqet et.al.** The study modified the geometry of the ceiling fan blade, to increase the efficiency and performance of conventional ceiling fan with different rotational speed. The result indicated that the modified ceiling fan airflow and service value increased at 300rpm [92].According to that the 3-D ceiling fan blade model was prepared using Catia V5 and it exported to Ansys 19.2 software to conduct the static structural analysis.



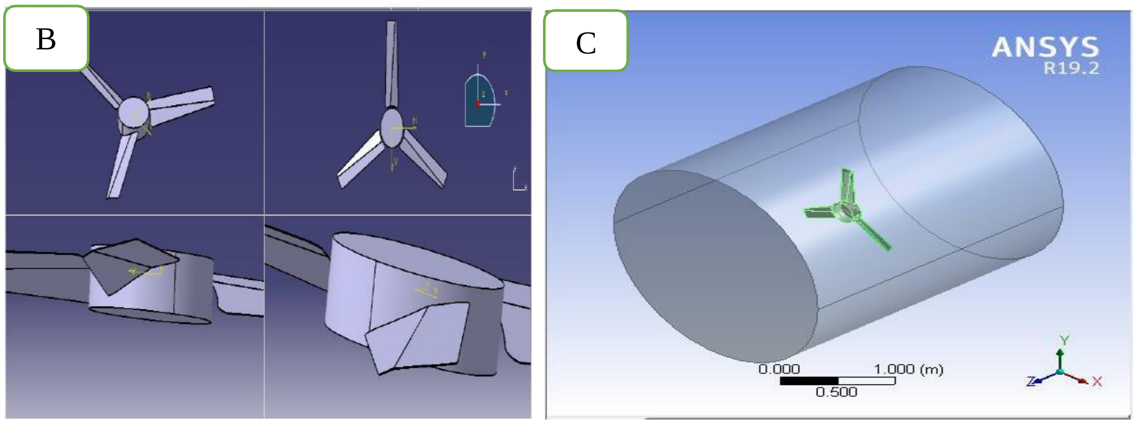


Figure 3.20.Ceiling fan blade geometry used for structural and CFD analysis

A) Ceiling fan blade model geometry of previous work [95], B) Ceiling fan blade model geometry on Catia.V5. And C) The ceiling fan blade model imported to Ansys 19.2 software.

Table 3.6. Ceiling fan blade geometry specific dimensions used [92]

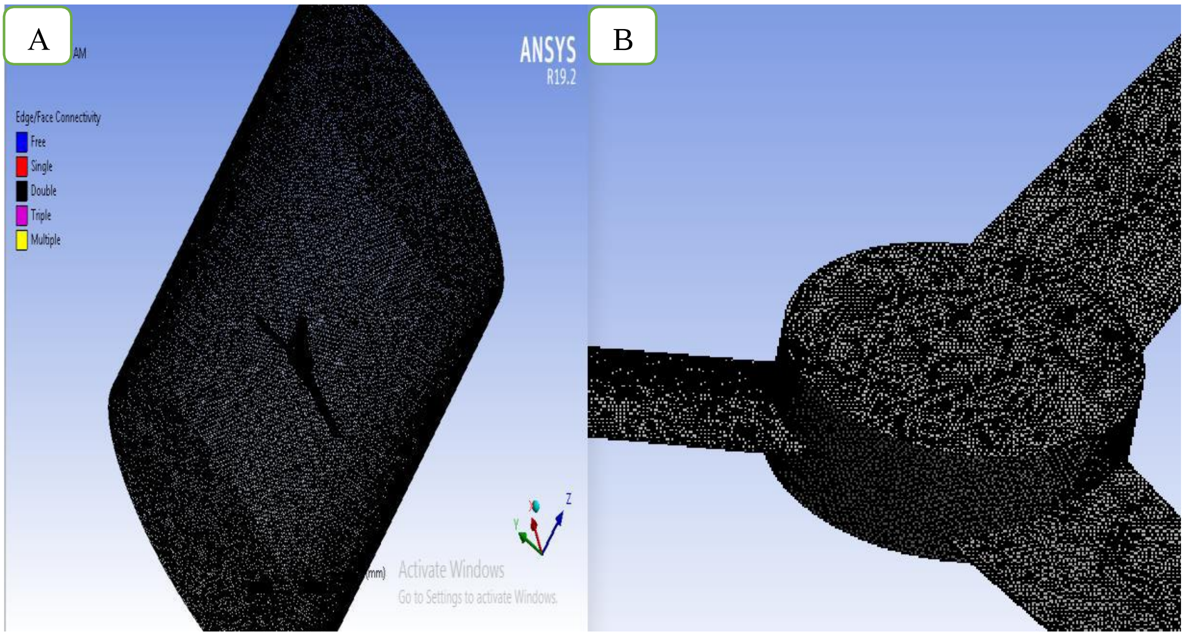
Geometric Attribute	Dimension
Fan hub diameter	0.26m
Fan Blade length	0.57m
Fan diameter	1.42m
Fan blade thickness	0.001m
Fan blade bend angle	11.8°
Fan blade rake angle	5°
Fan blade root chord	0.16m
Fan blade tip chord	0.12m

3.7.1 The fluid flow analysis of ceiling fan blade

For a fluid flow analysis, mainly two parts were developed. The first one rotating body that includes the hub and propellers. The second part contain the boundary cell zone. The rotating body was offset into the boundary wall at the center of 1.5m diameter and 3m height [93].

❖ Material, setup, cell zone, and solution initialization

The fluid flow analysis has different data filling methods and boundary conditions. This includes flow type (laminar/turbulent), steady/transient, flow direction (clockwise or counterclockwise), fluid and solid axis of rotation, mesh size, and fan rotational speed. To find out the ceiling fan static pressure on the blade surface and the air velocity. The rotational speed was 300rpm. Since the previous work reported that high airflow speed and airflow volume performance achieved at that rotational speed of 300rpm [92]. Figure: 3.20. Shows the imported model of ceiling fan blade on Ansys19.2.The model was meshed with 2mm, 3mm and 5mm mesh sizes. The specification filled on a set-up section and the static pressure and air velocity was displayed.



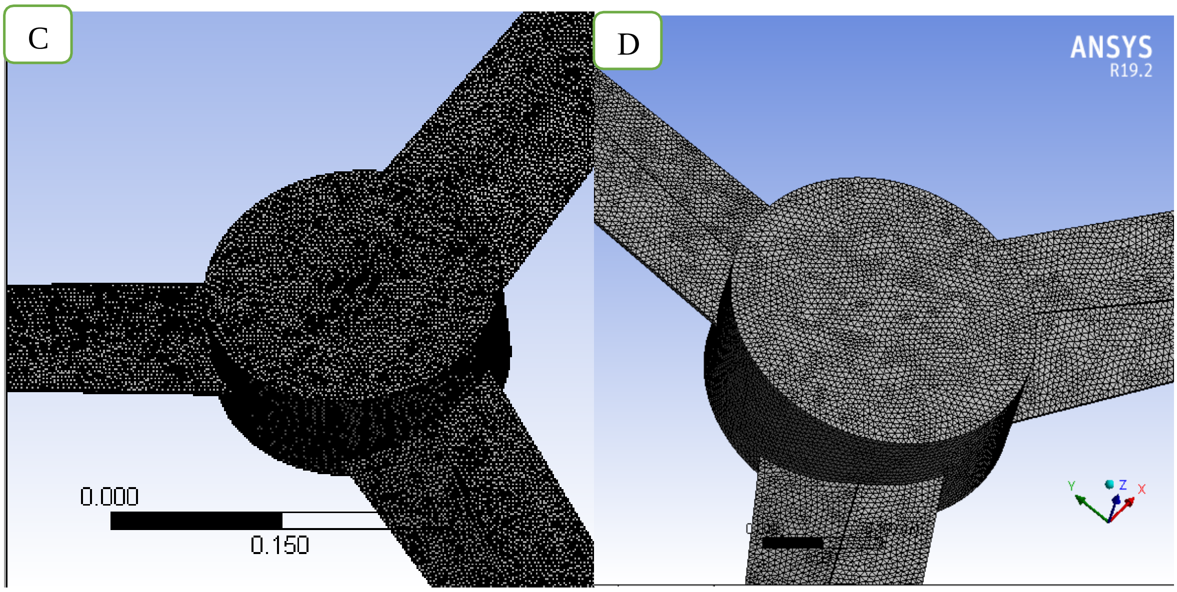


Figure 3.21. Mesh size of a ceiling fan blade with 2mm, 3mm and 5mm size

A) Ceiling fan & rational zone meshed, B) 2mm mesh size C)3mm mesh size D) 5mm mesh size

Figure: 3.22 &23. Describes the static pressure developed on the upper surface of the ceiling fan blades with in different mesh size (2mm, 3mm and 5mm). Based on the result, the 2mm, 3mm and 5mm mesh size shows different static air pressure and air velocity.

The static pressure developed on the blades surface and the air velocity shows on the fluid flow result are, for 2mm mesh size 151.7Pa and air velocity of 1.54 -18.8m/s, for 3mm mesh size 165.7 Pa and air velocity of 1.8-18.9m/s, and for 5mm mesh size 216.4 Pa and the air velocity of 1.5-10.3m/s. Depending on the above result the highest static pressure developed on the superficial blade surface was exhibited on 5mm mesh size and it applied for static structural analysis.

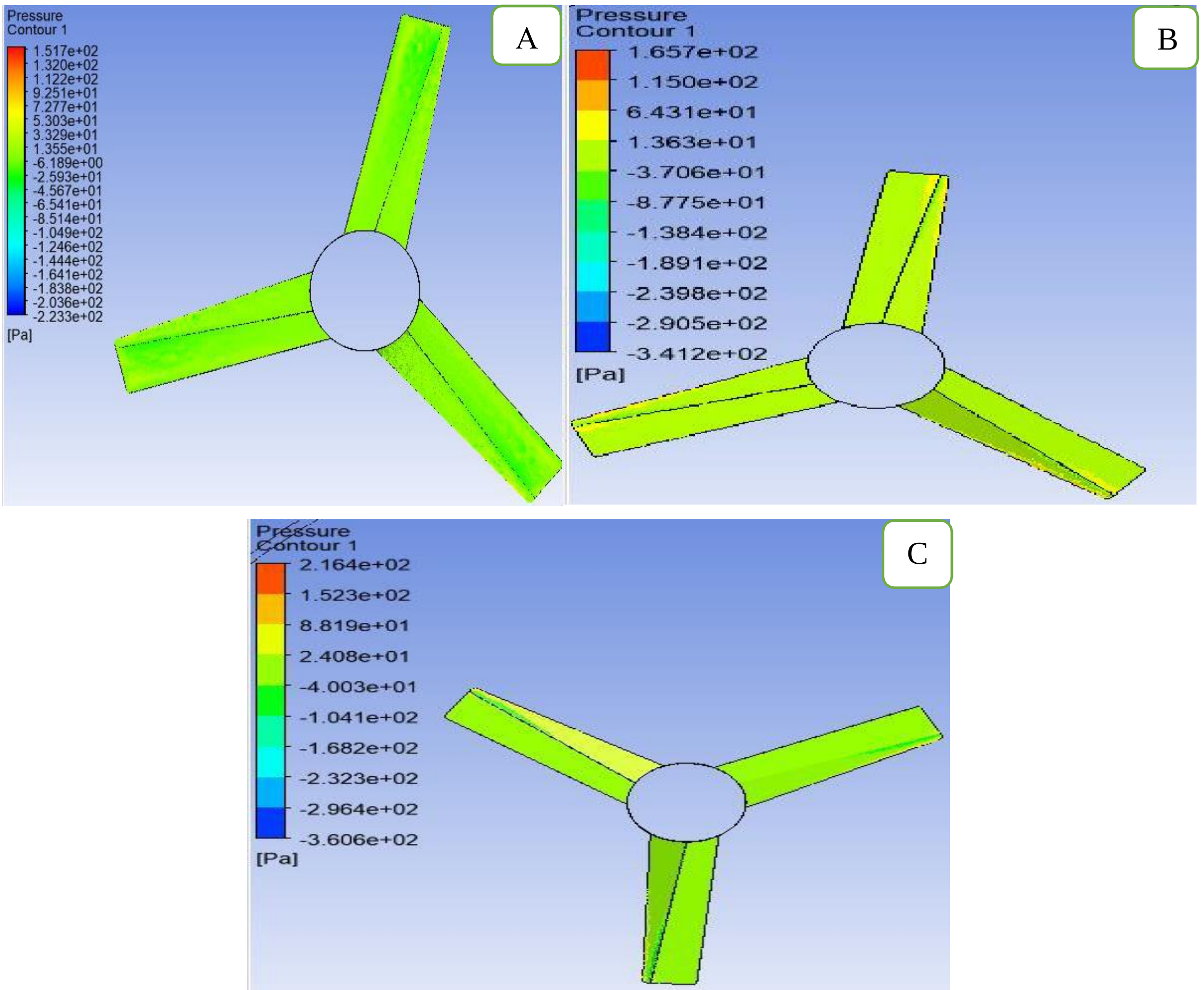


Figure 3.22. Static pressure on a blade surface

A) Static pressure on 2mm mesh, B) static pressure on 3mm mesh, and C) static pressure on 5mm mesh

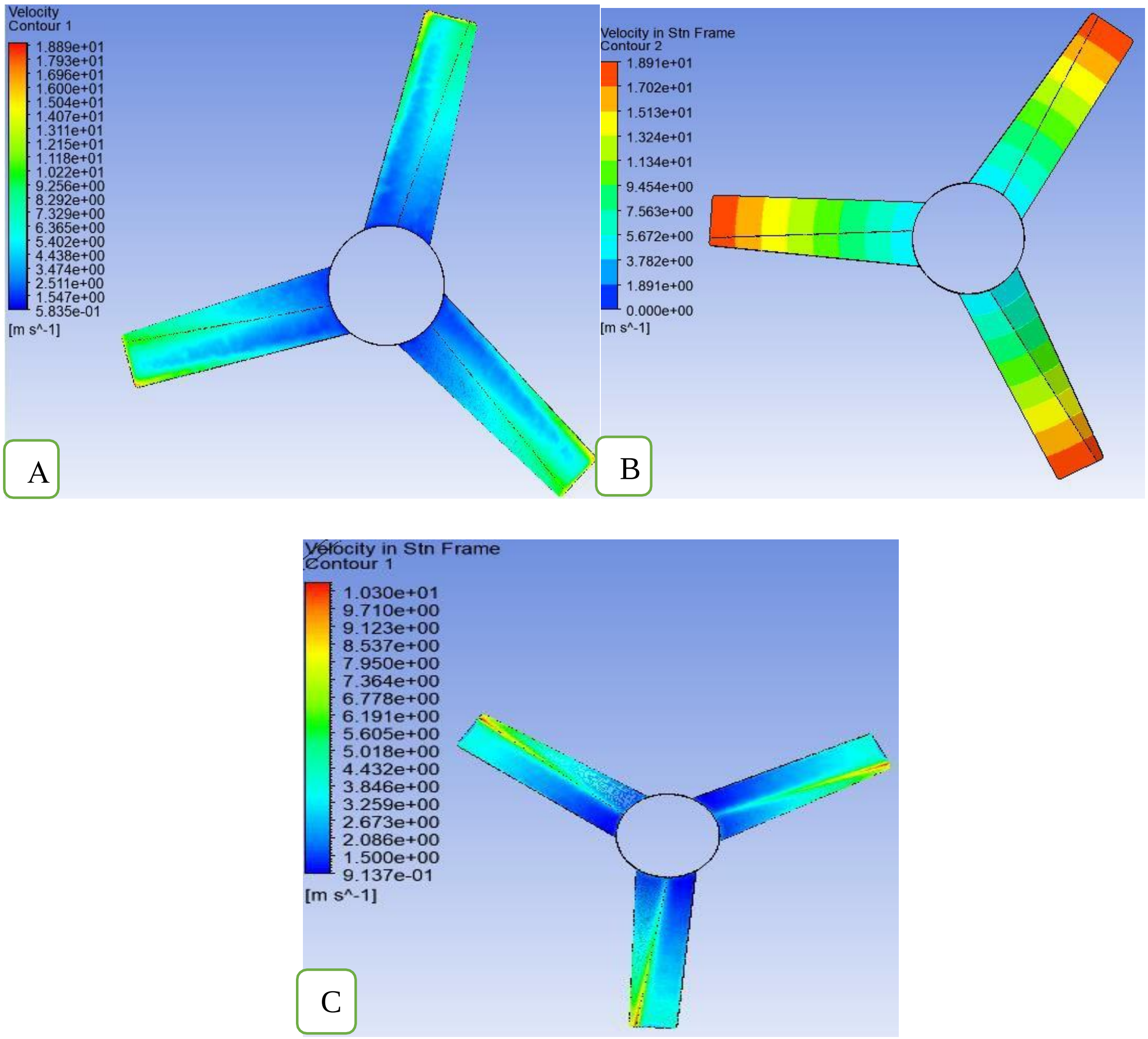


Figure 3.23. The air velocity developed with different mesh sizes

A) The air velocity at 2mm mesh size, B)the air velocity at 3mm mesh size, C) the air velocity at 5mm mesh size

3.7.2. Static structural analysis of a ceiling fan blade

To examine the stress and deformation of the blades, the fluid flow analysis data was linked with static structural work bench. The static pressure developed on the surface of the blades was imported into the static structural analysis.

There are different researches have been worked to enhance a ceiling fan performance according to blade design modification, number of blades, rotational speed variation, and material replacement. **Neway.S.et.al.** Studied "Jute Reinforced PLA Bio-composite for the

Production of Ceiling Fan Blades". It examined a ceiling fan blade that developed from treated Jute fabric reinforced Polylactic acid composite and it compared with "Usha Aluminum (Al alloy 1050H14)" ceiling fan blade. The comparison was based on amount of air delivery, air velocity, power, weight, and service value. In addition it characterized the tensile strength and shear strength of the composite. Based on the result the composite blade shows high air velocity and it reduced 20% of power consumption (15.65W). The air delivery was lower than the aluminum blade due to the lower surface area of the composite blade [78].

For the current HFBFREC stress and material deformation comparison aluminum alloy is considered because, it is a material mostly used to manufacture ceiling fan blade. Besides Jute Polylactic acid composite and Al-alloy1050-H14 also used to compare with current fabricated hybrid composite. Parameters used for stress and deformation analysis were static pressure induced on blade surfaces, materials density, self-weight, and the gravitational force of each blade material.

Table 3.7. Ceiling fan blade materials used for static structural analysis

Materials	Density (g/cm^3)	Weight of the blade(Kg)	Ultimate tensile strength(MPa)	Materials gravitational force($Kg.m/s^2$)
Aluminum alloy	2.77	0.567	310	5.55
Jute/Polylactic acid composite	1.42	0.29	99	2.845
Al-Alloy1050-H14	2.8	0.571	105-145	5.58
Current material	1.20	0.24	68.3	2.35

❖ Working Principle of static structural and fluid flow analysis

To examine the stress and deformation of the ceiling fan blades, the CFD analysis data were linked and imported into the static structural work bench. Besides the imported pressure displayed on the static structural analysis. For comparison of stress and deformation of materials, hybrid flax-banana epoxy composite was compared with aluminum alloy. Because currently fan blades are mostly made from aluminum alloys. For stress and deformation analysis, parameters that are taken into consideration are imported static pressure, materials density, and blades self-weight. The general procedure is presented as follows.

- Using specific blade geometry and rotational speed of 300rpm, the fluid flow analysis (CFD) was conducted. The static pressure developed on the superficial surface of the blade was displayed.
- The total pressure on the surface of the blade was imported into Static structural analysis work bench.
- On static structural analysis, the fan blades were considered as a cantilever beam, and each of the blades was fixed with the hub at the root of the blade.
- The total pressure imported and loaded on the surface of the propellers, besides the gravitational forces and fixed supports were applied as a boundary condition for each blade.

To obtain the Von-misses stress and materials deformation the CFD output pressure exported into static structural analysis for different materials. In this section different material properties and parameters are filled such as Engineering data, model, setup, solution, and results.

❖ Engineering Data

In this section different material properties and parameters that taken from experimental tensile test result are filled. For example: - density, Poisson's ratio, young’s modulus, and ultimate tensile strength of the materials. Figure: 3.24. Shows how the data’s are filled in engineering data section and linked each other.

