Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite

By

Meseret Tadesse Yilma

A Thesis submitted in partial fulfillment of the requirements for the degree of Masters in Manufacturing Engineering

Department of Mechanical Design and Manufacturing Engineering program

School of Mechanical Chemical and Materials Engineering

Office of Graduate Studies

Adama Science and Technology University

November, 2021

Adama, Ethiopia

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Declaration

I declare that thesis entitled "Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite", is my own work and has not been submitted to any university for similar purpose. The references used in this thesis are duly recognized by proper citations.

Name	Signature	Date
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I, the major advisor of this thesis works hereby certify that I have closely advised the student while developing this thesis work and read the draft thesis entitled “Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite” prepared under my guidance by Meseret Tadesse Yilma. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

Name	Signature	Date
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(Co-advisor)		

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I/we hereby certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated into the final thesis work entitled "Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite" by Meseret Tadesse Yilma.

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We, the undersigned, members of the Board of Reviewers of the thesis open defense by Meseret Tadesse Yilma have read and evaluated the thesis intitled "Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite" and assisted the understanding of candidate about the thesis research. this is, Therefore, to certify that the thesis.

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Glory to the almighty God and his mother for protecting and blessings me to complete my study.

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CONTENTS

LIST OF TABLES

FIGURE

FIGURE **PAGE**

List of Acronyms

Abbreviation	Description
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
Aver.	Average
BBD	Box–Behnken Design
BGRP	Bamboo and Glass Reinforced Polypropylene
CSM	Chopped Strand Mat
EFB	Empty Fruit Bunch
FRP	Fiber Reinforced Polymer
FTIR	Fourier transforms infrared spectroscopy
GCG2C	Hybrid glass–Carbon Fiber-Reinforced Polymer Composite
GFRP	Glass Fiber Reinforced Polymer
H_2SO_4	Sulfuric Acid
HCL	Hydrochloric Acid
KIC	Knowledge and Innovation Community
MAPP	Maleic Anhydride grafted Polypropylene
N.D	Not Defined
NaOH	Sodium Hydroxide
NF	Natural Fibers
NFRC	Natural Fiber Reinforced Composite

PEI	Polyetherimide
PLA	Polylactic Acid
PMC	Polymer Matrix Composite
POM	Polyoxymethylene
RC	Reinforced Concrete
RFRVE	Reinforced Vinyl Ester
RSM	Response Surface Methodology
SEM	Scanning Electron Microscopy
Std Dev	Standard Deviation
STE	Static Transmission Error
VARTM	Vacuum Assisted Resin Transfer Molding
XRD	X-ray Diffraction
EDX	Energy Dispersive X-ray Analysis
PV	Pressure and Volume
UD	Uni directional

NOMENCLATURE

MC	Mass of Composite
Mf	Mass of fiber
MPa	Mega Pascal
mm	Millimeter
MR	Mass of Resin
VR	Volume of Resin
Vf	Volume of fiber
ρc	Density
GPa	Giga Pascal
Wt.%	Weight of Percentage
Wf	Weight of fiber
Wc	Weight of Composite
Wm	Weight of Matrix

Abstract

Natural and synthetic fibers have several advantages due to their light weight applications in the automobile industry. Properties like mechanical strength, low-density, better thermal and acoustic insulation and low cost were very attractive. In this thesis, an investigation of the input parameters and mechanical properties of epoxy-based hybrid composites reinforced with glass/bamboo fibers was carried out. Composite samples were prepared based on Taguchi's L_9 *orthogonal array design using a hand lay-up technique at room temperature. The fiber content, alkali treatment and epoxy resin concentration were optimized based on the general linear model and Taguchi analysis to get the maximum level of mechanical properties like tensile strength, flexural strength, compressive strength, hardness and impact strength. Results showed that the maximum tensile strength was 232.1MPa, maximum compressive strength 76.97MPa, maximum Rockwell hardness 67.93N/mm*^{2}*, maximum flexural strength 536.33MPa and the highest impact strength was 5.03J/M. The results revealed that fiber content of 20 wt.%, alkali treatment of 8 wt.% and epoxy resin with 65 wt.% were estimated to be the optimal parameters. Analysis of Variance (ANOVA) was conducted to identify the significant factors and established all the three factors as being significant. The amount of bamboo fiber was found to be the most significant parameter which greatly affected the mechanical properties of the hybrid composites. It was demonstrated that the mechanical properties of the epoxy-based natural fiber-reinforced polymer composites can be effectively improved.*

Key words: *optimization, mechanical properties, bamboo fiber, hybridization*

CHAPTER ONE

1. INTRODUCTION

1.1 Natural fibers and natural fiber reinforced composites

Natural fibers (NFs) are a very easy to obtain, extensively available material in nature. They reveal some outstanding material properties like biodegradability, low cost per unit volume, high strength, and specific stiffness. Composites made of NF reinforcements seem to carry some diverse properties over synthetic fibers, such as reduced weight, cost, toxicity, environmental pollution, and recyclability. These economic and environmental benefits of NF composites make them predominant over synthetic fiber-reinforced composites for modern applications. One of the most important materials used in polymer-based composites are plant fibers. This is due to their Biodegradability, low cost, and renewability (Tripathi & Yadav, 2017b).

The main drawback of using natural fiber is its high level of moisture absorption and insufficient adhesion between untreated fibers and the polymer matrix, which can lead to deboning with age (Bledzki & Gassan, 1999). In polymer composites, the reinforcing phase can either be fibrous or non-fibrous (particulates) in nature and if the fibers are derived from natural resources like plants or some other living species, they are called natural-fibers. Natural fibers as reinforcement in composite materials have recently attracted the attention of researchers because of their several advantages (Mahesh et al., 2017). Natural fibers are hair-like or thread-like, naturally existing substances with a high aspect ratio. Based on their source, natural fibers are classified into three categories: animal fibers (silk), vegetable fibers (abaca), and mineral fibers (asbestos). It is well known that natural fibers are now on the verge of replacing synthetic fibers (glass fibers, carbon fiber, etc.). in many areas of application due to their advantages like low cost, low weight, and biodegradability. One of the most important materials used in polymer-based composites are plant fibers. This is due to their biodegradability, low cost, and renewability (Panda, n.d.).

Natural fibers and synthetic fibers have several advantages that have made them particularly attractive to the automobile industry. These include relatively good mechanical strength, low density, better thermal and acoustic insulation and low cost. According to the need the different type of fibers composites (Natural, synthetic and composite of natural and synthetic) can be reinforced (Kumar et al., 2019). The term "natural fibers" may refer to a very wide category of fibers. All the fibers are derived from natural sources. They may either be Animal fibers (animal hair, chicken feather etc.) or Plant Fibers (Leaf, seed, etc.). The Natural fiber composites having more environmental advantages such as lower pollutant emissions, lower greenhouse gas emissions and end of life biodegradability of components. The utilization of natural or synthetic fibers in the fabrication of composite materials has revealed significant applications in a variety of fields such as construction, mechanical, automobile, aerospace, biomedical, and marine (Clyne & Hull, 2019).

The natural fibers are highly complex structures. Their three-dimensional structure is found to consist of Cellulose, Hemicelluloses, Pectin and Lignin. They contain hydroxyl ions, and are distributed throughout the fiber wall. Interestingly, natural fibers may be considered as being tiny fiber reinforced composites on their own. They are made up of mainly cellulose fibrils (acting as fibers) embedded in a matrix of lignin. Apart from these, they also contain various extraneous compounds such as low weight extractives and inorganic ash (Panda, n.d.).

The main reason of using natural fiber is when they are added to plastic or polymer matrices, they significantly improve mechanical performance of the entire composite. An improvement in strength and stiffness is obtained without significant increase in density or the cost of the material.

Table 1.1 Comparative properties of some of the widely used Fibers

Fiber	Specific Gravity	Tensile strength (MPa)	Tensile Modulus (GPa)
Jute	1.3	393	55
Sisal	1.3	510	28
Flax	1.5	344	27
Sun hemp	1.7	389	35
Pineapple	1.56	170	40
Bamboo	0.86	520	36
E glass	2.5	3400	28
Kevlar 29	1.44	2860	64
Carbon fiber (As-24)	1.8	4000	245

1.2 Bamboo Plant

Bamboo is not grass nor wood, while it has two of its characteristics. It belongs to the family of the Bambusoideae. It is estimated that 60–90 hectare of bamboo exists, encompass approximately 1100–1500 species and there are about 600 different botanical species of bamboo in the world. Bamboo mainly grows in tropical and sub-tropical regions of Asia, Latin America and Africa (S. George, 2010). Bamboo is a natural product and will therefore always have some extent of irregularity. It is therefore suggested that in Western European countries, the bamboo culm should be used in functions where the measurement requirements are not entirely precise or fixed, as in temporary buildings (e.g., pavilions and tents) or small civil projects (e.g., bridges). Furthermore, bamboo can play a role as a non-supporting or finishing material.(Lugt & Dobbelsteen, 2005). It is obvious that ecological materials satisfy fundamental requirements like pollution prevention and cost minimization. The use of agricultural by-products, which are environmentally friends, such as rice husk, coconut fibers, sisal and bamboo, minimizes energy consumption, conserves non-renewable natural resources, reduces pollution and maintains a healthy environment (S. George, 2010). Bamboo is the core of this materials that fulfills these advantages.