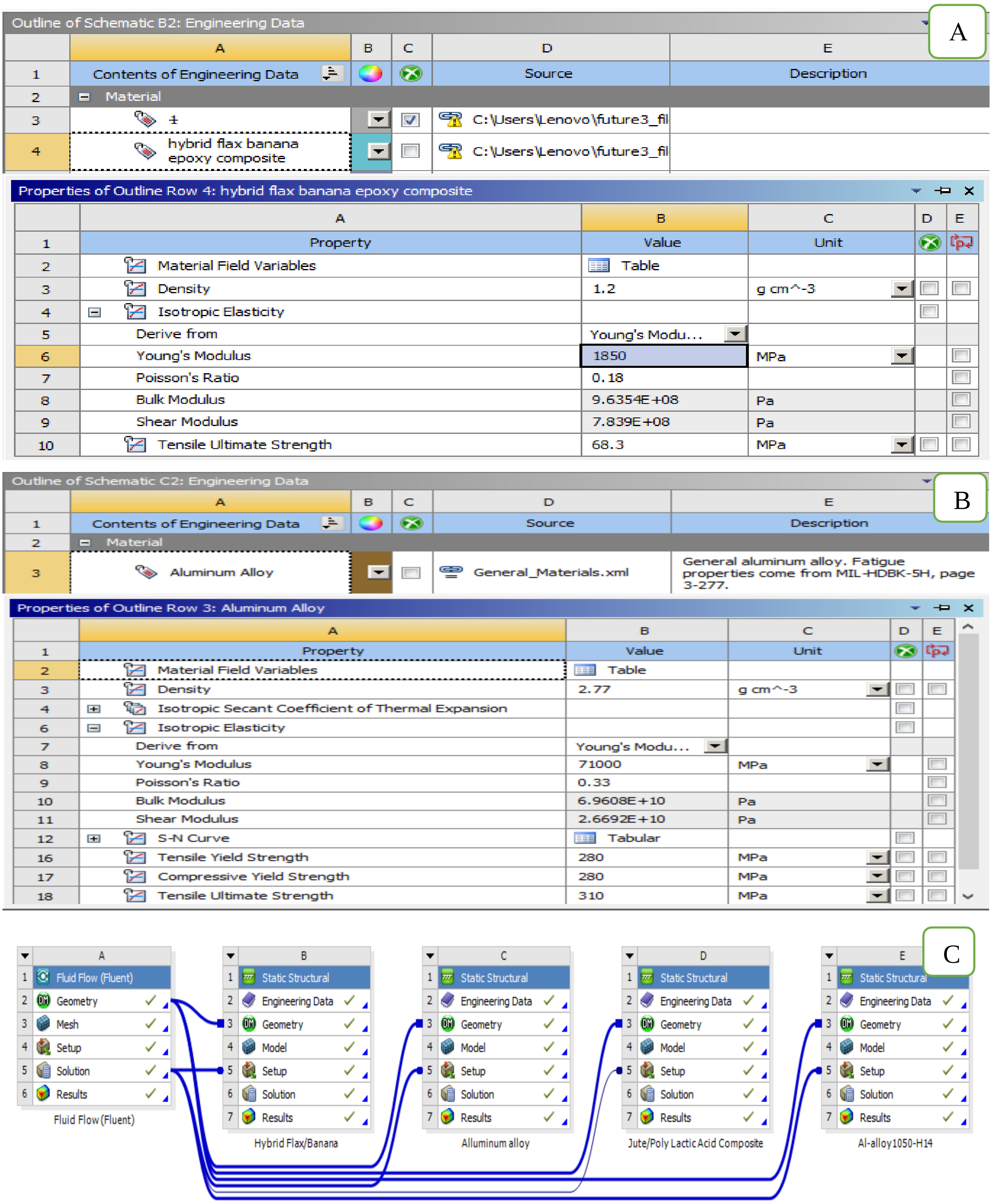


Figure 3.24.Workbench material properties in engineering data

A) Workbench material properties of HFBFREC, B) workbench material properties ofaluminum alloy and C) developed static pressure exported into static structural analysis

❖ Boundary conditions and solved solution

After the fluid flow(fluent) analyses was linked to static structural analysis work bench, the propellers are meshed with 2mm size to determine the Von-misses stress and total deformation of the blades. Boundary conditions

- ✓ The fixed supports are applied at the bottom of the blades.
- ✓ The Imported pressure loaded on the surface of the blades.
- ✓ The gravitational force applied for each blade.

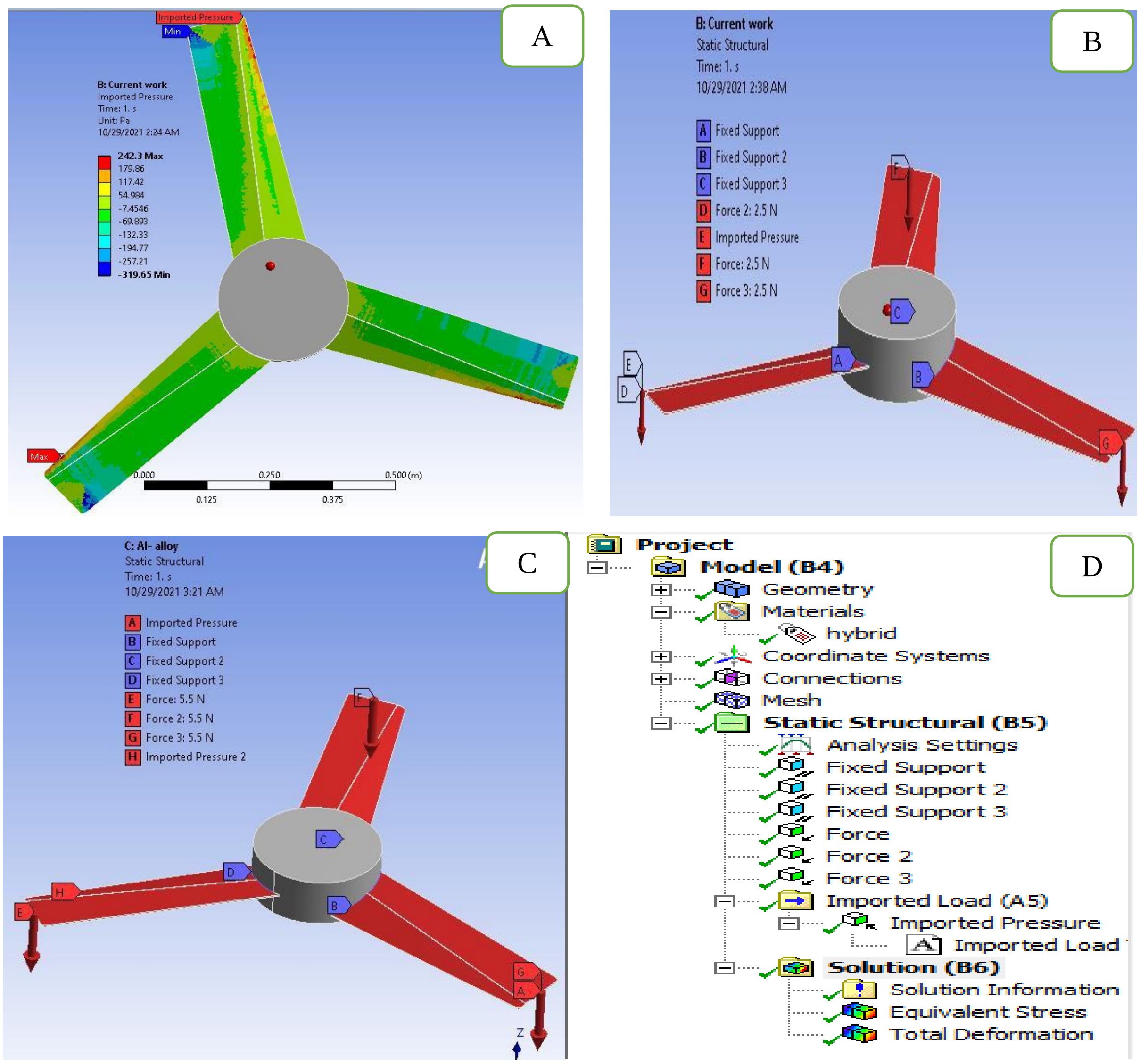


Figure 3.25.Appplied boundary condition and solved solution

A) static pressure on the blade surfaces loaded from fluid flow , B) a boundary condition applied on current hybrid composite(HFBFREC), C) a boundary condition applied on aluminum alloy, and D) solved static structural analysis solution

- Figure 3.25A, shows the imported static structural pressure on the surface of the propellers.
- Figure 3.25(B & C) describes the applied boundary condition such as blade roots are fixed at the hub and the gravitational forces are applied on each mater blades surfaces.
- Figure 3.25D shows a solved structural analysis solution. The gravitational forces applied on ceiling fan blades are depending on a materials density and self-weight which taken from (Table 3.7.).

Chapter Four

Result and Discussion

4.1. The hybrid composite test result

The experimental test results of tensile strength, flexural strength, impact strength, and water absorption property of HFBFREC was determined and discussed. In addition, a finite element analysis of ceiling fan blades with four types of materials was conducted. For experimental tests, eleven compositions were prepared with different volume fractions to determine the effects of fiber to matrix volume fraction, fiber hybridization, and fiber surface modification on the properties of composite materials. The ceiling fan blade structural analysis of equivalent stress and total deformation analyzed using Ansys 19.2 workbench.

4.1.1. Tensile strength of hybrid composite

The tensile strength was examined from eleven compositions. The specimens prepared from 20mm length of chopped fibers, random fiber orientation, treated and untreated fibers with 60/40%, 70/30%, and 80/20% fiber matrix volume fractions. Five test specimens were tested for each composition, and three relative results were taken as the final result. The ultimate tensile stress, modulus of elasticity, tensile strain, and stress-strain curve were measured and calculated based on the following equations.

$$\sigma = \frac{F}{A_0} \quad \text{Eq (4.1), [94].}$$

$$\varepsilon = \frac{l_0}{l} \quad \text{Eq (4.2), [94].}$$

$$E = \frac{\sigma}{\varepsilon} \quad \text{Eq (4.3), [94].}$$

The stress-strain curves of HFBFREC each composition specimen was measured under the tensile load. Each composition shows different results according to their fiber to matrix volume fractions. The result was recorded and exhibited under the following figures.

<u>Composite 1, 2, and 3:</u> are prepared from treated 70/30% volume fraction and with hybrid volume ratio of flax-banana 50/50%, 75/25% and 25/75%. From all composition five specimens were tested and three related results were taken. All specimens were tested based on ASTM- D3039.

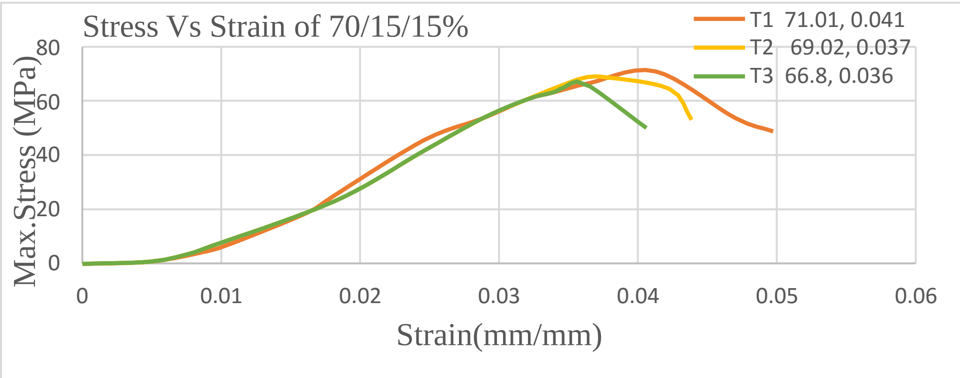


Figure 4.1. Stress-Strain graph of treated 70/15/15%

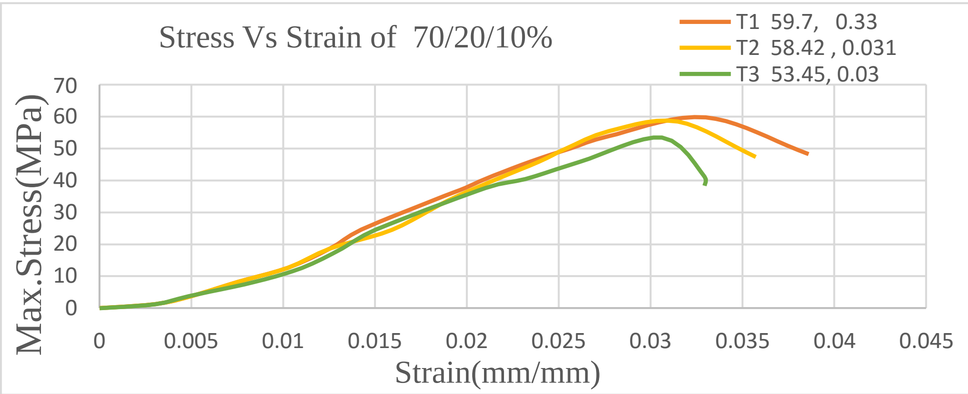


Figure 4.2. Stress-Strain graph of treated of 70/20/10%

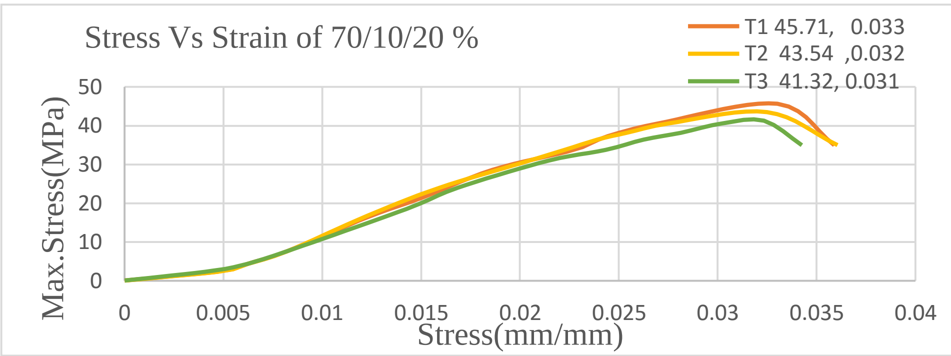


Figure 4.3. Stress-Strain graph of treated of 70/10/20%

<u>Composite 4, 5, and 6:</u> are prepared from treated 60/40% volume fraction and with hybrid volume ratio of flax-banana 50/50%, 75/25% and 25/75%. From all composition five specimens were tested and three related results were taken. All specimens were tested based on ASTM- D3039.

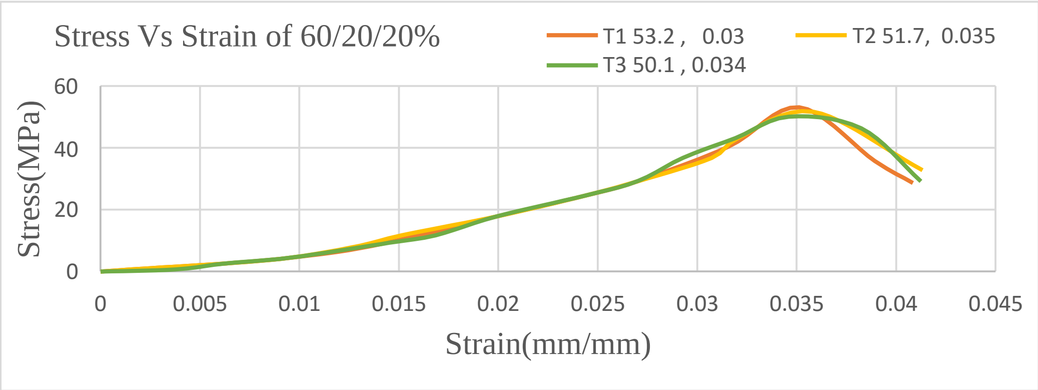


Figure 4.4. Stress-Strain graph of treated of 60/20//20%

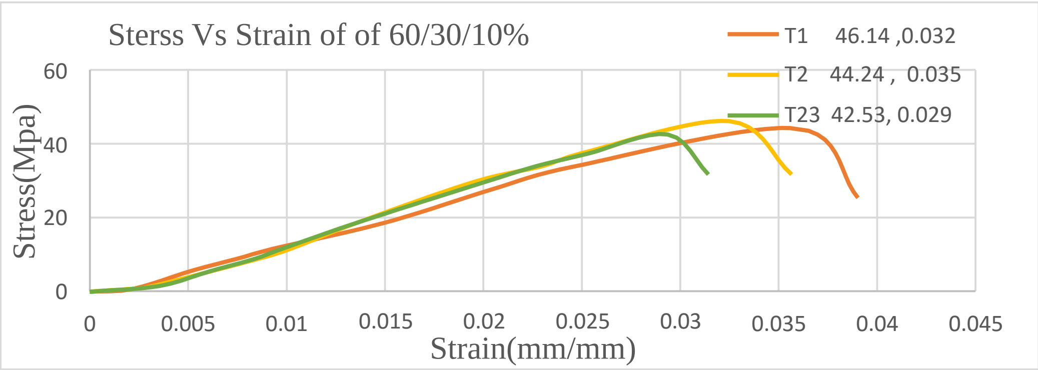


Figure 4.5. Stress-Strain graph of treated of 60/30//10%

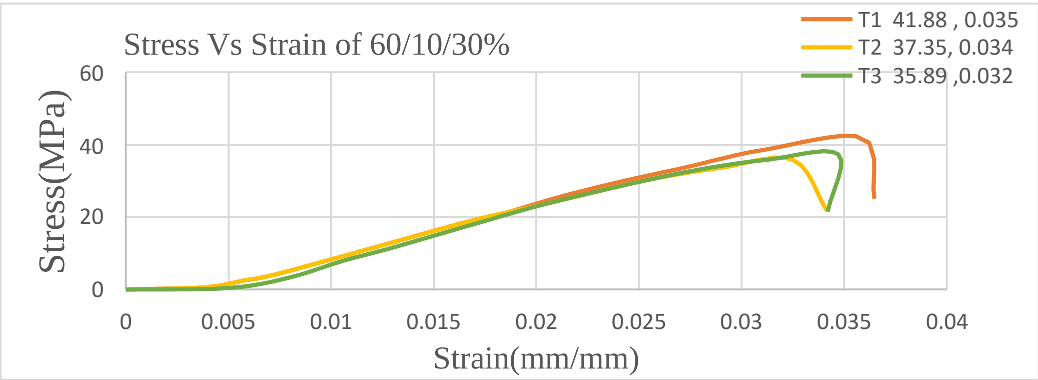


Figure 4.6. Stress-Strain graph of treated of 60/10//30

<u>Composite 7, 8, and 9:</u> are prepared from treated 80/20% volume fraction and with hybrid volume ratio of flax-banana 50/50%, 75/25% and 25/75%. From all composition five specimens were tested and three related results were taken. All specimens were tested based on ASTM- D3039.

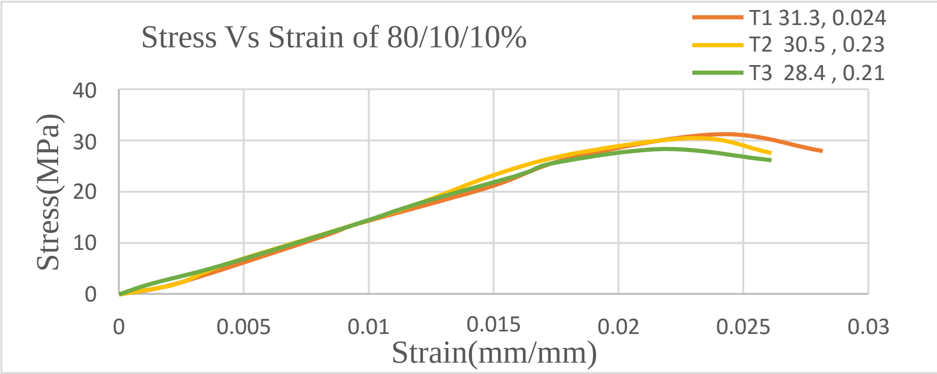


Figure 4.7. Stress-Strain graph of treated of 80/10//10%

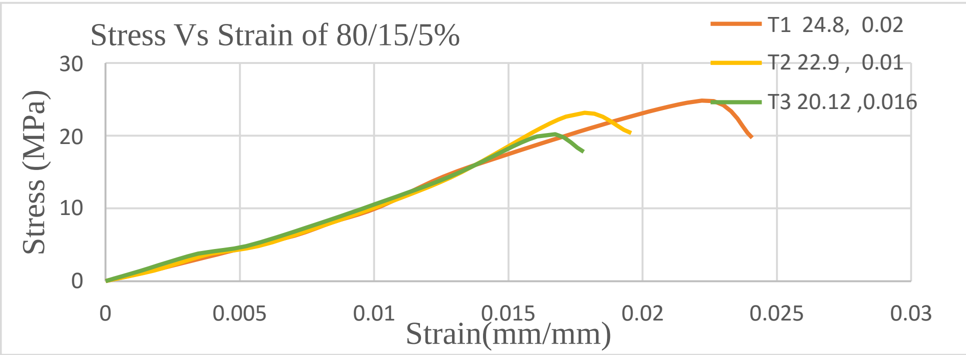


Figure 4.8. Stress-Strain graph of treated of 80/15/5%

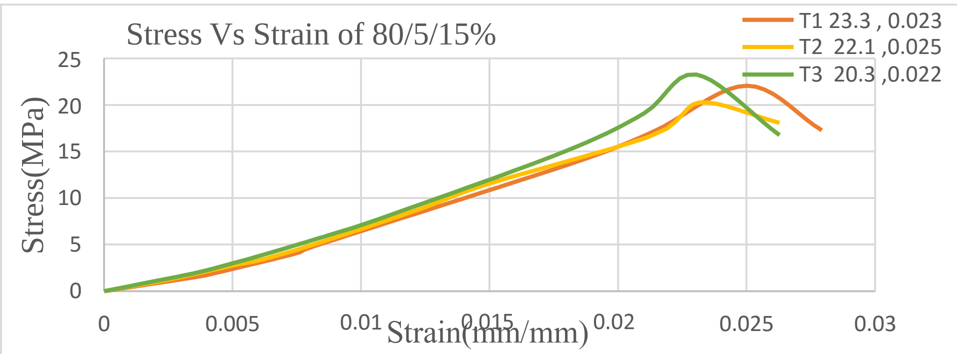


Figure 4.9. Stress-Strain graph of treated of 80/5//15%

Untreated Composite 10 and 11: These tests were carried out to determine the effect of fiber surface treatment on hybrid composites property. The composites were fabricated with equal fiber to resin and fiber to fiber volume fraction of the treated one. The specimens were prepared from untreated 60/20/20% & 70/15/15% volume fraction. The fibers hybridization ratio of flax and banana was 50/50%, 75/25% and 25/75%. From all composition five specimens were tested and three related results were taken. All specimens were tested based on ASTM- D3039.