1.3 Bamboo fibers

Bamboo fibers are an abundant natural material with mechanical properties comparable with those of glass fibers that are commonly used in fiber reinforced plastic composites. Bamboo fibers stand out from the group of natural fibers due to the fast growing and high yield of this plant. The advantage of bamboo fibers is in their high specific stiffness, high strength, low weight, low cost, biodegradability, non-abrasive nature and sound absorption. The mechanical properties of bamboo, such as stiffness, impact strength and flexibility, are high and comparable to those of synthetic fibers such as glass fiber. The potential for the development of structures made of bamboo has already been researched. However, its application in composite materials has been somewhat limited. Bamboo is one of the ecological materials that has many distinct characteristics, such as: It reaches its maximum strength in just few years; it is renewable material; Have simple production process; Have fairly good mechanical properties High specific strength, non-abrasive, eco-friendly, bio-degradability characteristics, have low cost and weight (Lugt & Dobbelsteen, 2005).

Studies have revealed that the percentage compositions of bamboo fibers vary according to the bamboo age, region, and environmental conditions, and thus the percentage composition of cellulose, lignin, hemicellulose, and ash. In fact, about 90% of the total weight of bamboo is made of fiber, while the other remaining 10% of constituents are tannins, pigments, ash, fat, protein, and pectin. Table 1.2 shows the composition of a few natural fibers (Panda, n.d.).

1.4 Diversity of Bamboo in Ethiopia

Different bamboo species are available here in Ethiopia. Ethiopia has Africa's biggest bamboo Resources and this wooden grass can be harvested in sustainable cycles on 30%- 40% of the mature culms every two years (S. George, 2010). The total resource base of Ethiopia is confined to two indigenous bamboo species out of more than 1500 species of bamboo in the world and 43 species in Africa. The highland bamboo (Yushania alpina), 8cm diameter and 17m height cover 15% and the monotypic genus lowland bamboo (Oxythenantera abyssinica), with solid culms at maturing age, 5cm diameter and 7m high covers 85% (S. George, 2010).

Table 1.2 Composition of a few Natural Fibers

Natural Fiber	Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)
Coir	43	45	-	-
Banana	65	5	-	-
Sisal	47-62	7-9	21-24	0.6-1
Jute	41-48	21-24	18-22	0.8
Bamboo	26-43	21-31	15-26	1.7-5
Kenaf	44-57	15-19	22-23	2-5
Cotton	85-90	0.7-1.6	1-3	0.8-2
Wood	40-45	26-34	7-14	< 1

The location of the bamboo rich sources in Ethiopia are as shown in Figure 1.1 (S. George, 2010).

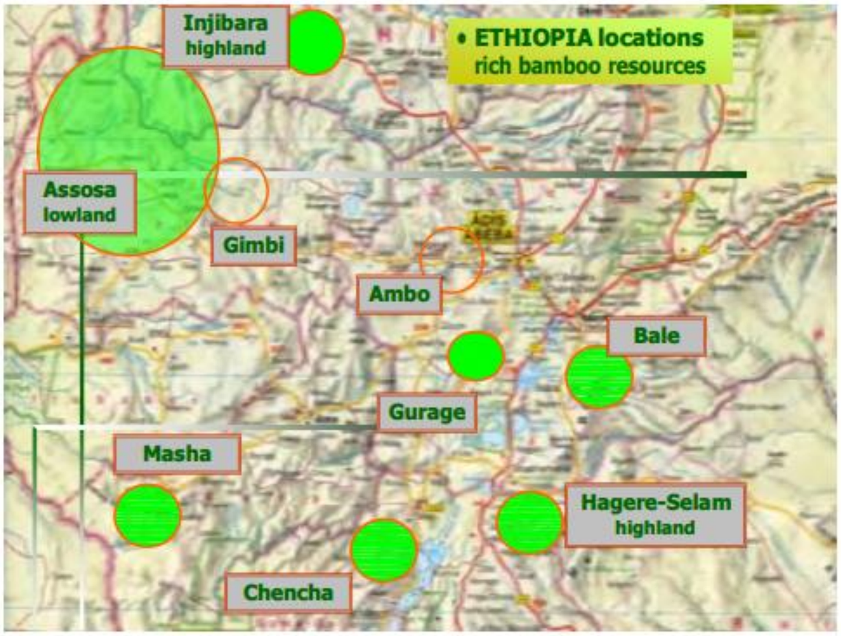

Figure 1.1 Diversity of Bamboo in Ethiopia

1.5 Bamboo fiber-reinforced composites

There are a substantial number of open studies on bamboo fiber reinforced composites, especially fiber-reinforced thermoplastic polymers (polypropylene, polyethylene, polylactic acid and polybutylene succinate) and fiber reinforced thermosetting resins (polyvinylchloride, polyester, novolac and epoxy resins). In recent years, researchers have focused on biodegradable composites made out of natural fibers and bio-resins. Investigations were carried out on bamboo fiber filled natural rubber composites and on the properties of chemically modified soy protein resin reinforced by bamboo fibers. Resin on the basis of cornstarch blended with bamboo fibers was also investigated as a fully biodegradable material. In an effort to solve problems with industry wastes, the study on epoxy resin filled with bamboo fibers and red mud was made. Red mud is solid waste that remains after refining bauxite in the process of fabrication of aluminum.