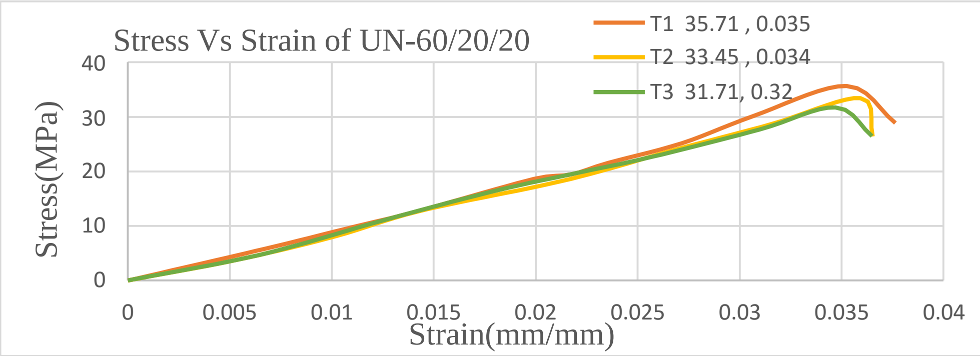


Figure 4.10. Stress-Strain graph of untreated of UN-60/20/20%

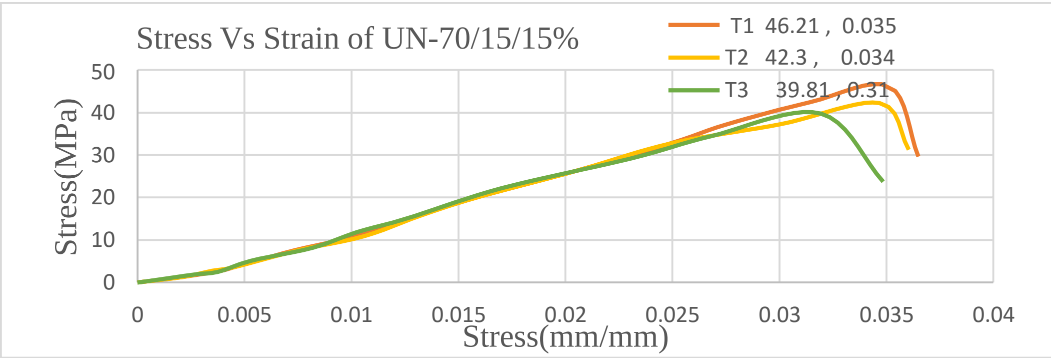


Figure 4.11. Stress-Strain graph of UN-70/15/15%

The stress-strain curves done using the raw data of specimens that recorded under the uni-axial tensile load of specimen stress and longitudinal deflection.

The above figures (4.1. up to 4.11.) clarifies the stress and strain curve of all compositions under the uniaxial load. As shown on the figures, the stress increased linearly with the strain until it reached to the specimen ultimate tensile strength and get fractured.

- **<u>The average tensile strength and elongation of treated and untreated hybrid composite result.</u>**

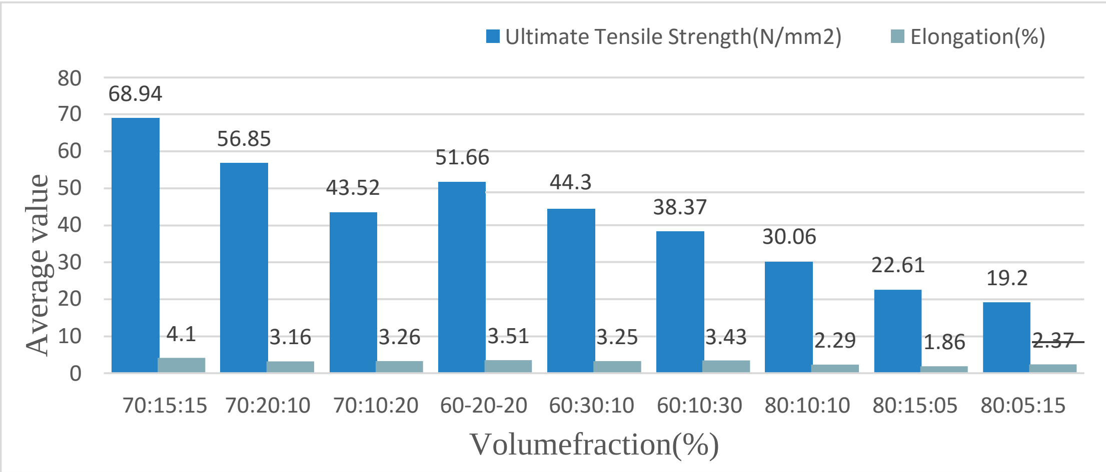


Figure 4.12. Average tensile strength, and elongation of treated 70/30, 60/40%and 80/20%

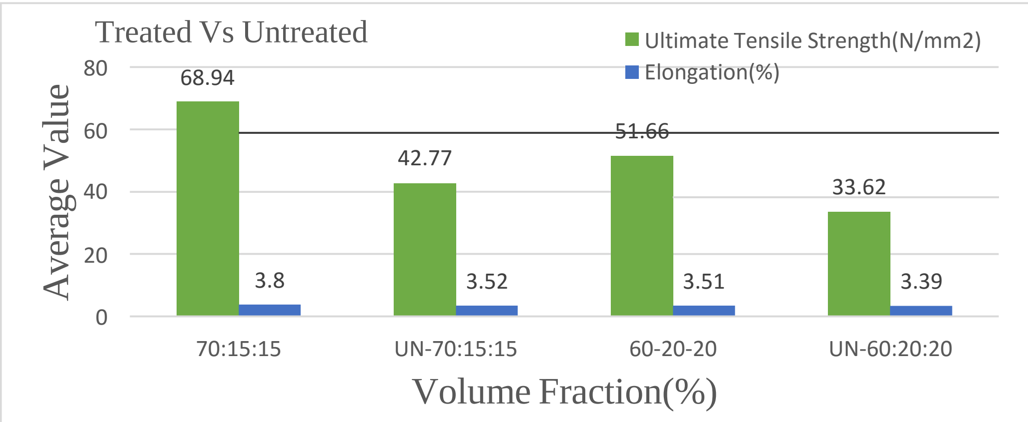


Figure 4.13. Average tensile strength and elongation of treated Vs untreated specimens

Based on the tensile test result, the highest tensile strength was achieved from 70/30% matrix to fiber volume fraction category. The specimen 70/15/15% exhibited the highest tensile strength of 68.94MPa, Modulus of elasticity 1.85GPa and 4.1% elongation.

The second tensile strength result was observed on the specimen of 70/20/10% .It achieved tensile strength of 56.85MPa, Modulus of elasticity 1.79GPa and 3.16% elongation.

The minimum tensile strength was exhibited on 80/5/15% volume fraction. The tensile strength of 19.27 MPa, modulus elasticity of 0.9 GPa and 2.37% elongation.

❖ **Tensile modulus of elasticity test result for all treated and untreated compositions.**

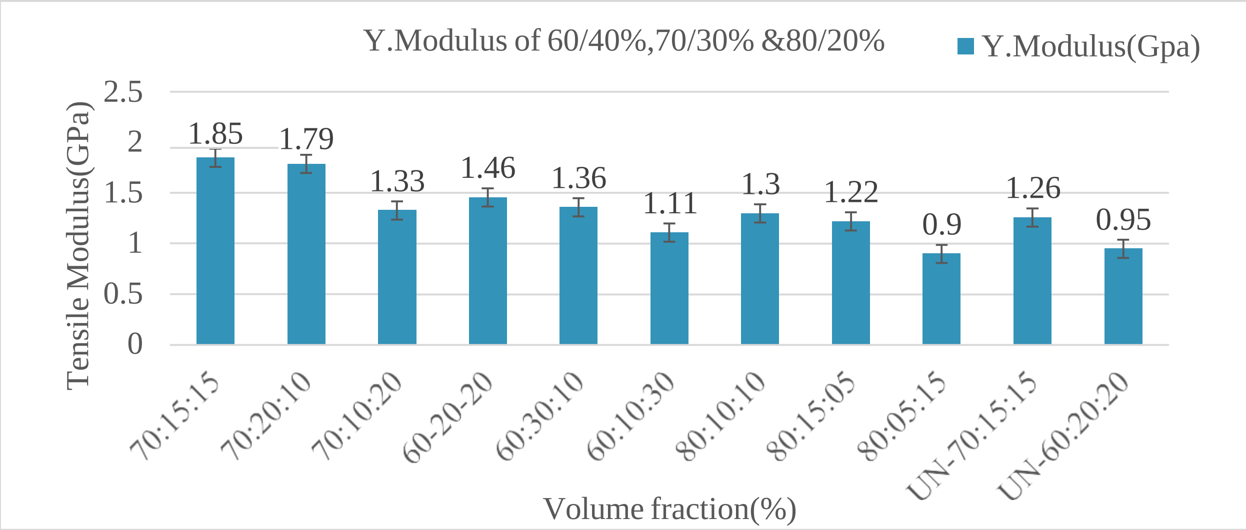


Figure 4.14.Tensile modulus of treated Vs untreated70/30, 60/40%and 80/20%

4.1.2. Flexural strength of the hybrid composite

Bending is a straining of materials around a straight axis. During the bending operation, the material inside the neutral plane is compressed while the material outside the neutral plane is stretched. There are two types of bending tests three-point bending and four-point bending. The difference between the two test methods are the maximum bending moment and maximum flexural stress. In the case of four-point bending configuration, bending moment and flexural stress are constant and uniform between the central forces. In a three-point bending configuration, the maximum flexural stress is found on the span center [95].

The composite specimen flexural stress, maximum load at failure and deflection were recorded from the universal testing machine and calculated using this equation.

$$\sigma = \frac{3PL}{2bh^2} \quad \text{Eq (4.4.), [96]}$$

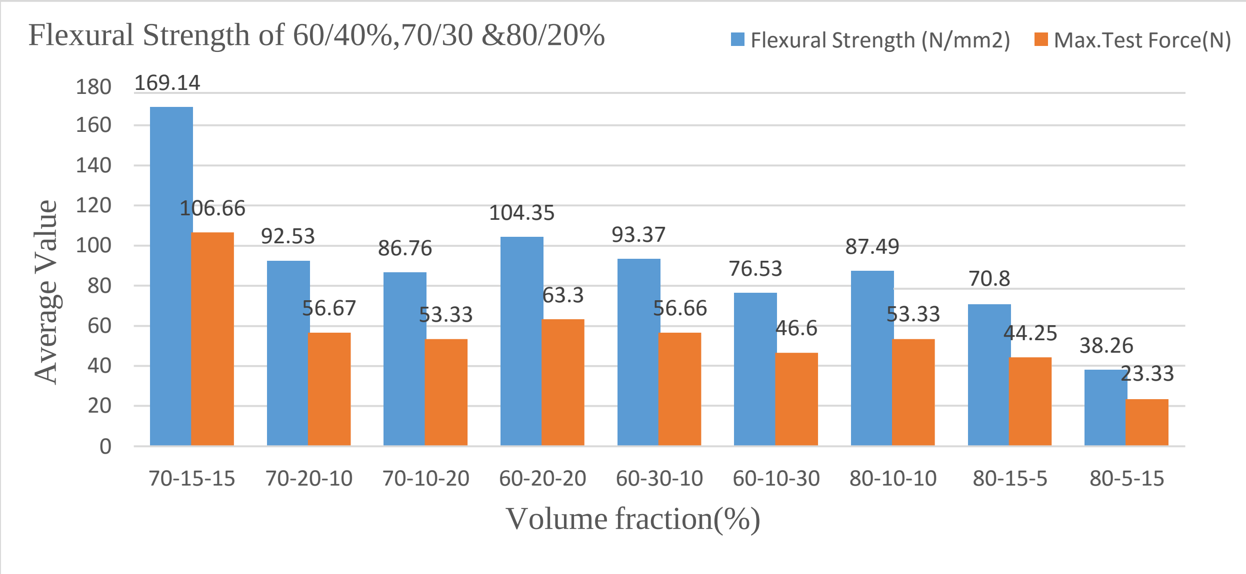


Figure 4.15.Max. Applied load and Flexural Strength of 70/30%, 60/40%, and 80/20%

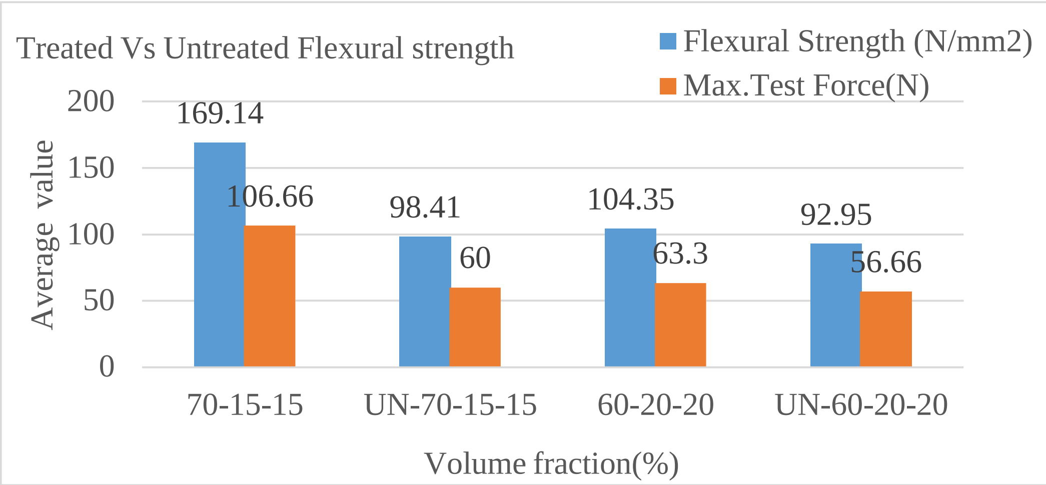


Figure 4.16.Max. Applied load and Flexural Strength of Treated Vs Untreated

The flexural strength result shows, 70/30% matrix to fiber volume fraction exhibited the highest flexural strength and resistance to applied load. Depending on the result 70/15/15% shows the highest flexural strength of 169.14N/mm^2, and maximum applied load 106 N.

The second highest value of flexural strength was attained on 60/20/20%, which was 104.3MPa with a maximum load resistance of 63.3N. The minimum flexural strength of 38.26 N/mm^2 exhibited on 80/5/15% composite specimen with a maximum load of 23.33N.

4.1.3. Impact strength of the hybrid composite

Natural fiber composite impact energy absorption is dependent on fibers' hydrophobicproperty, matrix to fiber volume fraction, reinforcement alignment, length of the fiber, fabrication method, testing method, and fiber hybridization ratio.

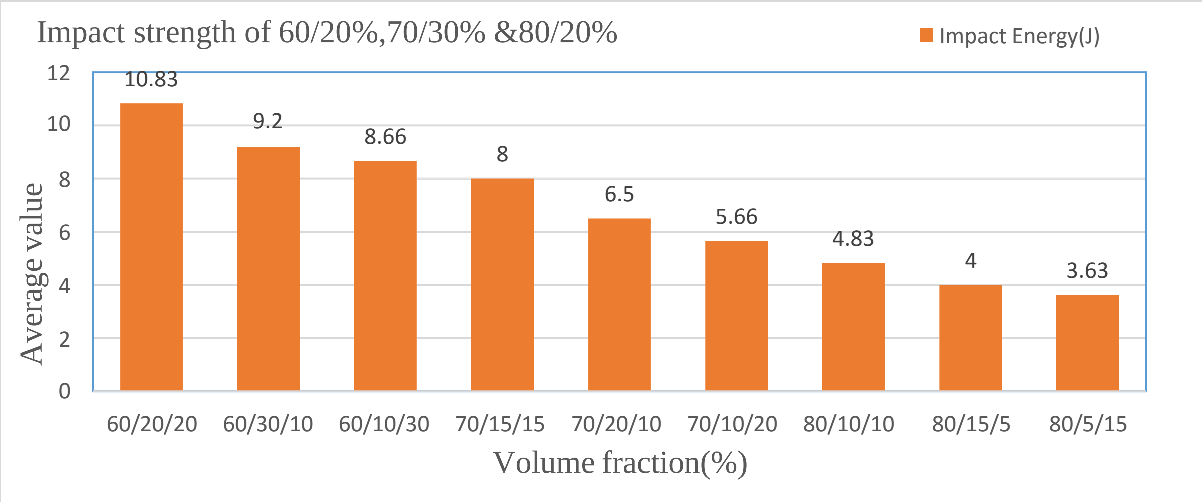


Figure 4.17.Impact strength of treated 70/30%, 60/40 and 80/20

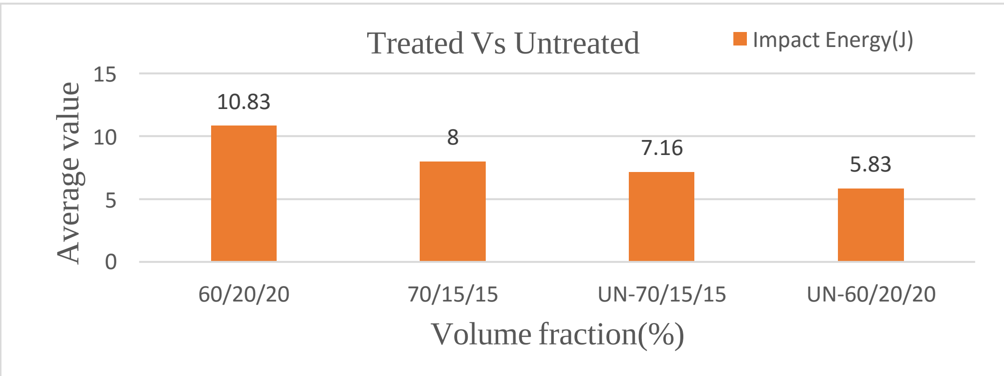


Figure 4.18. Impact strength of treated Vs Untreated, 70/30%, and60 /40 %

The highest impact energy absorption capacity observed on 60/40% matrix to fiber volume fractions category. As Figure 4.17. Shows a composition that attained the highest impact strength was 60/20/20% of 10.83J. The second highest impact energy absorption capacity was observed on 60/30/10% of 9.2J. The minimum impact strength of materials was observed on 80/5/15% volume fraction 3.63J.

4.1.4. Water absorption capacity of the hybrid composite

Since natural fibers are hydrophilic, they have a high tendency to absorb moisture and water. The materials made from natural fibers shows easily swelled when exposed to the humid atmospheric region. Due to that reason hybrid flax-banana fiber reinforced epoxy composite water absorption property tests were conducted. The test used to examine, the capacity of specimens to resist water penetration or water absorption percentage of composite material.

The water absorption property test was conducted using the ASTM-D570-99 standard test method. The specimen dimension was prepared with 64mmx13mmx3mm. Five specimens were immersed in water from each composition of 60/40%, 70/30%, and 80/20%.

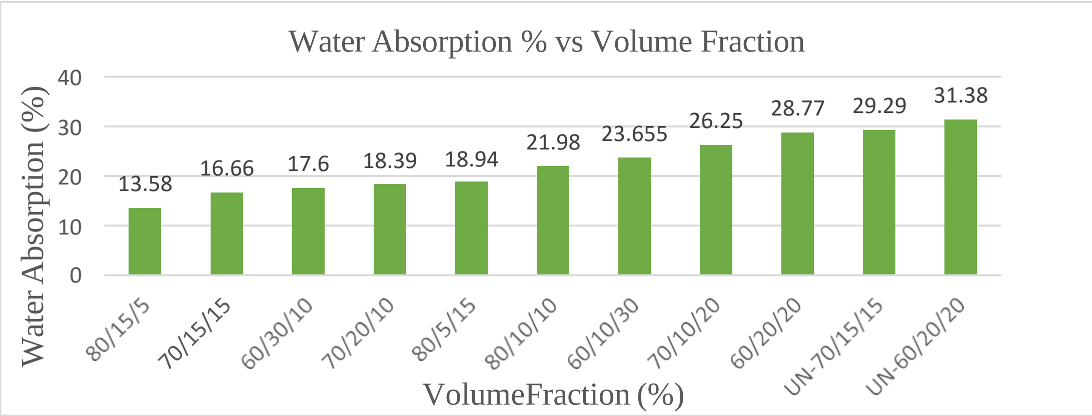


Figure 4.19. Water absorption property of all HFBFEC specimens

The water absorption results showed a significant difference between composite specimens according to fiber loading percentage, individual fibers' water absorption property, fibersurface treatment, and volume fraction of epoxy matrix to fiber's ratio.

A composition that has lower fiber content 80/15/5% volume fraction showed the least water absorption property of 13.58%. The highest water absorption property observed on UN-60/20/20% of 31.38%.

4.2. Discussion

Table 4.1.Overall result of all composition mechanical and water absorption properties.

Volume fraction of epoxy/flax/banana	Tensile Strength(MPa)	Flexural strength(MPa)	Absorbed Impact Energy (J)	Water absorption (%)
70/15/15	**68.94**	**169.14**	8	**16.66**
70/20/10	**56.85**	**106.66**	6.5	18.39
70/10/20	43.52	86.76	5.66	26.25
60/20/20	51.66	104.35	**10.83**	28.77
60/30/10	44.3	93.37	**9.2**	17.6
60/10/30	38.37	76.53	8.66	23.65
80/10/10	30.06	87.49	4.83	21.98
80/15/5	22.61	70.8	4	**13.58**
80/5/15	**19.2**	**38.26**	**3.63**	18.94
UN-70/15/15	42.77	98.41	7.16	29.29
UN-60/20/20	33.62	92.95	5.83	**31.38**

- **Effects of fiber and matrix volume fraction on properties of HFBFREC**

The tensile strength result according to fiber matrix-volume proportion, shows significant effects on the composite material's tensile strength property. The ultimate tensile strength of composites are continuously raised from 20 to 30% of fibers content(80-70% matrix volume), but when it reaches to 40% fiber content(60% resin volume), it started to decline and the result was reduced from 68.9MPa to 51.66 MPa. In addition 80/20% volume fraction composition shows a short stress-strain curve. It indicated the material was early failed within a small range of tensile loading and it was highly rigid material.

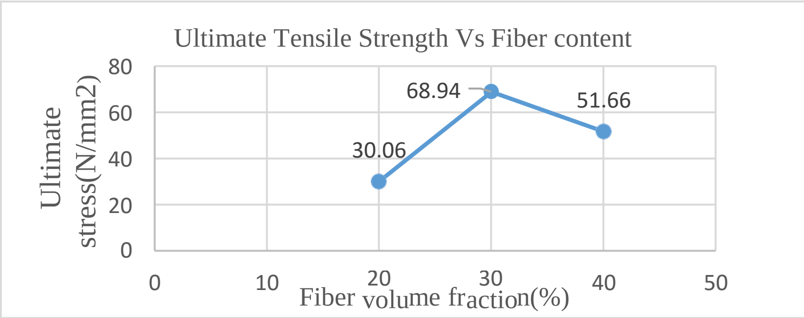


Figure 4.20.Fiber content Vs. tensile strength

The composite specimens bending resistance also raised up when the fiber content increased from 20% up to 30%. However, it reduced when the fiber content reached at 40%. Figure: 4.21 clarified, the composite material bending strength was declined from 169.14 to 104.35 MPa .The result indicates, the fibers contents that hybridized with matrix material should be on the balanced level. If it's beyond that, the fibers were not uniformly wetted, and fiber accumulations can occur. Fiber agglomeration cause poor stress transformation from the matrix to the fibers, and it leads the composite materials to be early delaminated and fractured.

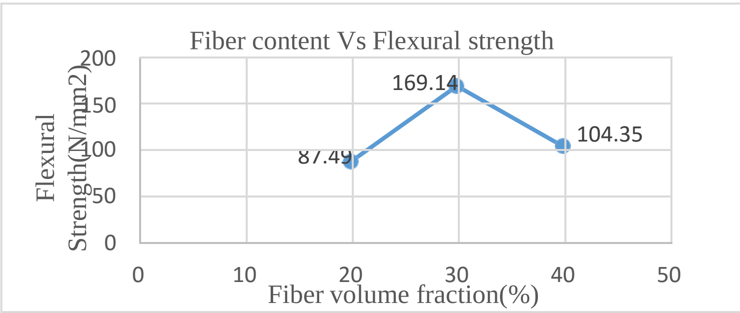


Figure 4.21.Fiber content Vs. flexural strength

The impact energy absorption of the specimens was linearly increased with the fiber content.as shows on figure 4.22, the impact strength of specimens was increased linearly with fiber content from 20% up to 40%. It indicates that if there is high fiber content, the materials can absorb high impact energy. However, if the fiber content is more than or equal to matrix percentage the fibers can't be wetted uniformly and fully covered by the matrix. If the reinforcement is not fully covered by the matrix, a stress that created on the matrix surface cannot be uniformly distributed to the fibers. This leads the material impact energy absorption can be decreased and it will be easily delaminated with small amount of energy.

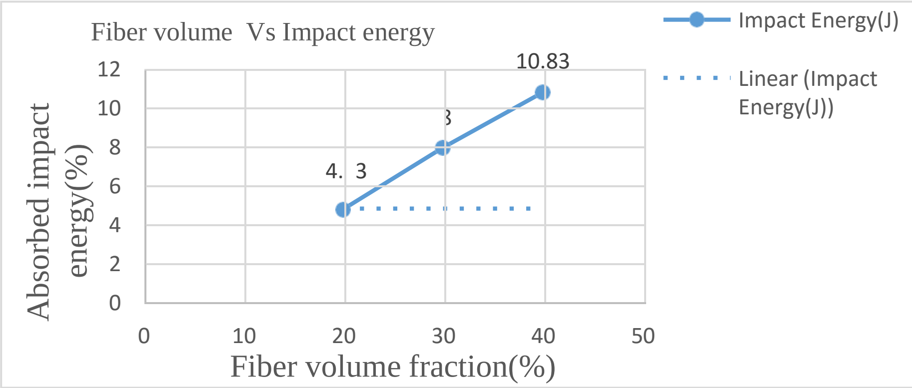


Figure 4.22. Fiber content Vs. impact strength

The water absorption of the composite specimens increased when the fiber content was raised. The 80/20% matrix to fiber volume fraction category showed lower water absorption property. A composition with high volume fraction of matrix (80%) shows low water absorption property and vice versa. Figure 4.23.shows low water absorption property of composites can be attained by reducing the fiber content. Overall, 80/20% volume fraction category showed lower water absorption than others, such as 80/15/5% presented 52.79% less water absorption property than 60/20/20%.

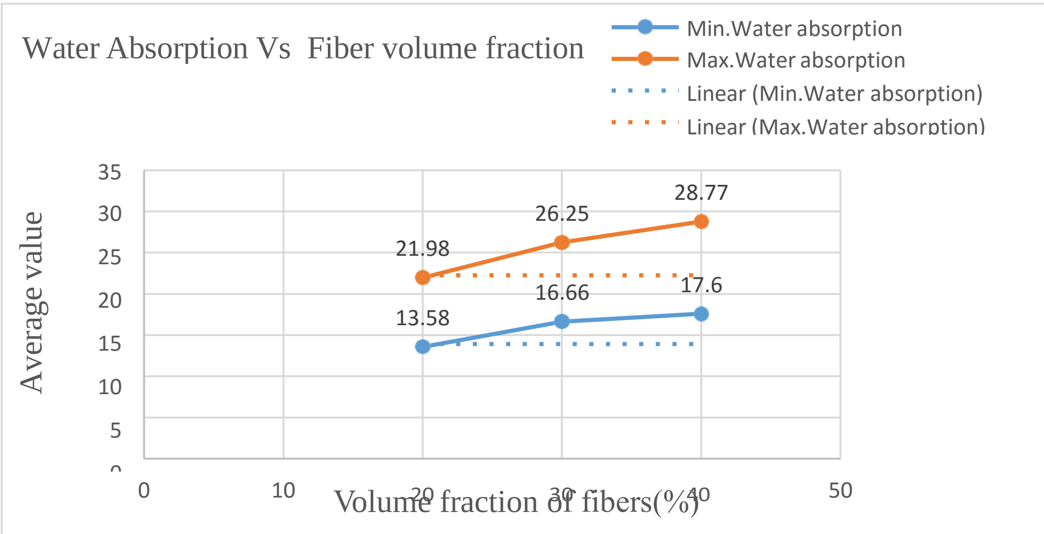


Figure: 4.23. Fiber content Vs. water absorption

❖ Fibers hybridization ratio effects on properties of HFBFREC

The flax to banana fiber ratio used for hybrid composite fabrication was 1:1, 3:1and 1:3. As figure 4.12- 4.17 clarifies, fibers hybridized in equal amount (1:1 flax /banana volume fraction), the highest mechanical property achieved. For instance 70/15/15% and 60/20/20% volume fraction shows the highest tensile strength 68.94Mpa, flexural strength 169.4 MPa, impact energy absorption 10.83J and modulus of elasticity 1.85 GPa.

The second highest mechanical and the least water absorption property was found on 3:1, flax/banana fibers volume fraction. Such as 70/20/10%, tensile strength of 56.85Mpa and flexural strength of 106.66 MPa. Besides 60/30/10% attained impact energy absorption of 9.2J and 80/15/5%, water absorption of 13.58%.

On the other hand, compositions with large banana fiber content (3:1 banana/flax fibers volume fractions) shows the lowest mechanical and high water absorption property. Such as 80/5/15% 70/10/20% and60/10/30 exhibited higher water absorption properties. This occur due to the high water and moisture absorption property of banana fiber.

❖ Fiber surface modification effects on properties of HFBFREC

The alkaline (NaOH) treated and untreated HFBFREC shows significant variation in mechanical and water absorption properties. The specimens were prepared and examined with equal volume fraction of fiber-matrix and fiber to fiber proportion.

Figure 4.13 &4.14. clarifies the alkali(NaOH) treated fiber-reinforced composites achieved higher tensile strength, tensile modulus, and elongation result than untreated one. For instance UN-70/15/15 result shows 42.77MPa, 1.26GPa & 3.53%.the UN-60/20/20% also attained 33.62Mpa ,0.95 GPa & 3.39% respectively. Overall the treated composites showed 37.92%-52.67 % higher tensile strength and 31.8%- 34.93% highest modulus of elasticity than untreated composites.

The fiber surface modification has a substantial effect on the flexural strength of composite materilas. Figure4.16.illustrate the alkali (NaOH) treated hybrid composite achieved thehighest flexural strength. According to the result, a treated 70/15/15% > UN-70/15/15% and atreated 60/20/20% >UN-60/20/20%. The flexural strength result shows 169.4 MPa > 103.89

MPa and 104.32 MPa>92.95MPa respectively. In general, the treated HFBFEC's have 10.89-38.6% flexural strength than untreated one.

The hybrid composite impact energy absorption capacity result shows, the treated a 60/20/20% >UN-60/20/20% volume fraction. Similarly, the 70/15/15% > UN-70/15/15% volume fraction. Figure 4.18 clarify, the impact strength of 10.83J > 5.83J, and 8J > 7.16J respectively. According to the results fiber modified composite specimen achieved 10.25 -33.84 % impact energy absorption capacity than the untreated one.

The water absorption property also shows a large difference between treated and untreated compositions. The untreated composite specimens such as, UN-60/20/20%, and UN-70/15/15 shows 31.38 % and 25.29% water absorption. When it compared to a treated composite, the 70/15/15%, and 60/20/20%, it achieved low water absorption properties 16.66% and 28.77%. Which offers high absorbency variation of 8.39% -34.1%.

4.3. Verification for experimental results

As shown in table 4.2. The mechanical test experimental results were compared with the previous experimental researches. Based on that, the HFBFREC shows competitive properties of tensile, flexural, and impact strength.

Table 4.2. Comparison of different natural fibers reinforced composite literature

Hybrid composition	Polymer matrix	Volume fraction (%)	Fiber treatment	Tensile strength (MPa)	Flexural strength (MPa)	Impact absorbed energy(J)	Authors
Flax/Banana /Epoxy	Epoxy	60/40 &70/30	Treated	51.2& 68.94	106.6& 169.14	10.83	Present work
Flax/Banana	Epoxy	60/40	Not treated	39	13.54	16	[93]
Hemp/Flax & Banana/Pine apple	Epoxy	60/40	Treated	-	87.57	-	[94]
Flax/banana /waste leaf	Epoxy	60/40	Treated	58.81	168.08		[42]
Flax, banana, and jute	Epoxy	70/30	Treated	61	-	-	[95]
Jute/banana/ glass	Epoxy		Treated	22.76	-	9	[96]

Table4.3.illustrated the tensile strength verification of different composite materials with different load applications by using static structural analysis on Ansys software. These references were used for the estimation of load application. The HFBFREC experimental test result was verified using structural analysis (FEA), for this analysis, the composition which exhibited the highest tensile strength 70/15/15% composition was tested. the material property which inserted into engineering data static structural analysis were density 1.2g/cm^3, ultimate tensile strength 68.94MPa, Young's modulus 1.8 GPa, and poisons ratio 0.18, in addition, the tensile specimen was assumed to like isotropic material.

The specimen was fixed at the bottom. The 4800N was applied on the top in the longitudinal direction. As the result shown the maximum stress and deformation-induced on the specimens were 71.14Mpa and 8.64mm. When compared to the experimental result, the deviation was 3.09%.

Table.4.3. Previously used tensile loads for composite materials verification on FEA

Fiber/Matrix	Polymer matrix	Volume fraction (%)	Applied load(N)	FEM UTM (MPa)	Authors
Present work	Epoxy	70/30	4800	71.14	-
Glass/kenaf & Glass/Aolevera	Epoxy	70/30	3550	99.02	[97]
Banana	Epoxy	60/40	2817.5	50.6	[98]
Jute/Banana	Polyester	70/30	1560	22.98	[99]
Human hair	unidentified	70/30	3000	239.08	[100]
Flax/Glass	Epoxy	-	-	83.88	[101]

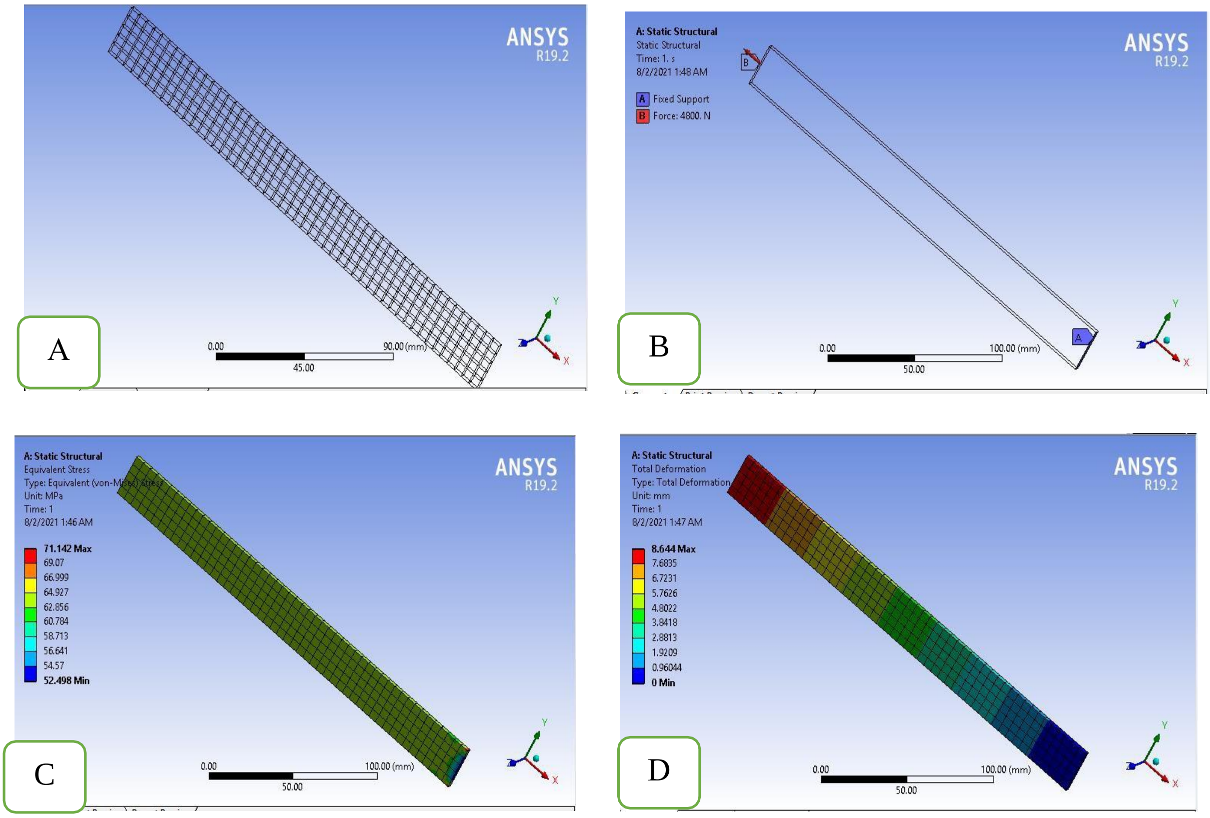


Figure 4.24. Tensile strength test of 70/15/15% verification on Ansys' 19.2

A) Meshed specimen, B) boundary condition (fixed support & applied load), C) Von-misses stress and D) a total deformation of tensile specimen

4.3.1. Test specimens failure and failure modes

Composite specimens can be shown different types of failure modes according to failure area and failure locations. It depends on the material type, manufacturing method, experimental test examination method, and applied loading rate and displacement.

In the case of tensile strength test result, most of the specimens were shows explosive gauge middle (XGM) and lateral gauge middle failure modes (LGM). Most of the untreated UN-70/15/15% and UN-60/20/20% composite specimens were shows failure at Lateral grip of the top and bottom (LGT/B) sections. Figure (4.26.) describes the tensile specimen's appearance after failure and failure codes.

According to the flexural strength test result, most of the specimen's failures occurred at the center of the specimen span length. It indicated, that the specimen's failure mode shows tension, failure area at the loading nose, and failure location in the middle of the specimen.

In case of the impact strength test, most of the specimens were fractured at the notched area, which was found in the middle of the span length of the specimens. However, some of the specimens were not fractured and bended at the notched area. It shows the material has high stiffness, and it can absorb high impact energy than other specimens.

The specimens after failures are shown below in figures: 4.26., and figure 4.27.

Figure 4.25. Tensile, flexural, impact, and water absorption specimens after test

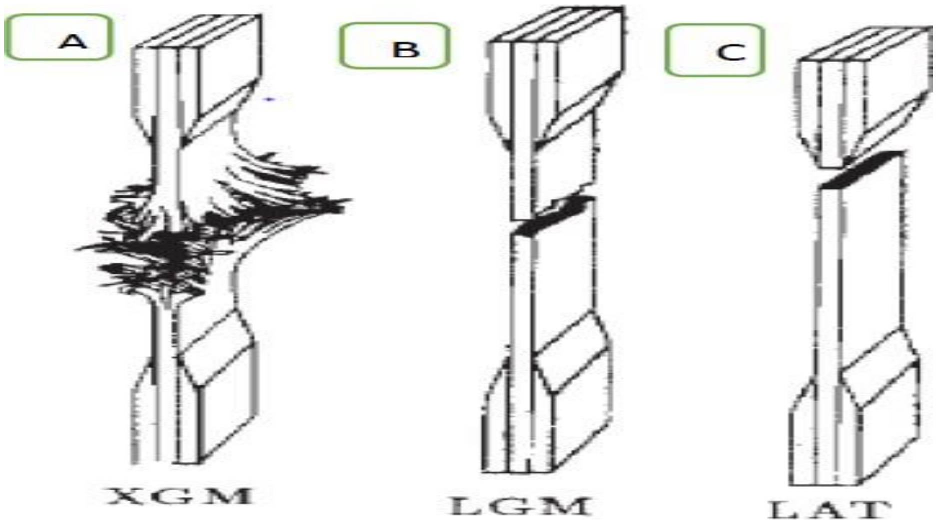


Figure 4.26.Composite material specimen failure modes

A) Explosive Gauge Middle, B) Lateral Gauge Middle, and C) Lateral at Grip Top[94].

4.4. Static structural analysis result and discussion

4.4.1. Equivalent stress (Von-misses) of ceiling fan blades

Figure: 4.27 shows the maximum stress induced on the hybrid flax-banana fiber reinforced epoxy composite and Aluminum-alloy blade surfaces. As the result shows, the Von- misses stress induced on the hybrid flax-banana composite (HFBFREC) blades, a maximum stress of 2.42 MPa were induced. Similarly on the Al-alloy blades, a maximum stress of 5.31MPa observed. Based on the conducted result the aluminum blades develop 54.4% stress than the hybrid composite material. This stress result variation is occurred due to the materials self-weight and gravitational forces.

4.4.2. Total deformation of ceiling fan blades

The maximum deformation occurred on the blade surfaces are shows on Figure: 4.28. Depending on the result, the flax-banana hybrid reinforced composite blades shows 0.9mm deformation. On the other hand the Al-alloy blades exhibited 0.708mm deformation. As the result shows the aluminum alloy blades exhibited lower deformation than the hybrid flax-banana reinforced composite (HFBFREC). The two materials blades deflection variation occurred because aluminum has high stiffness and tensile strength property than the HFBFREC blades.