The mechanical shortcomings of homogenous materials and the need for composites were realized in the early 1950s, with the advent of the space age. Almost all homogenous materials have their inherent shortcomings in mechanical respect. When they are stiff and sufficiently hard, they are most brittle and hardly processible; when they are ductile and well processible, they are not stiff and hard enough. By the combination of materials, it proved possible to attain a situation in which the “whole is more than the sum of its parts”. Composites were a need in the evolution of engineering materials. The simplest combination is that of only two materials, one acting as reinforcement and the other as the matrix (Panda, 2012). The composite materials have advantage over other conventional materials due to their higher specific properties such as tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable the structural design to be more versatile. Due to their many advantages, they are widely used in the aerospace industry, in a large number of commercial mechanical engineering applications, such as machine components, Internal combustion engine parts, railway coaches, flywheels, process industries, sports and leisure equipment; marine structures; and biomedical devices (Panda, n.d.).

Natural fiber reinforced composites have beneficial properties such as low density, less expensive, and reduced solidity when compared to synthetic composite products, thus providing advantages for utilization in commercial applications (automotive industry, buildings, and constructions). Using natural fibers as reinforcement for polymeric composites introduces positive effect on the mechanical behavior of polymers (Mohammed et al., 2015). Generally, composite materials are classified and related to constituents as depicted in Figure 1.2 (Reinforced, 2013).

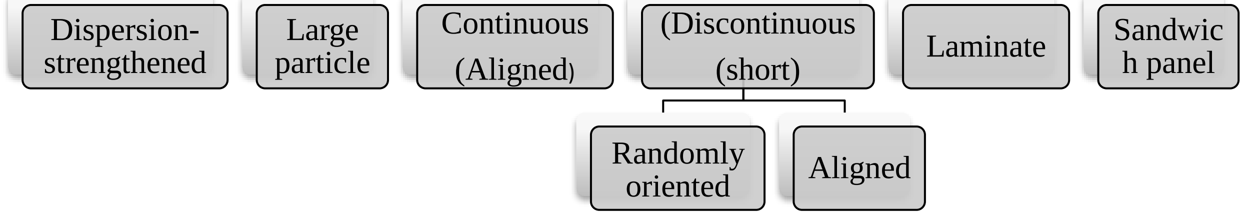

Figure 1.2 Composite Materials Classification

Fiber-reinforced polymer (FRP), also Fiber-reinforced plastic, is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. FRPs are commonly used in the aerospace, automotive, marine, and construction industries. Composite materials are classified according to their content, i.e., base material and filler material. The base material, which binds or holds the filler material in structures, is termed as a matrix or a binder material, while filler material is present in the form of sheets, fragments, particles, fibers, or whiskers of natural or synthetic material. Composites are classified into three main categories based on their structure (Altenbach et al., 2018).

Composite materials can be classified into many categories depending upon types of matrix material, types of reinforcing material, and nature of reinforcement. According to the type of matrix materials, composite materials are classified into three categories, such as metal matrix composites, ceramic matrix composites and polymer matrix composites. Metal matrix composites are made by dispersing a reinforcing material into a metal matrix. A composite with very high temperature resistance, high stiffness and strength can be produced by using a metal matrix. Ceramic matrix composite is made by dispersing a reinforcing material into a ceramic matrix. High temperature stability, high modulus, high hardness, high corrosion resistance, high thermal shock resistance, and low density characterize ceramics. However, they are brittle materials and possess low resistance to crack propagation, which is manifested in their low fracture toughness. The main reinforcements employed are silicon carbide and alumina (Cantor et al., 2003).

Polymer Matrix Composites are made by dispersing a reinforcing material into a polymer matrix. Types of reinforcements, type of polymer and the interface between them are mainly determining the properties of PMCs. In general, because of low mechanical properties such as strength and stiffness of polymers are insufficient for many structural purposes when compared to metals and ceramics (Akay, n.d.). These difficulties are overcome by reinforcing particle and fiber materials with polymers. Processing of polymer matrix composites does not require high temperature and pressure and also required simple manufacturing equipment's. For this reason, polymer composites developed rapidly and became popular for several applications. Polymers are divided into two categories such as thermoplastics and thermosets.