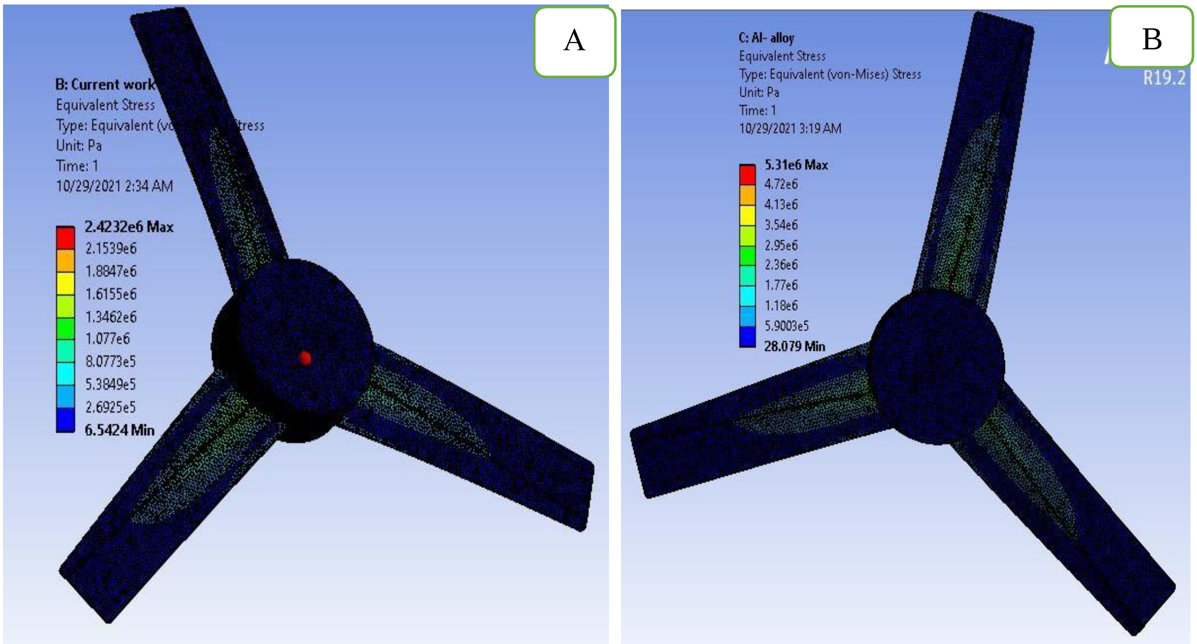


Figure 4.27.The Von-misses stress developed on the ceiling fan blades surface

A) Equivalent stress developed on HFBFREC blades and B) Equivalent stress developedon aluminum blades

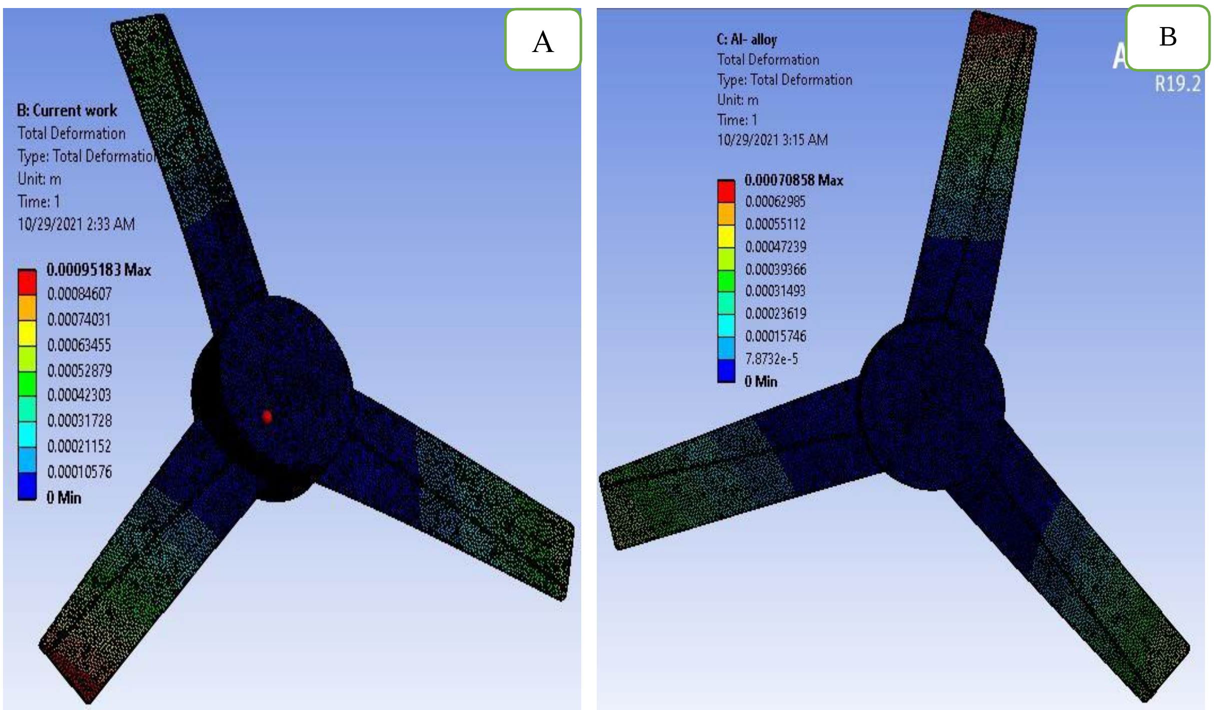


Figure 4.28.The total deformation developed on the ceiling fan blades

A) total deformation developed on HFBFREC blades and B) A total deformation developed on HFBFREC blades

Figure: 4.27 &4.28.Describe the total deformation and of HFBFREC and aluminum alloy, as the result.

- The Von-misses stress induced on the HFBFREC shows 2.4Mpa and on the aluminum alloy shows 5.31Mpa respectively.
- The result shows the HFBFREC shows 0.9mm deformation and the aluminum alloy shows 0.708mm deformation respectively.

Note: - the maximum stress and deformation developed on Al-alloy1050-H14 and on Jute-Polylactic acid reinforced composite, displayed in the appendix section.

Chapter Five

Conclusion and Recommendation

5.1. Conclusion

Overall, to achieve the main objective of the study, hybrid flax-banana fiber reinforced epoxy composite was fabricated with volume fraction of 60/40%, 70/30, and 80/20%. The flax to banana fiber volume fraction ratio was 1:1, 3:1, and 1:3, in both treated and an untreated one. The composite fabrication include the flax and banana fibers extraction and physical properties test (density, length, width, lumen diameter, and cell wall thickness).The HFBFREC specimen's tensile, flexural, impact, and water absorption properties were characterized based on ASTM standard testing methods.

- In tensile and flexural strength properties, 70/15/15% composition shows the highest ultimate tensile strength of 68.9Mpa, modulus of elasticity 1.85GPa, and flexural strength of 169.14N/mm^2.
- According to impact strength property, 60/20/20% volume fraction achieved the highest impact strength of 10.83J.
- In the water absorption test, 80/20% exhibited the lowest water absorption of 13.58%. Besides, 70/20/10% composition also shows the second low water absorption property, 16.88%. It's also observed that fibers surface modification, the volume fraction of fiber, matrix, and fibers loading percentage have significant effect on the composite materials' mechanical and water absorption properties.
- Based on static structural analysis, stress and displacement results were compared using hybrid flax-banana fiber reinforced epoxy composite, Aluminum alloy, Al-alloy1050H-14, and Jute Polylactic Acid Composite.

For each material, pressure from fluid flow analysis was loaded on the surface of the propellers, and the gravitational load was applied.

Based on the result, the hybrid flax-banana fiber reinforced composite (HFBFREC) shows the lowest stress of 2.42MPa and deformation of 0.9mm.

Aluminum alloy shows the highest equivalent stress of 5.31MPa and the lowest deflection of 0.7mm.

- ❖ The static structural analysis result of hybrid flax-banana epoxy composite (HFBFHEC) indicates lower equivalent stress, and according to weight reduction, it reduces 57.14% weight than aluminum alloy.

5.2. Recommendation

Flax and banana fiber reinforced matrix composites are highly utilized in various manufacturing industries for structural and nonstructural applications due to their high strength to weight ratio, low density, and availability. However, they have high water and moisture absorption properties; due to this reason they cannot be used sufficiently. Proper fiber extraction, fiber hybridization, fiber surface modification, and good manufacturing methods should be applied to reduce limitations and overcome good mechanical properties. According to the manufacturing method, most natural fiber composites were manufactured using a hand-layup technique; the composite materials developed different kinds of defects such as the high amount of void content, crack, uneven fiber distribution, and fiber accumulation. Other manufacturing methods need to be applied to reduce these defects, and the natural composite materials will have competent properties and replace synthetic fiber composites.

5.3. Future work

According to natural fiber-reinforced composites demand and several advantages of hybrid fiber-reinforced composites, researches can be conducted on the following areas.

- ❖ Moisture absorption property of HFBFREEC.
- ❖ Fabricate HFBFREC ceiling fan blade prototype and compare air delivery, average airspeed, and mass flow with the conventional blades
- ❖ Study the suitability and durability of HFBFREC by manufacturing the ceiling fan blades prototype.
- ❖ Study the properties of HFBFREC for other structural applications with different matrix-fiber volume fractions, with different fiber orientation and fabrication methods.
- ❖ Wear resistance of HFBFREC for ceiling fan blade application.

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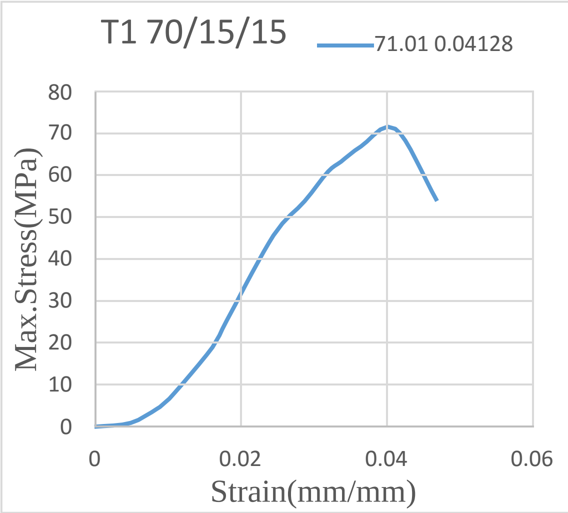
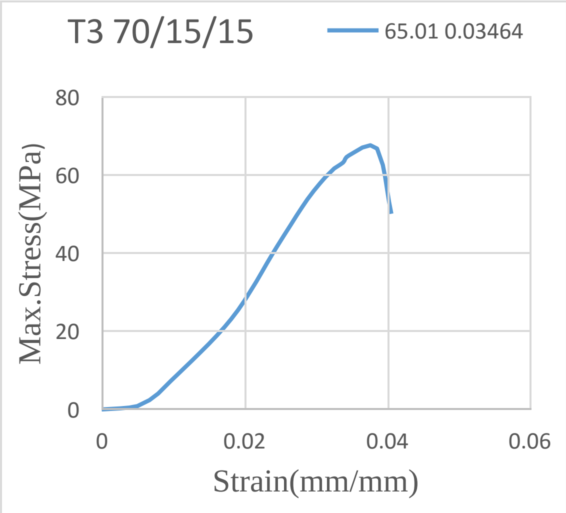
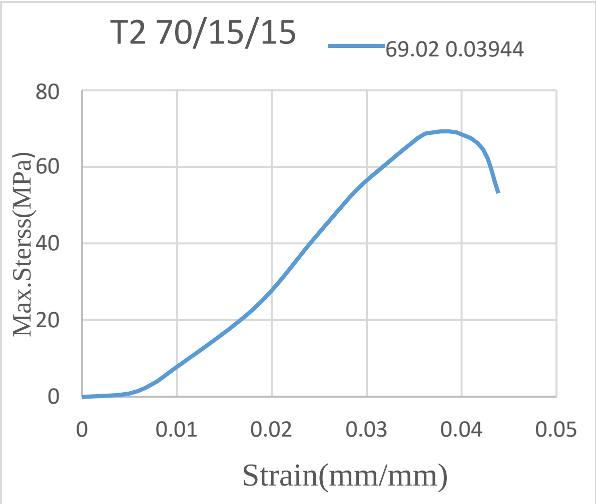
Appendix A

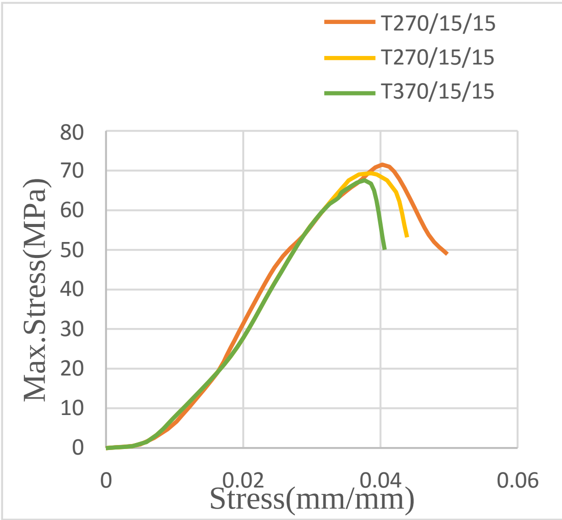
Stress versus strain graph of tensile strength test for 60/40%, 70/30%, 80/20% compositions.

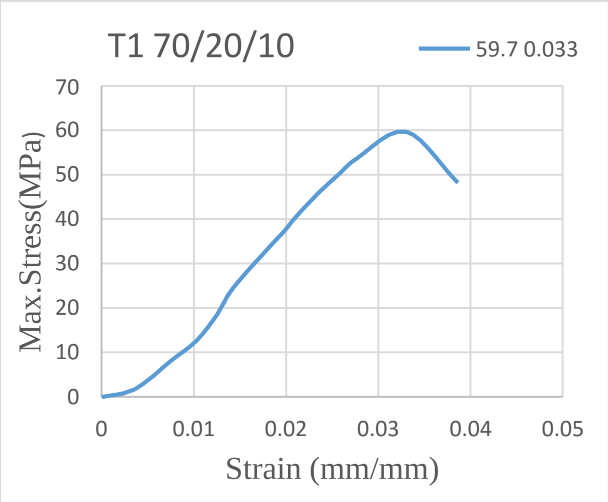
❖ Stress strain graph of 70/30% volume fraction composite.

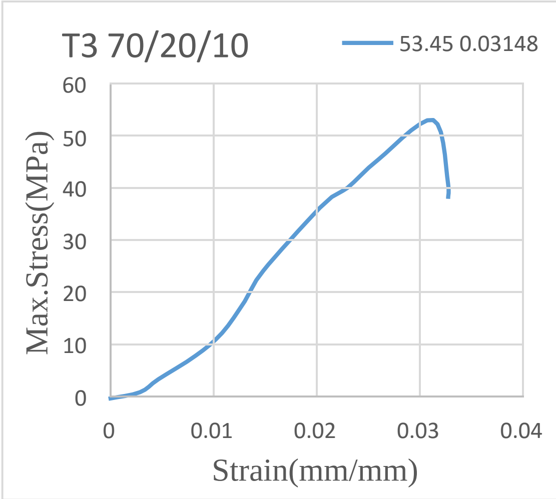


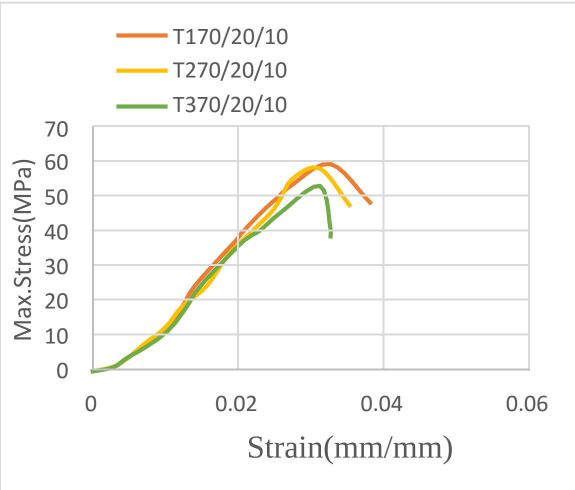


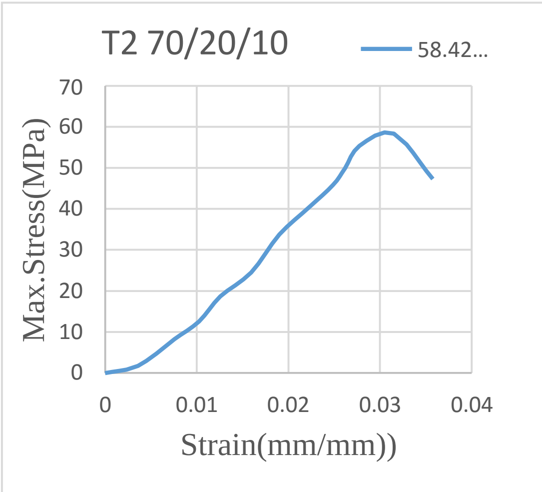


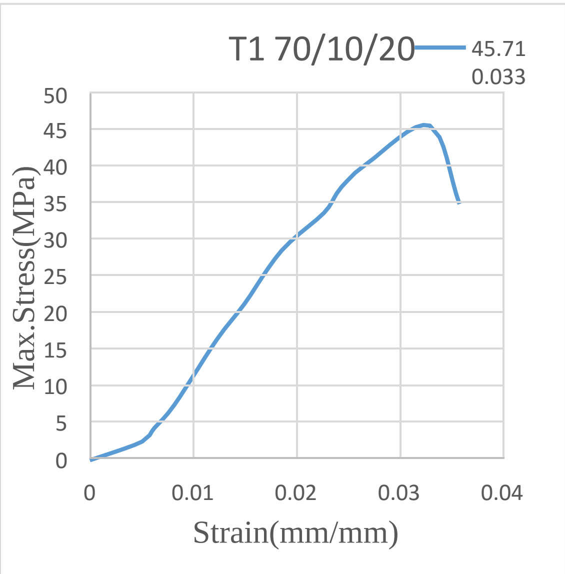


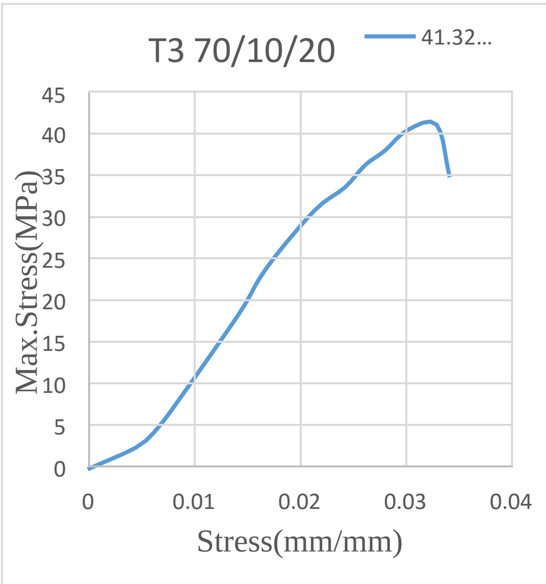

T1 70/20/10
59.7 0.033
Max.Stress(MPa)
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
Strain (mm/mm)

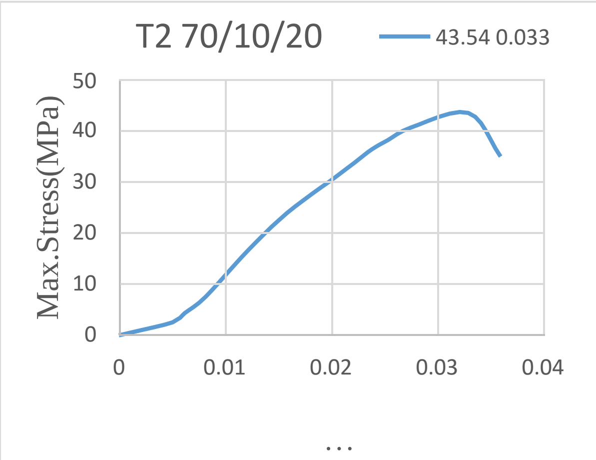

T3 70/20/10
53.45 0.03148
Max.Stress(MPa)
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

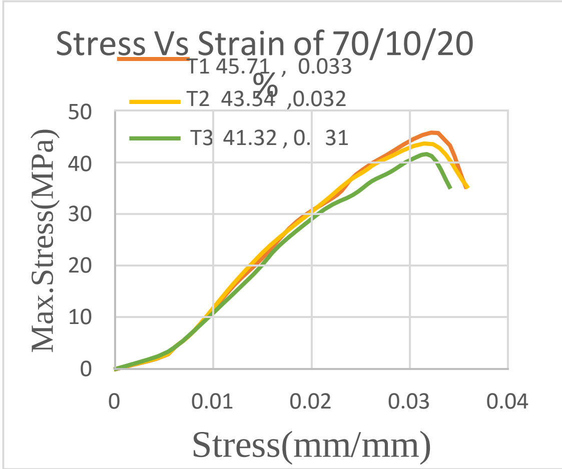

T170/20/10
T270/20/10
T370/20/10
Max.Stress(MPa)
70
60
50
40
30
20
10
0
0
0.02
0.04
0.06
Strain(mm/mm)


T2 70/20/10
58.42...
Max.Stress(MPa)
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
Strain(mm/mm))

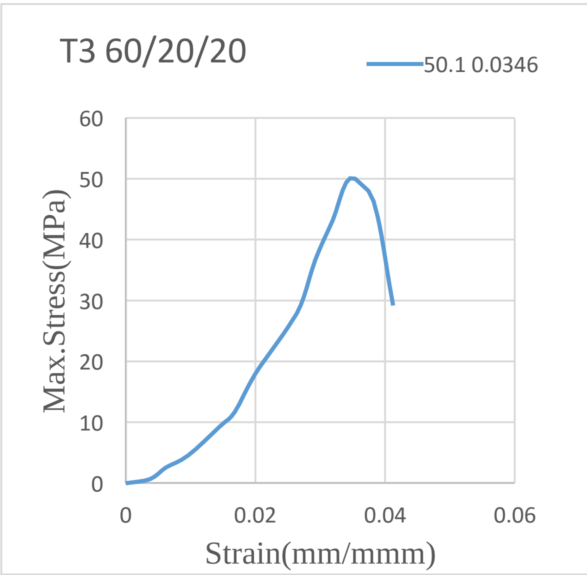

T1 70/10/20
45.71
0.033
Max.Stress(MPa)
50
45
40
35
30
25
20
15
10
5
0
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