Design of experiments is a technique to obtain the large amount of conclusive information from the small amount of work, energy, time, money, or other limited resource. The information consists of relationship between product and process parameters and the desired performance characteristic (Prabhu et al., 2019). Analysis of variance (ANOVA) is used to investigate the influence of process parameters on the response characteristics. The purpose of ANOVA test is to determine the significance of process parameters that affect the mechanical properties of composite fiber (Navaneethakrishnan & Athijayamani, 2015b).

1.6 The Need for Hybrid Composites

A hybrid composite is one which has two or more than two different reinforcement fibers inside the matrix. The interest in natural fibers was generated due to the high material and processing cost, toxicity and specific gravity of the synthetic fibers. However, the use of natural fibers has been somewhat restricted as they have poorer mechanical properties as compared to the synthetic fibers. Some of these drawbacks are namely, high moisture absorption, poor wettability, limited thermal stability and poor adhesion properties of natural fibers (Panda, n.d.). Hybridization allows composite designers to tweak the properties of the composite material as per their specialized requirements. As the whole idea behind composites is to get the best of all constituents, hybrid composites allow an excellent opportunity to get the best cost and performance ratio. Randomly oriented hybrid fibers are gaining much popularity. The constituent fibers are intimately mixed such that no clusters of either type are present in the composite.

In spite of several merits, natural fibers show lower modulus, lower strength and poor resistance when compared with composites reinforced with synthetic fibers such as glass, carbon and aramid. These limitations can be reduced by introducing hybrid composites where two or more fibers are reinforced to a single matrix. The interlinking of bamboo with glass fibers produces an advanced composite which has properties like low weight, good mechanical properties and tribological properties. Due to their low density, natural fibers are widely used as reinforcing agents as it is high biodegradability (Tripathi & Yadav, 2017b).

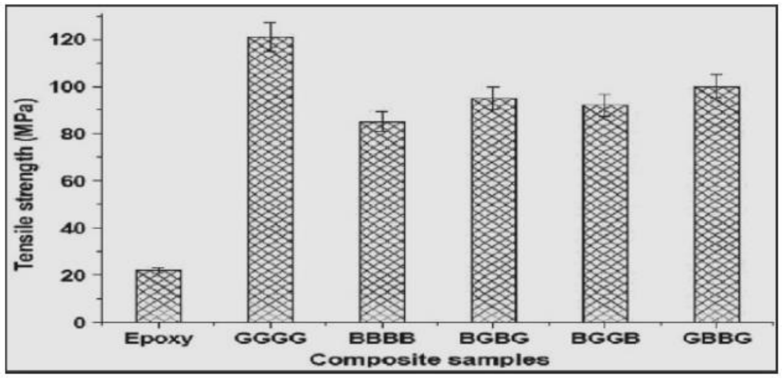

Figure 1.3 Tensile Strength comparison of bamboo glass hybrid composite

1.7 Statement of the Problem

Most recent studies have showed that Steel has less tensile strength than bamboo fibers. Steel has a tensile strength of 23,000 pounds per square inch. But bamboo surpasses steel with a noticeable lead of at 28,000 pounds (Kashyap vyas,2020). The weight of steel in most applications is a problem that renders the service life of the component due to weight. Since heavier metals and glass fiber composites affect the environment after disposal and need high manufacturing cost, they need to be replaced by natural fiber-based hybrid composites. Natural fiber-based hybrid composites are used for aerospace, automotive, and marine applications due to their advantageous properties. However, they are not widely utilized for light weight applications and their mechanical strength was not yet optimized.

Therefore, in this work, an optimization technique was applied to enhance the mechanical properties of fabricated composites so that they can be utilized for light weight applications such as simple automobile components, like doors, windows and dashboards.

1.8 Objectives

1.8.1 General objective

The general objective of this work is "Optimization of Process Parameters and Mechanical Properties of Hybrid Bamboo/Glass Fiber Reinforced Epoxy Composite for light weight applications"

1.8.2 Specific Objectives

1. To extract and chemically treat of bamboo fibers and, determine the fiber-matrix composition of the composite to be fabricated.

2. To optimize the process parameters like, alkali treatment, fiber and epoxy content using the Taguchi optimization method and DOE.

3. To test mechanical properties of developed composite material like, tensile strength, compressive strength, flexural strength, hardness, impact strength, water absorption property and microstructure of the composite.