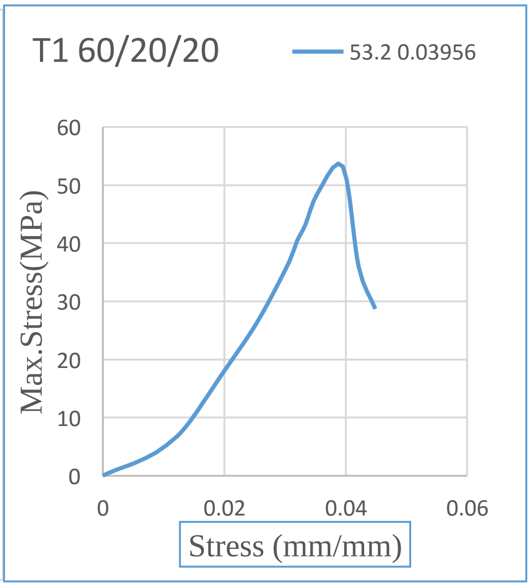

T3 70/10/20
41.32...
Max.Stress(MPa)
45
40
35
30
25
20
15
10
5
0
0
0.01
0.02
0.03
0.04
Stress(mm/mm)

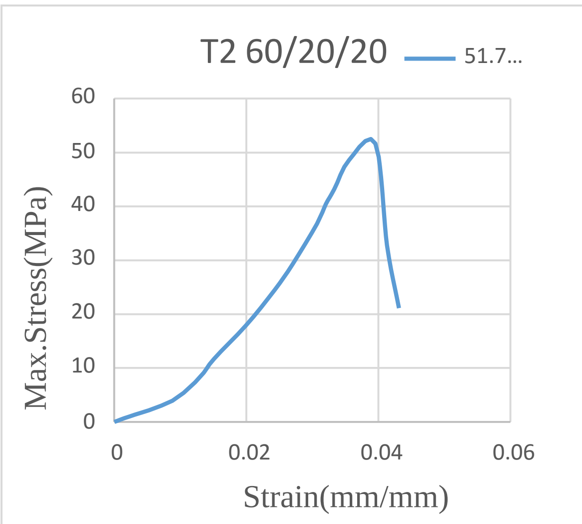


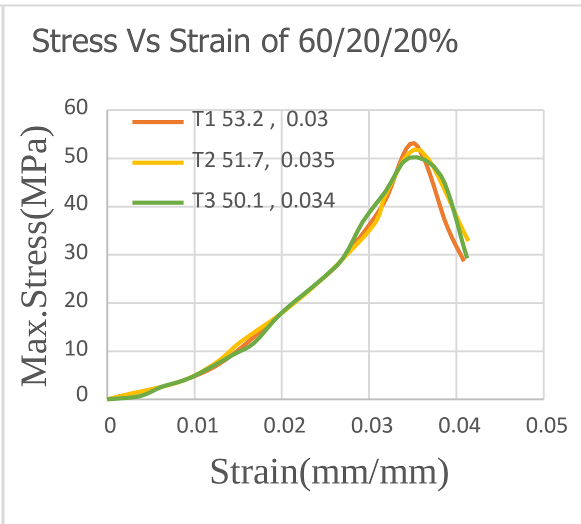


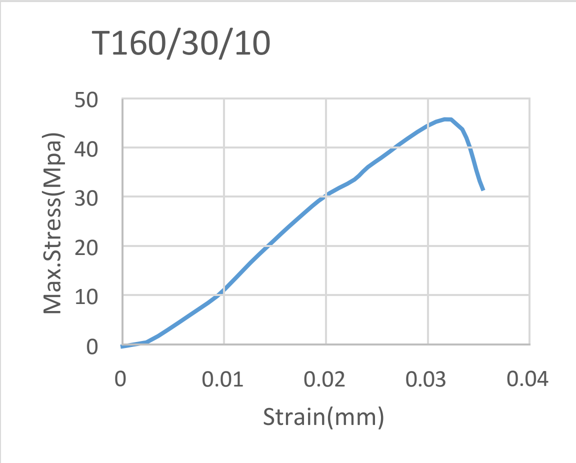
❖ <u>Stress-strain graph of 60/40% volume fraction composite.</u>

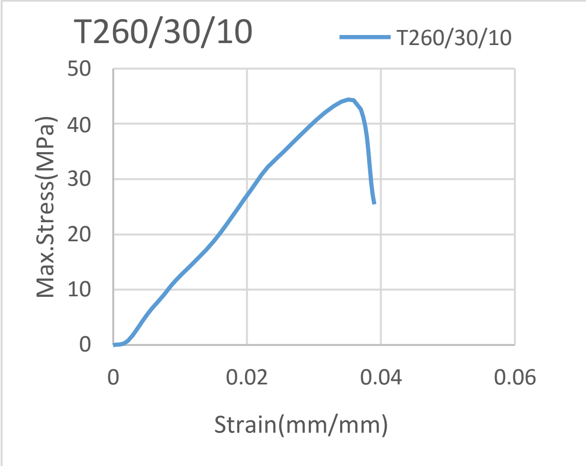


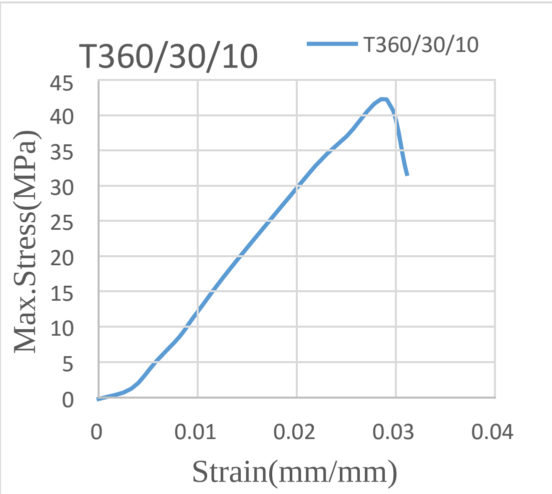


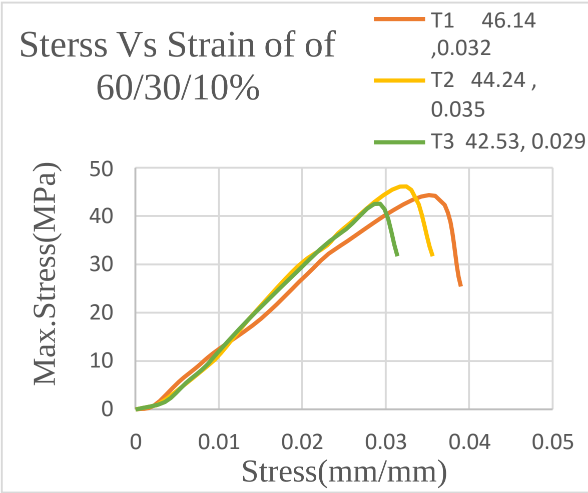


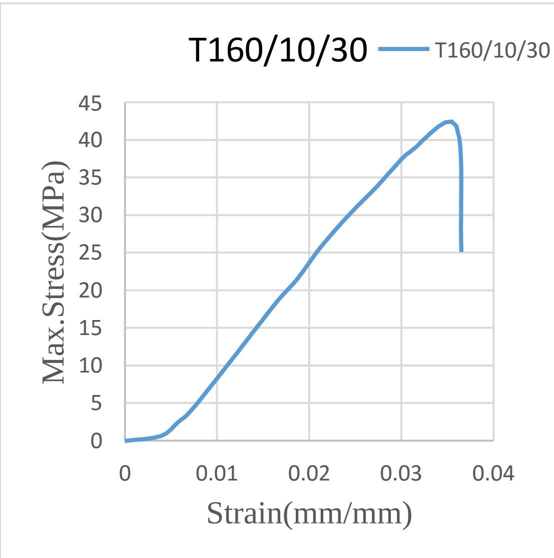


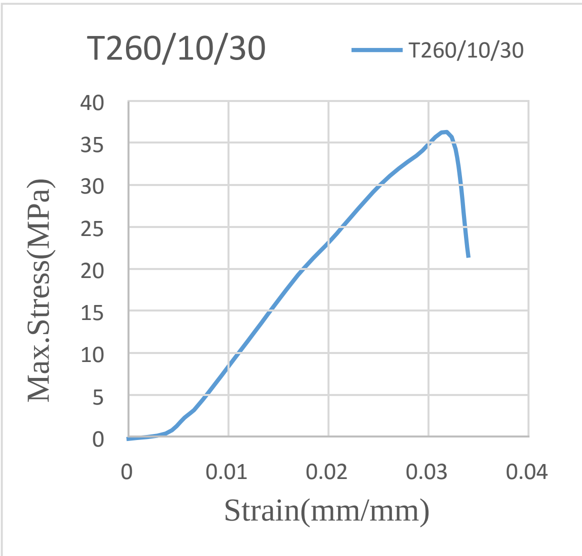

T160/30/10
Max.Stress(Mpa)
Strain(mm)

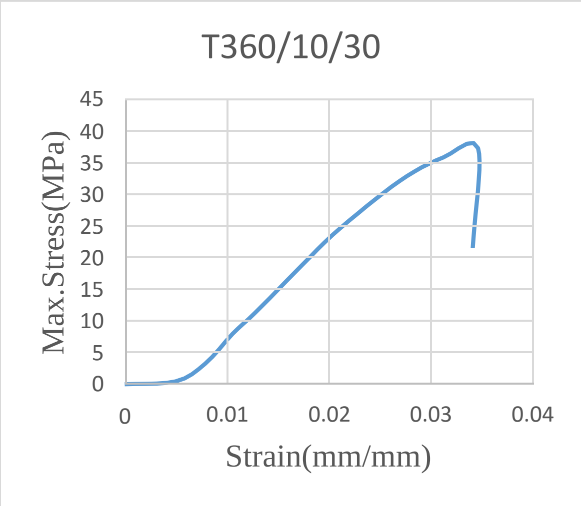

T260/30/10
T260/30/10
Max.Stress(MPa)
Strain(mm/mm)

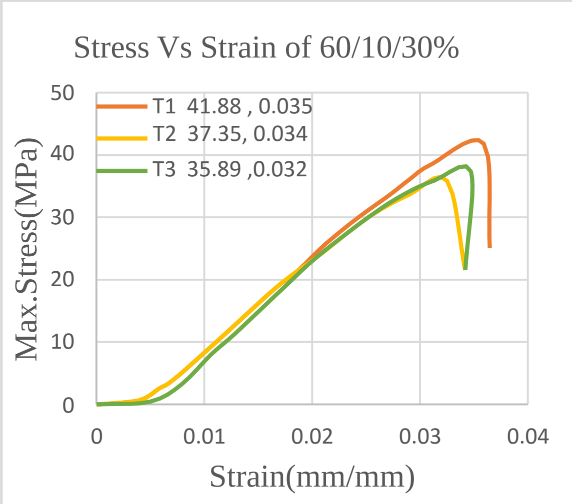

T360/30/10
T360/30/10
Max.Stress(MPa)
Strain(mm/mm)


Sterss Vs Strain of of 60/30/10%
T1 46.14 ,0.032
T2 44.24 , 0.035
T3 42.53, 0.029
Max.Stress(MPa)
Stress(mm/mm)

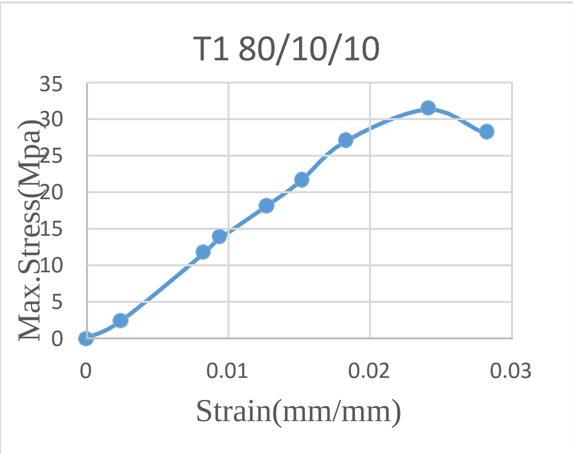

T160/10/30
T160/10/30
Max.Stress(MPa)
Strain(mm/mm)

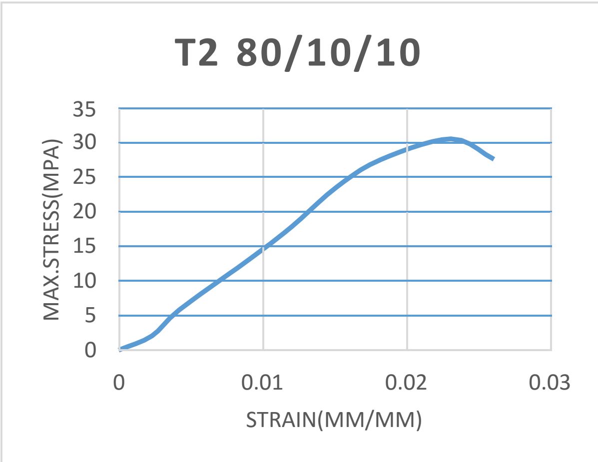

T260/10/30
T260/10/30
Max.Stress(MPa)
Strain(mm/mm)

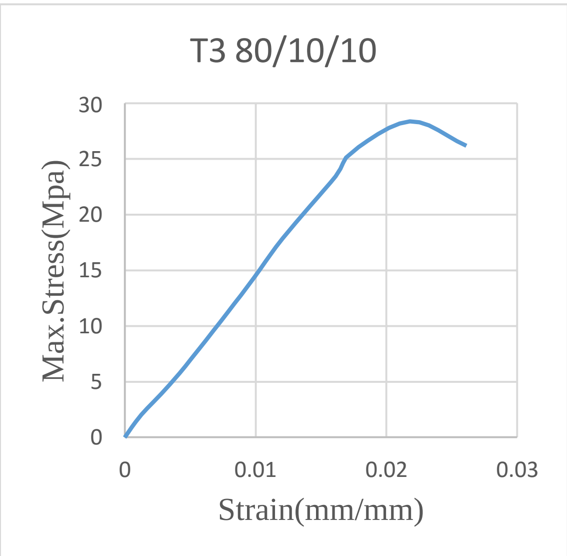


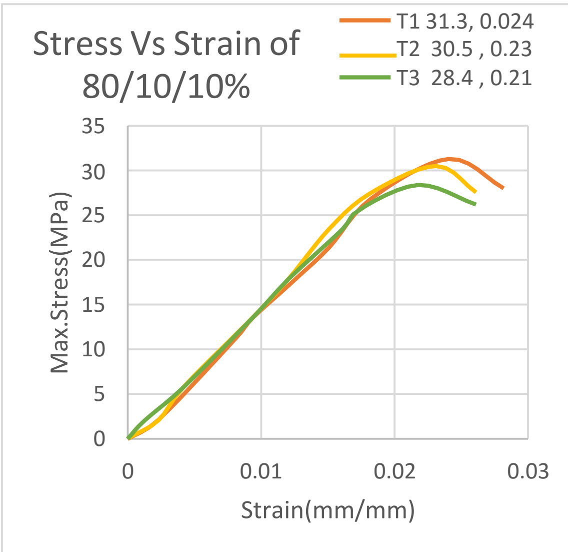


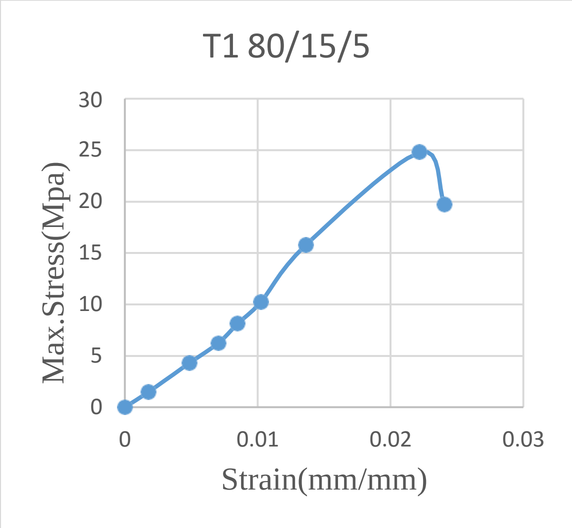
❖ <u>Stress-strain graph of 80/20% volume fraction composite.</u>

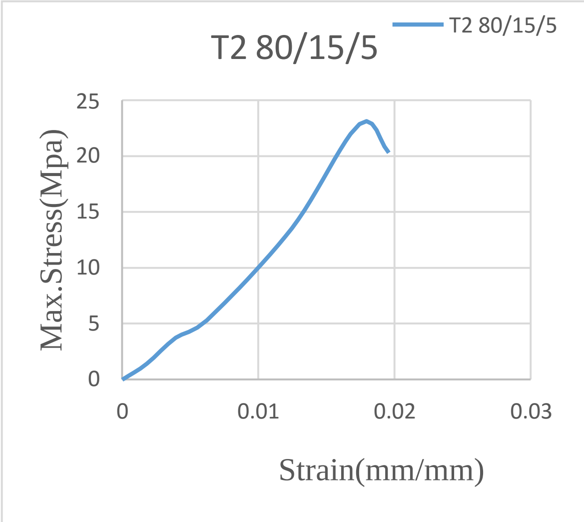


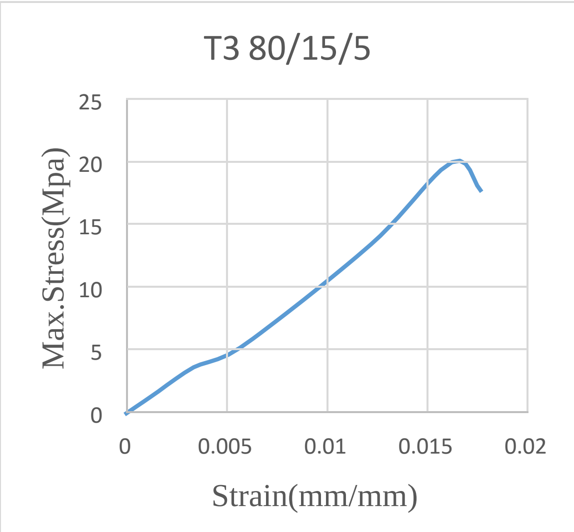


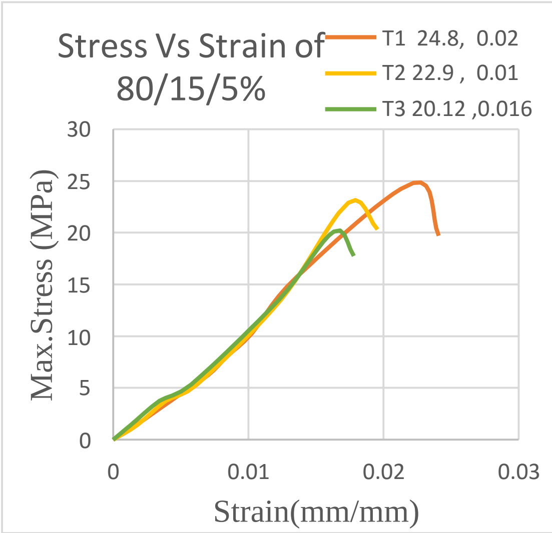


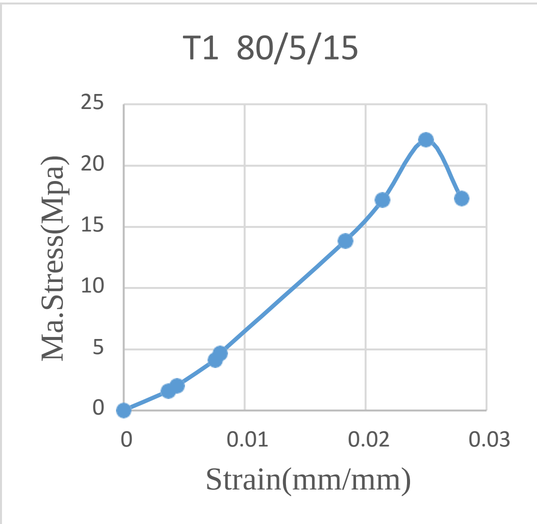


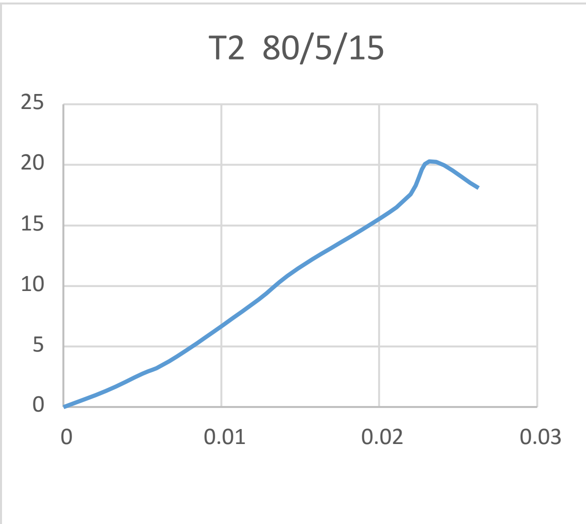

T1 80/15/5
Max.Stress(Mpa)
30
25
20
15
10
5
0
0
0.01
0.02
0.03
Strain(mm/mm)