1.9 Significance of the study

The significance of this study is to identify the main input parameters of a natural fiber-based hybrid composite which determine its mechanical properties. Bamboo/glass fiber reinforced epoxy hybrid composite material with better mechanical properties of tensile strength and hardness is important to be used as a raw material for concrete structures, furniture, decoration, car bodies and for automotive applications. A bamboo fiber agricultural plant can also be a source of income for farmers and industries can use it as a raw material due to its low price. Moreover, there are fewer environmental effects and waste from the production of this raw material in the composite.

1.10 Scope of the study

The motivation of this thesis is on the analysis and optimization of the input parameters and mechanical properties of a bamboo/glass fiber reinforced epoxy hybrid composite. This project uses optimization techniques such as Taguchi and analysis of variance and single response optimization. The proposed experiment is limited to fabricating the new hybrid composite with new tensile, compressive hardness, impact and flexural strengths. The study was carried out at Adama Science and Technology University from February 2021 to October 2021, to fabricate and characterize the mechanical properties of the composite.

CHAPTER TWO

2. LITERATURE REVIEW

This section focuses on the thesis work that has already been carried out for testing and optimizing the mechanical properties of the Fiber Reinforced Hybrid composites. Literature review of such work needs to be done in order to understand the background information available, the work already done and to show the relevance of the current work. This chapter presents a general idea input parameters that affect the mechanical properties of hybrid fiber reinforced composites and specifically on epoxy based reinforced composite with glass-bamboo fibers.

2.1 Reinforcements

2.1.1 Bamboo Fiber

Bamboo can be used as reinforced composite material based on extracting appropriate fibers in proper manner. Bamboo is the last sustainable plant resource that has not been vastly used. Many natural fibers have been studied as reinforcements for both synthetic polymers and biopolymers. The Plant fibers are comprised of cellulose fibrils dispersed in a matripilx of lignin and hemicelluloses. They also contain small amounts of free carbohydrates, proteins, extractives, and inorganics. Cellulose is the primary structural component of plant fibers and the most abundant naturally occurring polymer on earth. Hemicelluloses are polysaccharide polymers comprised of shorter polymer chains than cellulose. Lignin is an amorphous polymer of phenol-propane units. It can be a trusting agent that gives plant cell walls their rigidity. Bamboo fibers contain more lignin than many other natural fibers, which can make them brittle (Tripathi & Yadav, 2017b).

Bamboo is widely recognized as one of the most important non-timber forest resources because of the high socio-economic benefits from bamboo-based products. It is a natural composite, which consists of a lignin matrix and cellulose fibers. Cellulose fibers provide high tensile, flexural strengths and rigidity in its longitudinal direction. Because the strength and modulus of bamboo fiber are at least one order of magnitude greater than those of a lignin matrix, the bulk mechanical properties of the outer surface region of the reformed bamboo should be much higher than those of the inner surface (Mahesh et al., 2017). Bamboo fibers are an abundant natural material with mechanical properties comparable with those of glass fibers that are commonly used in fiber reinforced plastic composites. Bamboo fibers stand out from the group of natural fibers due to the fast growing and high yield of this plant (Tinoco, 2011). Bamboo could be utilized as a biodegradable filler at the end of use in polymeric composite materials to minimize environmental pollution rather than producing strong reinforcing fillers (Tripathi & Yadav, 2017b).

2.2 Matrix

Among the main groups of the matrix material, thermoset resin is the major one, which includes polyester, phenolic, polyurethanes and epoxy. In the hybrid composites of polypropylene reinforced with bamboo and glass fibers (BGRP), Maleic anhydride grafted polypropylene (MAPP) has been used as a coupling agent to improve the interfacial interaction between the fibers and matrix. The mechanical properties of the hybrid compositess were studied from tensile, flexural, and impact tests. Mechanical tests indicated an increase in tensile, flexural, and impact strength of the BGRP hybrid composites at a bamboo: glass fiber ratio of 15:15 in the presence of 2wt% of MAPP (Sanjay K. Nayak et al., 2009).

Epoxy

The advantages are high mechanical strength and good adherence to metals and glasses; the drawbacks are high cost and difficulty in processing. Epoxy resins are the most commonly used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxide has three members in its ring: one oxygen and two carbon atoms. The reaction of epichlorohydrin with phenols or aromatic amines makes most epoxies (Autar K. Kaw, 2013).

2.3 Hybridization of Bamboo/glass fiber

In the case of polymer composites, hybrid composites are the systems in which one kind of reinforcing material is incorporated in a mixture of different matrices, two or more reinforcing and filling materials are present in a single matrix, or both approaches are combined. The incorporation of two or more lingo cellulosic fibers into a single matrix has led to development of hybrid composites. The behavior of hybrid composites is a weighed sum of the individual components in which there is more favorable balance between the inherent advantages and disadvantages. While using a hybrid composite that contains two or more types of fiber has become common (Tripathi & Yadav, 2017b). Hybrid composites can be made from artificial fibers, natural fibers and with a combination of both artificial and natural fibers. Hybrid composites can help us to achieve a better combination of properties than fiber reinforced composites (Nunna et al., 2016).

Bamboo fiber (4–6mm length, diameter 85–120μm, density 0.863g/cm^3) and glass fiber (6mm, density 2.56g/cm^3) were used as reinforcement (Sanjay k. Nayak et al., 2009). The fibers with a thickness of 0.3mm were selected in random orientation form. The glass-chopped strand mat was used in making the hybrid composite (Rajulu & Reddy, 2010). the fiber orientation reinforced hybrid polymer nanocomposites that combine with hybrid composites i.e. BAMBOO/E-GLASS and epoxy polymer in the ratio of 0.1wt %, 0.2 wt.% and 0.3 wt.% percent of volume are to be considered (Mahesh et al., 2017).

2.4 Alkali treatment of bamboo fibers

The hybrid composites treated with alkali bamboo fibers possessed higher flexural properties. The surface changes in bamboo fiber will effectively remove the impurities and bond between fibers in which the various compositions classified in the different percentages will get different results from testing. This is due to the hydrophilic nature of bamboo fiber, which requires different methods for improving interfacial surface adhesion (Tripathi & Yadav, 2017b). The elimination of amorphous hemi-cellulose with alkali treatment leading to higher crystallinity of the bamboo fibers with alkali treatment may be responsible for these observations as shown in Figure 2.1 (Rajulu & Reddy, 2010) and (Bai & Rao, 2014). The mechanical and thermal properties of composite material consist of bamboo fiber reinforced epoxy resin. The investigation shows six wt. percentage NaOH treated bamboo fibers were optimal for the fabrication of bamboo fiber composites. The results confirmed that fracture toughness and flexural modulus of the composites monotonically increased with fiber length and content. However, for all samples, composites showed a negligible difference on in the flexural strength by using single fiber tensile tests, single fiber pull-out tests, Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy (Composites, 2018). An improvement in the mechanical properties of the composites was achieved with treatment of the bamboo fibers. A NaOH concentration of 6% was found optimum and resulted in the best mechanical properties (Modification & Polylactic, 2018).

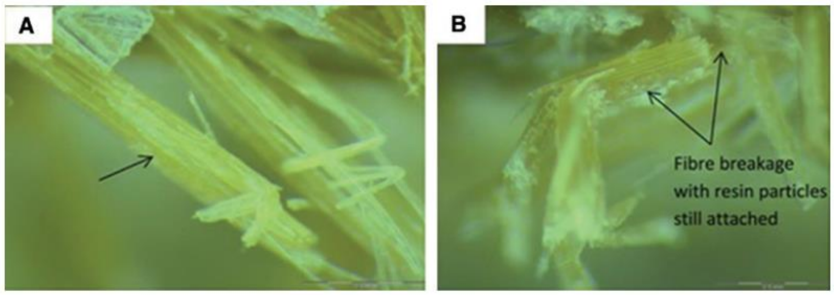

Figure 2.1 Microscopic observation of bamboo fibers: (A) untreated and (B) treated

The alkali-treated bamboo fibers/modified polyester composites have better performance than the untreated bamboo fibers. The study showed that the optimum flexural strength is reached with the alkali treatment of 8% NaOH concentrations with different treatment times (Sugiman et al., 2018). On the other hand, the highest tensile strength here was 356.8 MPa for the single-cellulosic fiber that was soaked for 12 h in 4 wt. % NaOH (Abeer Adel Salih et al., 2020).

A study was done on the effects of alkali treatment on the mechanical and thermal properties of sisal/cattail polyester commingled composites. Analytical results indicated that alkali pretreatment of the fibers enhanced the mechanical properties of the hybrid polyester composites, though only marginal differences were recorded in the thermal conductivity of the composites fabricated with treated and untreated fiber blends (Mbeche & Omara, 2020). The mechanical properties of hybrid composites improved by the treatment of natural fibers with NaOH, played a major role in improving the interfacial adhesion between fibers and matrix, thus enhancing the mechanical properties. Degradation in the mechanical properties mainly depended on the time of exposure and temperature related to various environmental conditions (Nunna et al., 2016) and (Abeer Adel Sali et al., 2020). The effect of alkaline treatment and fiber length on tensile and flexural properties is analyzed using a statistical approach. The bamboo fiber is extracted from the bamboo stem and cut into three different sizes (5mm, 10mm and 15mm) and chemically treated with three different percentages of NaOH (4%, 6% and 8%). The composite specimens are fabricated by hand using layup technique, tensile and flexural tests conducting as per Taguchi design. Analysis of variance (ANOVA) was performed. It was observed that fiber percentage is the most significant factor effecting tensile and flexural properties, followed by fiber length and NaOH percentage. The main effect plot revealed that a composite prepared with a fiber length of 10mm, treated with 6% NaOH and filled with 10 wt.% of fiber exhibited superior tensile and flexural properties. A correlation between tensile and flexural property with fiber length, NaOH% and fiber content were obtained by multiple linear regressions (Prabhu et al., 2019).