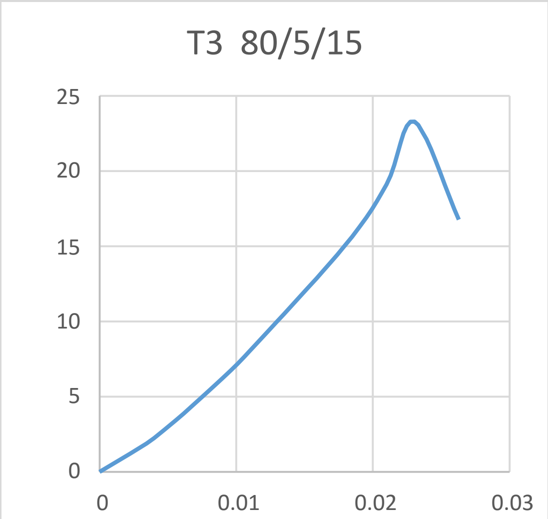

T2 80/15/5
T2 80/15/5
Max.Stress(Mpa)
25
20
15
10
5
0
0
0.01
0.02
0.03
Strain(mm/mm)

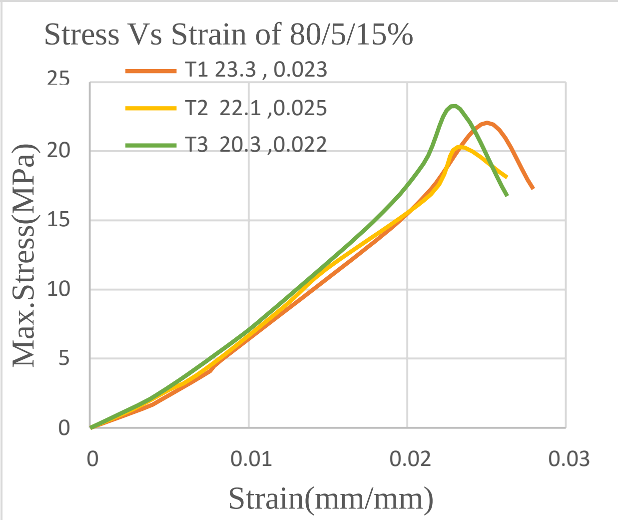

T3 80/15/5
Max.Stress(Mpa)
25
20
15
10
5
0
0
0.005
0.01
0.015
0.02
Strain(mm/mm)


Stress Vs Strain of 80/15/5%
T1 24.8, 0.02
T2 22.9 , 0.01
T3 20.12 ,0.016
Max.Stress (MPa)
30
25
20
15
10
5
0
0
0.01
0.02
0.03
Strain(mm/mm)

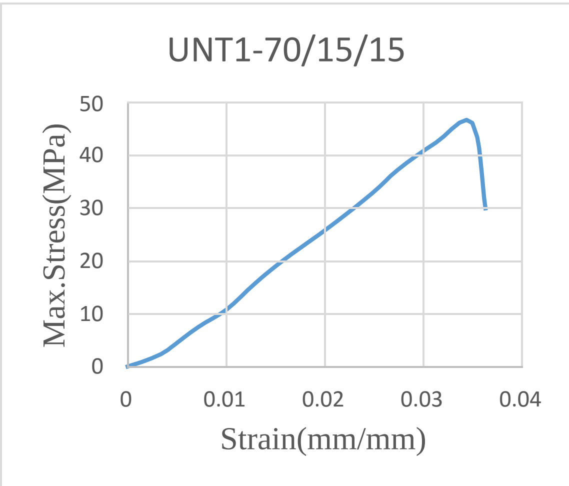

T1 80/5/15
Ma.Stress(Mpa)
25
20
15
10
5
0
0
0.01
0.02
0.03
Strain(mm/mm)

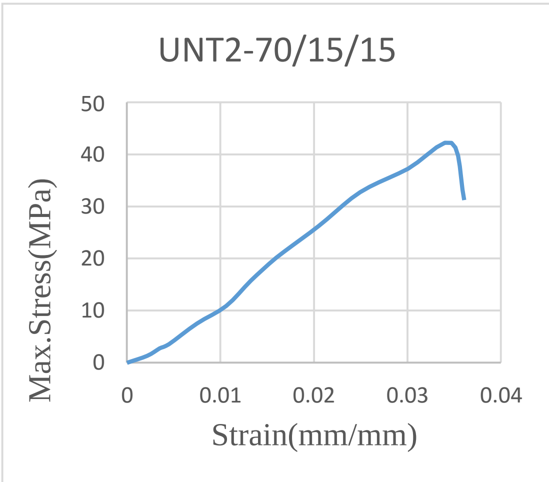

T2 80/5/15
25
20
15
10
5
0
0
0.01
0.02
0.03

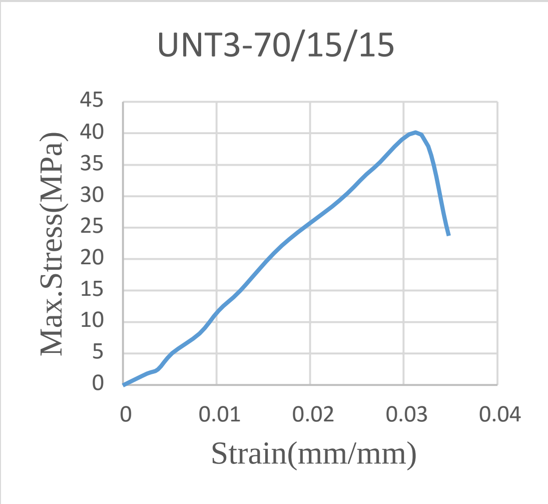


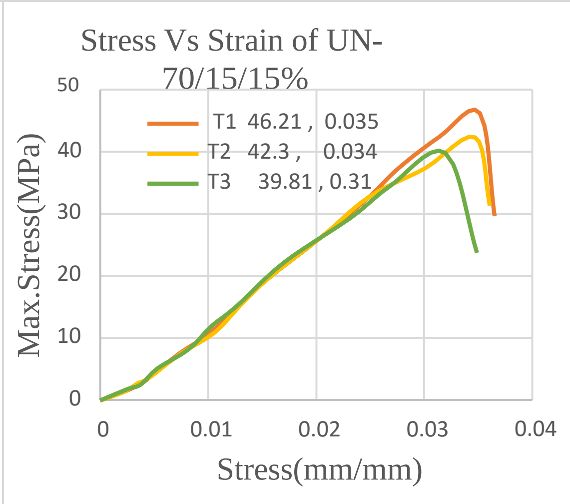


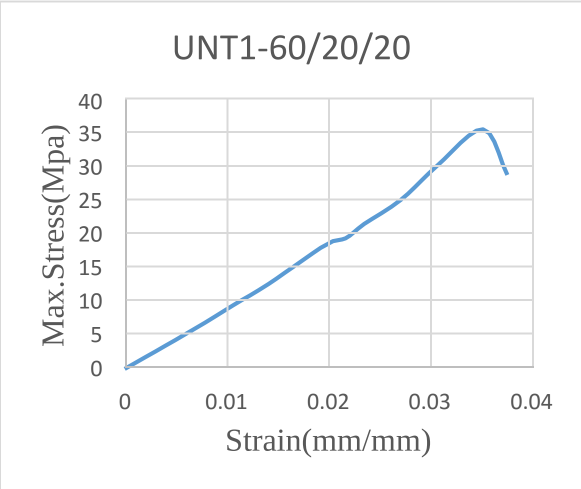
❖ <u>Stress-strain graph of untreated UN-60/40% and UN- 70/30%volume fraction composite.</u>

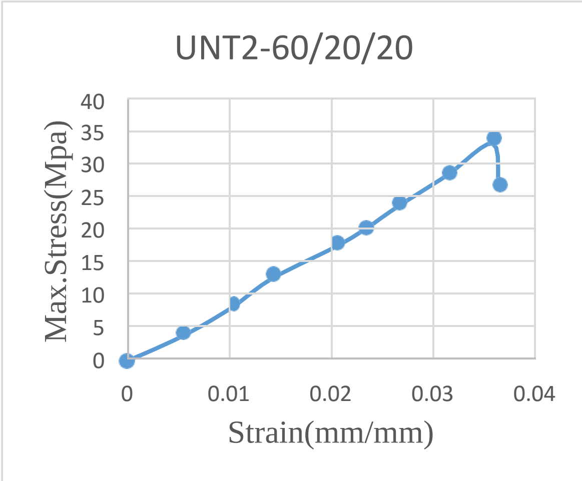


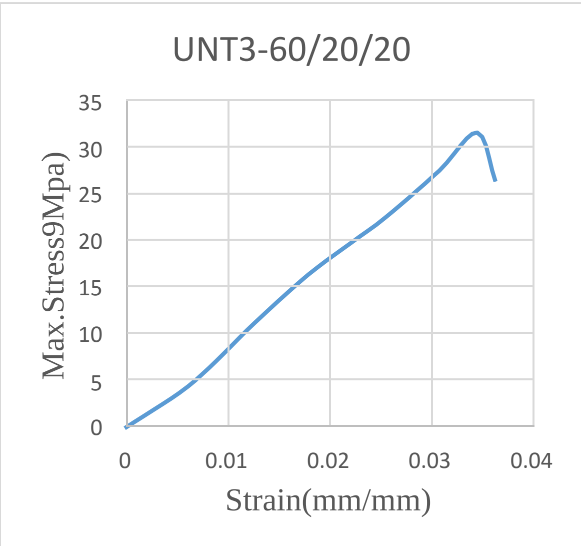


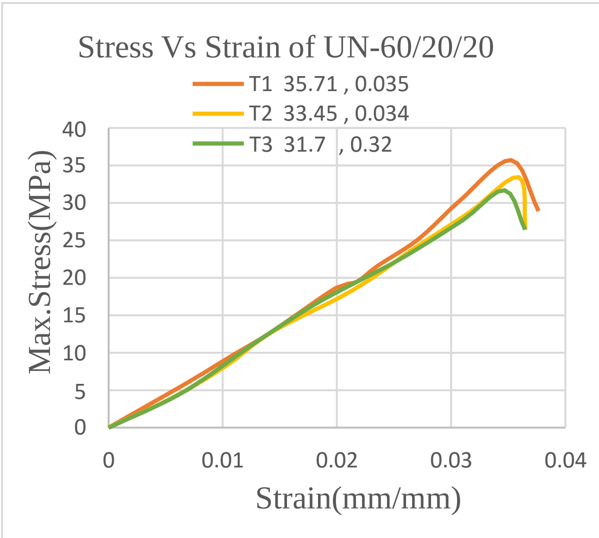

UNT3-70/15/15
Max.Stress(MPa)
0
5
10
15
20
25
30
35
40
45
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

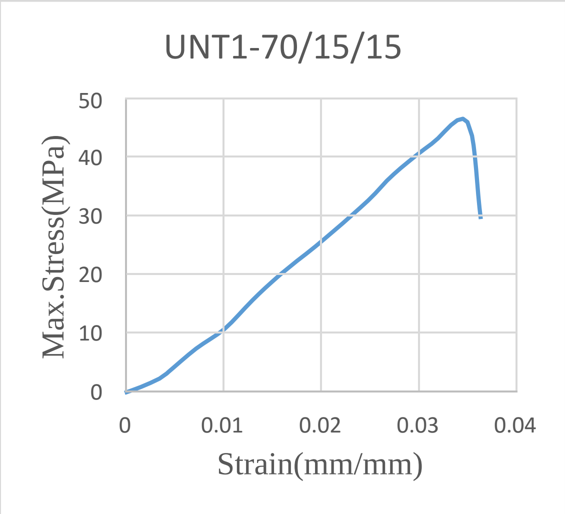

Stress Vs Strain of UN-70/15/15%
T1 46.21 , 0.035
T2 42.3 , 0.034
T3 39.81 , 0.31
Max.Stress(MPa)
0
10
20
30
40
50
0
0.01
0.02
0.03
0.04
Stress(mm/mm)

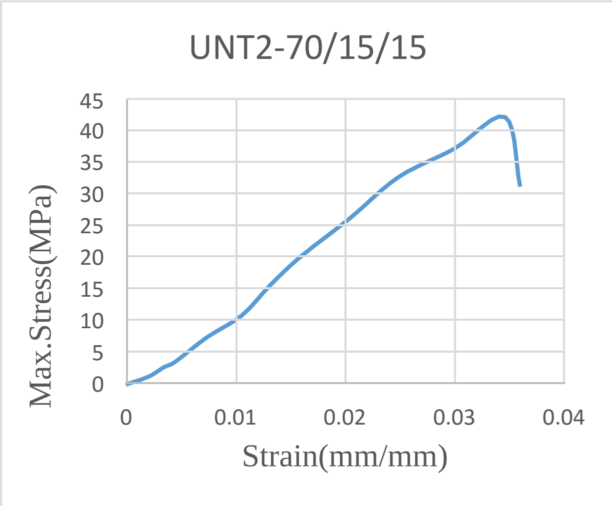

UNT1-60/20/20
Max.Stress(Mpa)
0
5
10
15
20
25
30
35
40
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

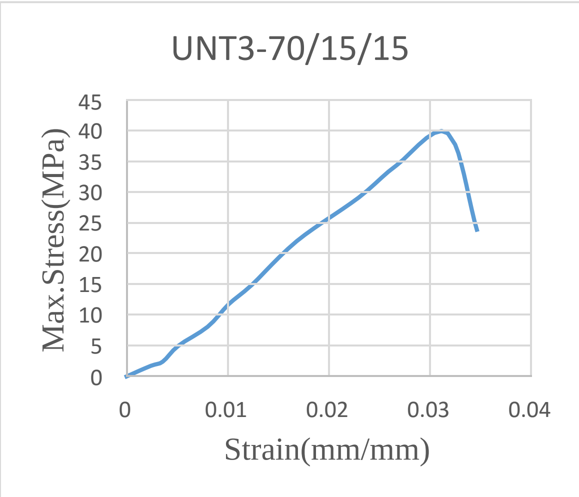

UNT2-60/20/20
Max.Stress(Mpa)
0
5
10
15
20
25
30
35
40
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

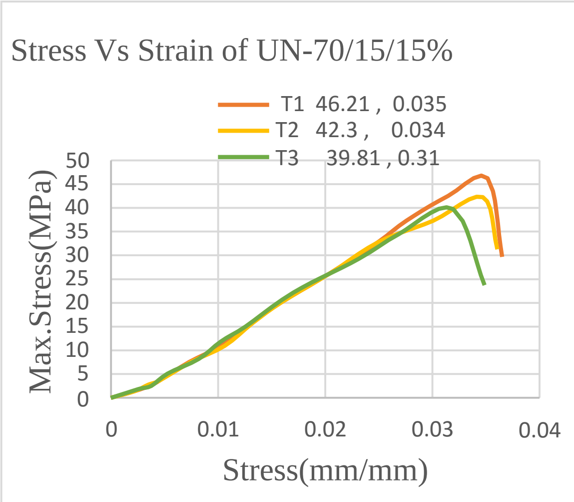

UNT3-60/20/20
Max.Stress9Mpa)
0
5
10
15
20
25
30
35
0
0.01
0.02
0.03
0.04
Strain(mm/mm)


Stress Vs Strain of UN-60/20/20
T1 35.71 , 0.035
T2 33.45 , 0.034
T3 31.7 , 0.32
Max.Stress(MPa)
0
5
10
15
20
25
30
35
40
0
0.01
0.02
0.03
0.04
Strain(mm/mm)

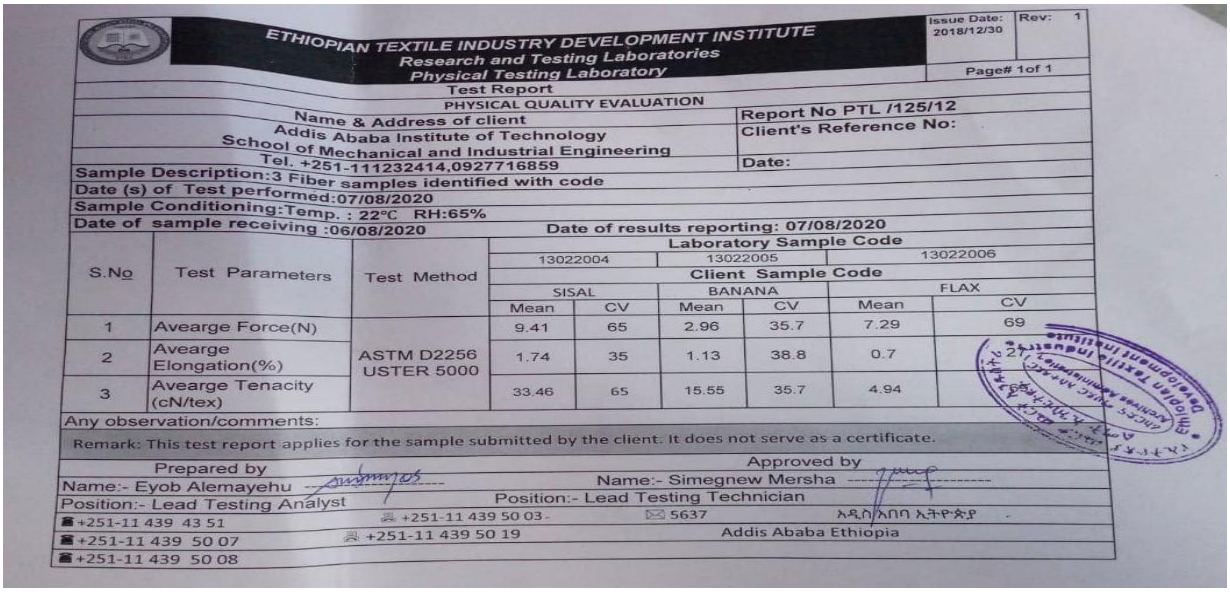

UNT1-70/15/15
Max.Stress(MPa)
Strain(mm/mm)


UNT2-70/15/15
Max.Stress(MPa)
Strain(mm/mm)


UNT3-70/15/15
Max.Stress(MPa)
Strain(mm/mm)


Stress Vs Strain of UN-70/15/15%
T1 46.21 , 0.035
T2 42.3 , 0.034
T3 39.81 , 0.31
Max.Stress(MPa)
Stress(mm/mm)

Appendix B



ETHIOPIAN TEXTILE INDUSTRY DEVELOPMENT INSTITUTE
Research and Testing Laboratories
Physical Testing Laboratory

Issue Date: 2018/12/30 | Rev: 1
Page# 1of 1

Test Report
PHYSICAL QUALITY EVALUATION

Name & Address of client
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
Tel. +251-111232414,0927716859

Report No PTL /125/12
Client's Reference No:
Date:

Sample Description:3 Fiber samples identified with code
Date (s) of Test performed:07/08/2020
Sample Conditioning:Temp. : 22°C RH:65%
Date of sample receiving :06/08/2020
Date of results reporting: 07/08/2020

S.No	Test Parameters	Test Method	Laboratory Sample Code 13022004		13022005		13022006	
			Client Sample Code: SISAL		BANANA		FLAX	
			Mean	CV	Mean	CV	Mean	CV
1	Avearge Force(N)	ASTM D2256 USTER 5000	9.41	65	2.96	35.7	7.29	69
2	Avearge Elongation(%)		1.74	35	1.13	38.8	0.7	
3	Avearge Tenacity (cN/tex)		33.46	65	15.55	35.7	4.94	

Any observation/comments:
Remark: This test report applies for the sample submitted by the client. It does not serve as a certificate.

Prepared by
Name:- Eyob Alemayehu
Position:- Lead Testing Analyst

Approved by
Name:- Simegnew Mersha
Position:- Lead Testing Technician

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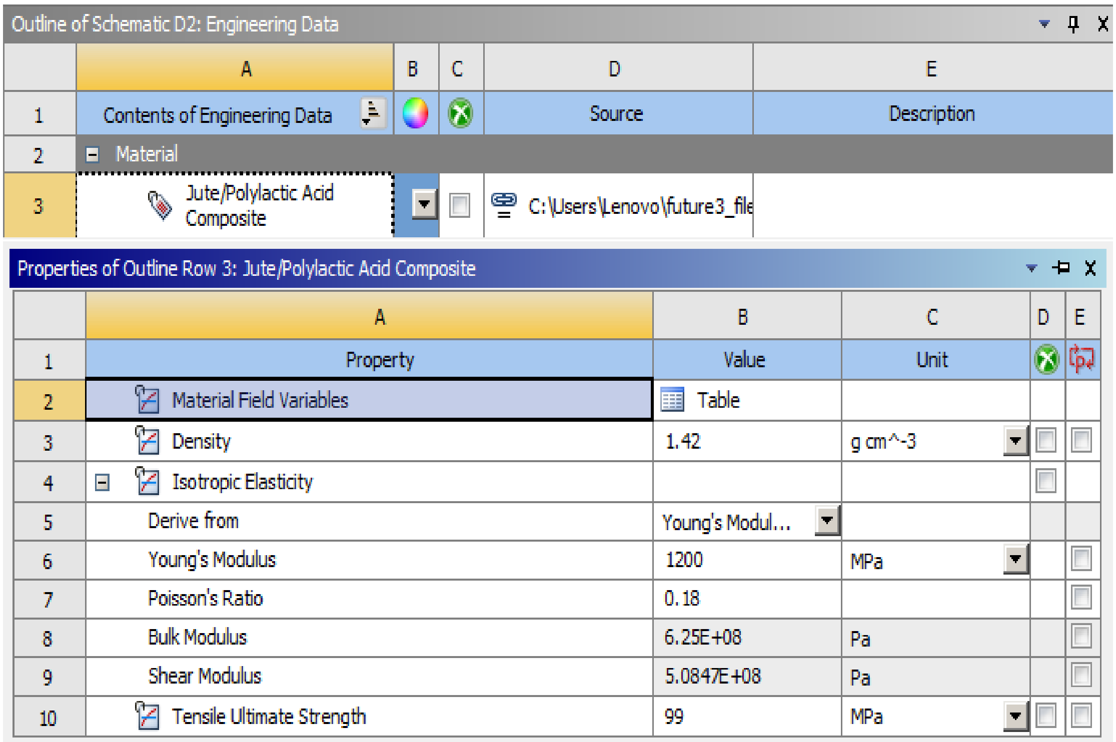
+251-11 439 50 07 | +251-11 439 50 19 | Addis Ababa Ethiopia
+251-11 439 50 08

Figure B1. Fibers average force, tenacity and elongation test result

- ❖ Von misses stress and total deformation for, Jute Poly Lactic Acid Composite and Aluminum alloy 1050-H14.



Outline of Schematic D2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Jute/Polylactic Acid Composite			C:\Users\Lenovo\future3_file	

Properties of Outline Row 3: Jute/Polylactic Acid Composite

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1.42	g cm^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modul...			
6	Young's Modulus	1200	MPa		
7	Poisson's Ratio	0.18			
8	Bulk Modulus	6.25E+08	Pa		
9	Shear Modulus	5.0847E+08	Pa		
10	Tensile Ultimate Strength	99	MPa		

Figure B2.Engineeing data for Jute-Polylactic reinforced composite

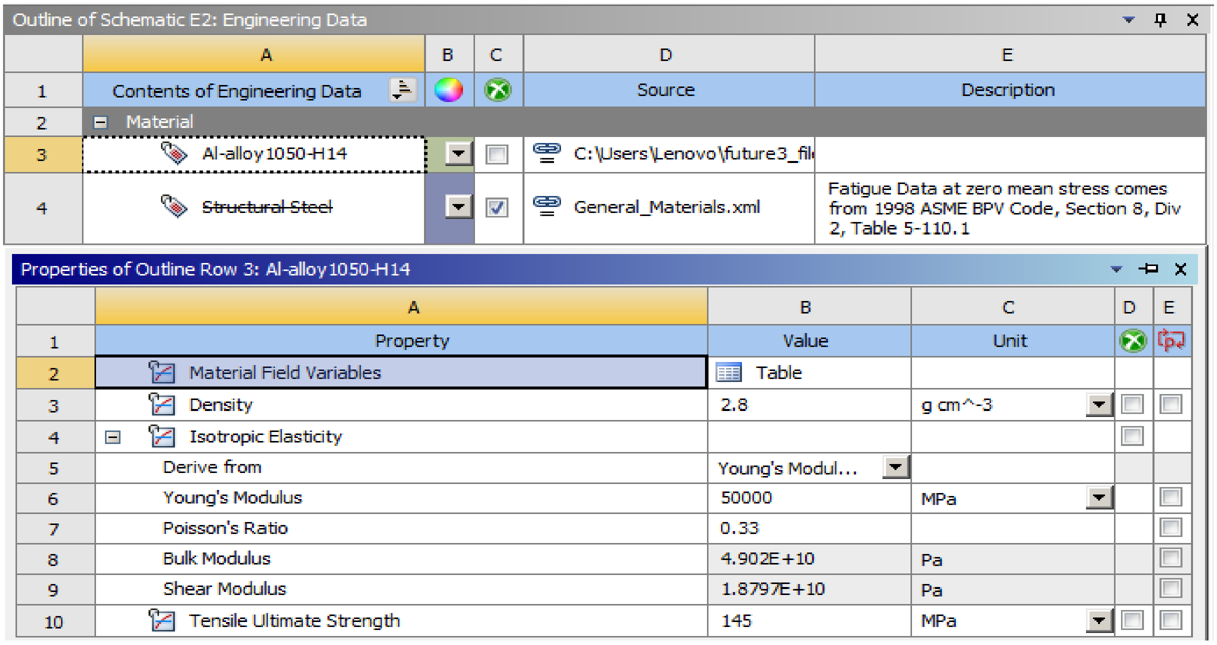


Figure B3. Engineering data for Al-alloy 1050-H14

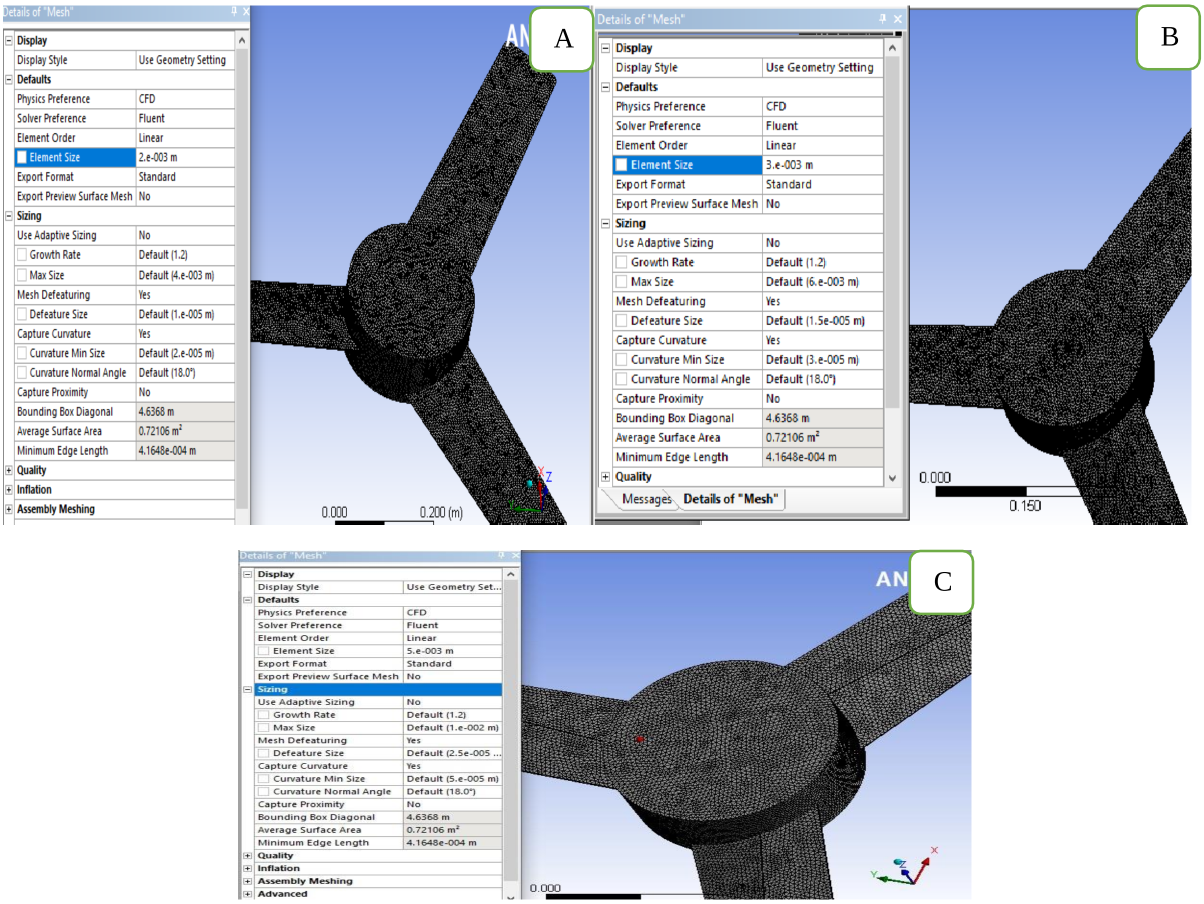


Figure B4. The mesh size of 2mm, 3mm and 5mm

A) 2mm mesh size, B) 3mm mesh size and C) 5mm mesh size

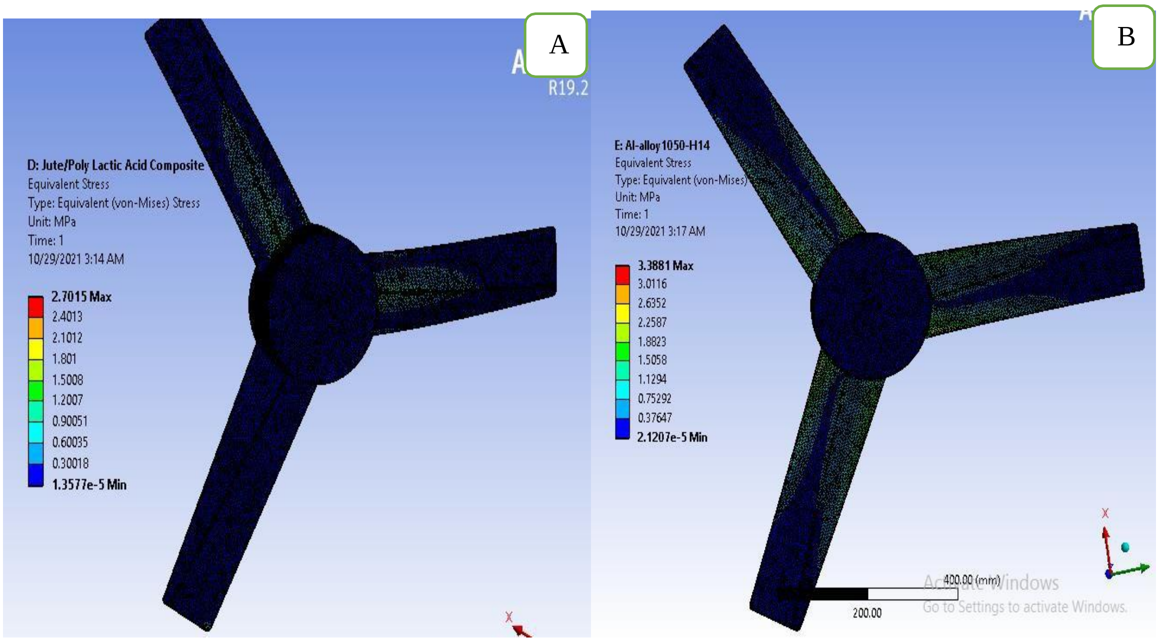


Figure B5. Von-misses stress of ceiling fan blades

A) For Jute-Polylactic reinforced composite & B) for Al-alloy 1050-H14

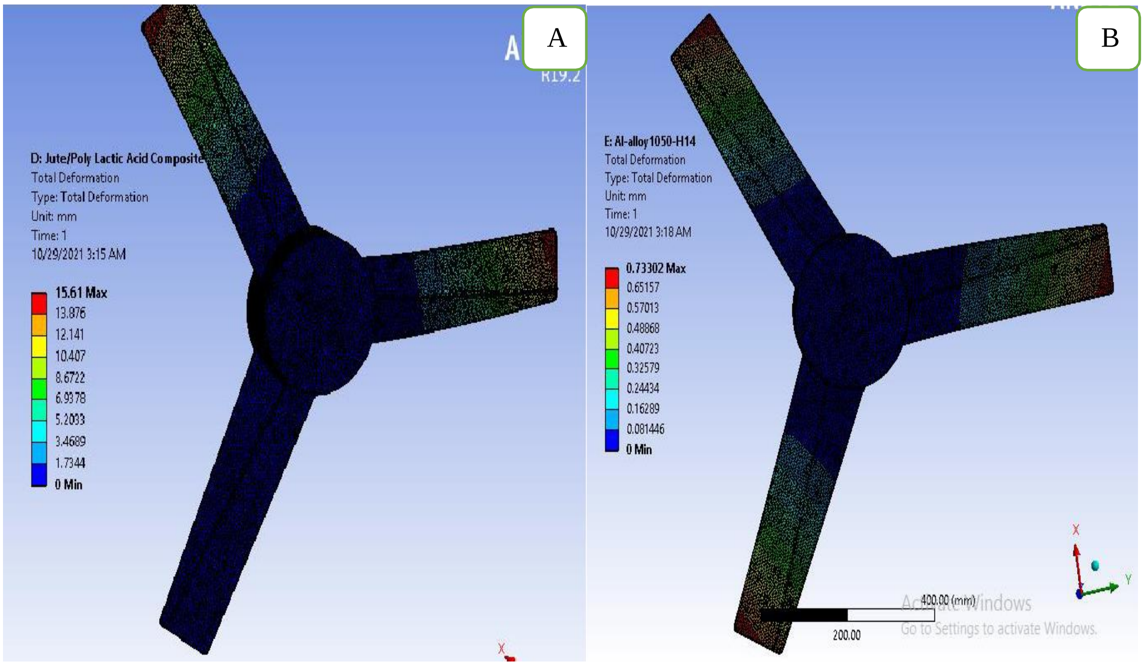


Figure: B6. Total deformation of ceiling fan blades

A) For Jute-Polylactic reinforced composite & B) for Al-alloy 1050-H14

Appendix C

Table C1.Epoxy Matrix and Hardner property

Specification	Epoxy resin LY556	Hardner HY951
Brand	Herebna	Herebena
Colour	Clear liquid	Clear Liquid
viscosity at room temperature	10000-12000(mPa*s)	10-20(mPa*s)
Density at room temperature	1.10-1.20 (g/cm^3)	0.98(g/cm^3)
Form	Liquid	Liquid
Drying Temperature	at Room temperature	at Room temperature
Curing Time	10-20min	10-20min
Capacity for Casting and Fiber Works	Epoxy Resin 1Kg and	Hardner HY951 100g
Application	Adhesives& Sealants, Building Coating, Appliance Paint	-
Categories	Filament winding, Pultrusion, and pressure molding	-
Grade Standard	Industrial Grade, Technical Grade, and Chemical Grade	-
Shelf Time	2 years	-

Table C2. Composition of flax and banana fibers

Fiber Type	Cellulose (%)	Hemi cellulose (%)	Lignin (%)	Pectin (%)	Authors
Flax Fiber	80	13	2	-	[43][102]
	62.21-69.61	16.86-22.30	5.18-7.96	1.20-2.12	[103][46]
	71	18.6-20.6	2.2	2.3	[56]
	40.11	28.27	15.08	3.1	[63]
	60-81	14-20.6	2-3	1.8-5	[34]
Banana Fiber	62-64	19	5	-	[44]
	60-65	6-19	5-10	3-5	[34]

Table C3. Physical properties of Flax and Banana fiber

Types of Fibers	Density (g/cm^3)	Moisture content (%)	Authors
Flax fiber	1.4	50-	[85]
	1.5	-	[33]
Banana Fiber	1.35	10-11.5	[44]
	1-1.5	-	[85]
	1.3-1.35		[34]

Table C4. Mechanical Properties of Flax and Banana Fibers

	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Flexural Modulus (Gpa)	Elongation at break (%)	Reference
Flax Fiber	345-1500	27.6	-	2.7-3.2	[34]
Banana Fiber	54	3.48	2-5		[44]
	529-914	27-32	-	1-3	[34]

Table C5 . Tensile strength test result of 60/40% composite

Volume fraction of Epoxy/Flax/Banana (%)	Max.Force(N)	Deformation (mm)	Max.Stress (Mpa)	Y.Modulus (Gpa)	Strain (mm/mm)	Elongation (%)
60/20/20	3990	8.78	53.2	1.51	0.035	3.51
	3877.5	8.96	51.7	1.44	0.035	3.58
	3757.5	8.65	50.1	1.44	0.034	3.46
Average	**3875**	**8.79**	**51.66**	**1.46**	**0.035**	**3.51**
60/30/10	3318	8.98	44.24	1.23	0.035	3.59
	3460.5	8.12	46.14	1.42	0.032	3.2
	3189.75	7.33	42.53	1.45	0.029	2.9
Average	**3322.75**	**8.14**	**44.3**	**1.36**	**0.032**	**3.25**
60/10/30	3141	8.98	41.88	1.16	0.035	3.59
	2801.25	8.68	37.35	1.07	0.034	3.47
	2691.75	8.13	35.89	1.10	0.032	3.25
Average	**2878**	**8.59**	**38.37**	**1.1**	**0.034**	**3.43**

Table C6. Tensile strength test result of 70/30% composite

The volume fraction of Epoxy/Flax/ Banana (%)	Max.Force(N)	Deformation (mm)	Max.Stress (Mpa)	Y.Modulus(Gpa)	Strain (mm/mm)	Elongation (%)
70/15/15	5325.75	10.32	71.01	1.7	0.041	4.128
	5176.19	9.33	69.02	1.8	0.037	3.732
	5010	9.02	66.8	1.85	0.036	3.608
Average	**5170.64**	**9.55**	**68.94**	**1.80**	**0.038**	**3.82**
70/20/10	4477.5	8.25	59.7	1.8	0.033	3.3
	4381.5	7.87	58.42	1.85	0.031	3.1
	4008.75	7.65	53.45	1.74	0.03	3.06
Average	**4289.25**	**7.92**	**56.8**	**1.73**	**0.031**	**3.16**
70/10/20	3428.25	8.25	45.71	1.38	0.033	3.3
	3265.5	8.12	43.54	1.34	0.032	3.248
	3099	8.08	41.32	1.27	0.032	3.232
Average	**3264.25**	**8.15**	**43.52**	**1.33**	**0.0326**	**3.26**

Table C7.Tensile strength test result of 80/20% composite

Volume fraction of Epoxy/Flax /Banana (%)	Max.Force(N)	Deformation (mm)	Max.Stress (MPa)	Y.Modulus (Gpa)	Strain (mm/mm)	Elongation (%)
80/10/10	2347.5	6.01	31.3	1.30	0.024	2.40
	2287.5	5.78	30.5	1.31	0.023	2.312
	2130	5.45	28.4	1.30	0.021	2.18
Average	2255	5.74	30.06	1.30	0.022	2.29
80/15/5	1860.75	5.55	24.81	1.11	0.022	2.22
	1717.5	4.35	22.9	1.31	0.017	1.74
	1509	4.08	20.12	1.23	0.016	1.632
Average	1695.75	4.66	22.61	1.22	0.018	1.864
80/5/15	1657.5	6.25	22.1	0.88	0.025	2.5
	1522.5	5.79	20.3	0.87	0.023	2.31
	1747.5	5.76	23.3	1.01	0.023	2.3
Average	1642.5	5.93	21.9	0.92	0.023	2.37

Table C8. Tensile strength test result of UN- 60/40% and UN-70/30%

V. fraction of Epoxy/Flax/Banana (%)	Max.Force(N)	Deformation (mm)	Max.Stress (Mpa)	Y.Modulus (Gpa)	Strain (mm/mm)	Elongation (%)
UN-60/20/20	2378.25	8.67	31.71	0.914	0.034	3.468
	2508.75	8.98	33.45	0.931	0.035	3.592
	2678.25	8.81	35.71	1.01	0.035	3.524
Average	2521.75	8.82	33.62	0.95	0.035	3.528
UN-70/15/15	3465.75	8.78	46.21	1.31577449	0.03512	3.512
	3172.5	8.67	42.3	1.21972318	0.03468	3.468
	2985.75	7.98	39.81	1.24718045	0.03192	3.192
Average	3208	**8.47**	**42.77**	**1.26**	**0.033**	**3.39**

Table C9. Impact strength test result

Impact Energy(J)	Specimen 1	Specimen 2	Specimen3	Average
60/20/20	11	11.5	10	10.83
60/10/30	9.5	8.6	9.5	9.2
60/30/10	9.5	8	8.5	8.66
70/15/15	8	9	8.9	6
70/20/10	7	6.5	6	6.5
70/10/20	5.5	5.5	6	5.66
80/20/20	5.5	4.5	4.5	4.83
80/15/5	5	3.5	3.5	4
80/5/15	4.2	3.5	3.2	3.63
UN-70/15/15	8	8	5.5	7.16
UN-60/20/20	5	7.5	7.5	5.83

Table C10. Flexural Strength result

Fiber surface modification	Specimen Type	V. Fraction of Epoxy/Flax/Banana	Max.Test Force(N)	Flexural Strength (N/mm2)	Deflection (mm)
Treated	B1	70/15/15	106.66	169.14	12.52
	B2	70/20/10	56.67	92.53	16.16
	B3	70/10/20	53.33	86.76	10.16
	B4	60/20/20	63.3	104.35	11.5
	B5	60/30/10	56.66	93.37	14.17
	B6	60/10/30	46.6	76.53	10.82
	B7	80/20/20	53.33	87.49	13.01
	B8	80/15/5	44.25	70.8	15.24
	B9	80/15/5	23.33	38.26	9.95
Untreated	B10	UN-70/15/15	60	98.41	11.91
	B11	UN-60/20/20	56.66	92.95	9.84

Table: C11. Water absorption test result

Composite Specimens code	Volume Fraction of Epoxy/Flax/ Banana Fiber	Wight Before Immersion	Weight after Immersion	Water absorption Percentage (%)
W1	70/15/15	3.96	4.62	16.67
W2	70/20/10	3.48	4.12	18.39
W3	70/10/20	3.2	4.04	26.25
W4	60/20/20	2.78	3.58	28.77
W5	60/30/10	1.86	2.3	23.65
W6	60/10/30	2.84	3.34	17.60
W7	80/10/10	2.984	3.64	21.98
W8	80/15/5	3.24	3.68	13.58
W9	80/5/15	2.27	2.7	18.94
W10	UN-60/20/20	3.76	4.94	31.38
W11	UN-70/15/15	3.14	4.06	29.29