Many studies have proven that the chemical modification of natural fibers can increase the mechanical properties of the composite, fiber-matrix adhesion, and compatibility of the natural fiber. The effect of NaOH concentration on bamboo fiber reinforced epoxy composites examining tensile strength and Mode I fracture behavior. They found that treatment of bamboo fibers with 6 wt.% concentration NaOH offers the highest ultimate tensile strength and maximum Mode-I plane strain fracture toughness (KIC) of the composite laminate (Mbeche & Omara, 2020). The effect of chemical treatment on the morphological and tensile strength of the EFB fiber. The treatments were by the types of treatments, 2% sodium hydroxide (NaOH) and combination of both NaOH and boiling water. The chemical treatment by NaOH led to enhancing the fiber surface topography, thermal stability, and tensile strength of the fiber, while the chemical treatment using NaOH and water boiling caused the higher thermal properties of the EFB fibers compared to untreated fibers.

The alkali-treated bamboo fibers/modified polyester composites have better performance than the untreated bamboo fibers. At room temperature, in general, the flexural strength increases with increasing alkali concentration, but the increase depends on the treatment time. At a relatively short treatment time (i.e., 0.5 hour), the flexural strength increases with increasing the alkali concentration. However, at relatively longer treatment times (i.e. 1-2 hours); the flexural strength reaches an optimum at an alkali concentration of approximately 8% (Sugiman et al., 2018).

Experimental investigation has been carried out to study the effect of Silicon carbide on bamboo/carbon fibers. The woven hybrid composite laminates were fabricated by using a hand layup method using L-5 Epoxy resin and K-6 hardener. Based on mechanical testing results, it is found that bamboo/carbon fiber mixed with silicon carbide is giving optimum mechanical properties. The addition of Silicon carbide to bamboo/carbon fibers has improved tensile and flexural strength (Journal et al., 2018). An investigation was done on two natural fibers of bamboo and sisal plants to characterize the tensile and flexural strength of the composite. The fibers were manually extracted from sisal and bamboo plants. After extraction, bamboo and sisal fibers were chemically treated with 8% and 5% sodium hydroxide, respectively, to remove the extra lignin and hemicelluloses so that the bond, interfacial adhesion and shear strength of the fibers could be improved. The experiment was conducted based on the Taguchi experimental method by considering the weight fraction of hybrid sisal/bamboo fibers. Fiber orientation and curing temperature as basic parameters which affect product strength (shemels Mosisa & Sirhabizu, 2019).

A study was presented that, the effect of alkali treatment of the bamboo fibers on the flexural and compressive properties of bamboo/glass fiber-reinforced epoxy hybrid composites. It was observed that both the flexural and compressive properties of the hybrid composite increased with glass fiber content. These properties were found to be higher when alkali-treated bamboo fibers were used in the hybrid composites. (Bai & Rao, 2014).

2.5 The effect of fiber orientation

Experimental investigation showed that, the effect of fiber orientation on mechanical properties of bi-directional Bamboo and E-Glass fiber reinforced epoxy hybrid composites, which results in composite with a 15° fiber orientations, shows better tensile strength compared with other different fiber orientations among the hybrid samples different fiber orientations such as 15°, 30°, and 60°. The hand lay-up method was adopted to prepare the samples (Venkatesha, 2020). The hybrid composites containing bidirectional fibers have better abrasion wear resistance and lower wear loss compared to the epoxy composites containing only unidirectional fibers. (NFRC) consisting of epoxy resin reinforced with jute fiber and bamboo fiber (Indu Shekar R et al., 2017) . Hybrid bamboo/glass fiber woven in different orientations such as 0°/90° and ± 45°

was used and its effect on mechanical properties was studied. The hybrid specimen with ±45° orientation yielded a tensile strength of 92.26 N/mm^2, flexural strength of 387.725 N/mm^2, which was higher when compared with others. (Retnam et al., 2014). Fiber percentage is the most significant factor effecting tensile and flexural properties, followed by fiber length and NaOH %. The main effect plot revealed that a composite prepared with a fiber length of 10mm length, treated with 6% NaOH and filled with 10 wt. % of fiber exhibited superior tensile and flexural properties (Prabhu et al., 2019). The experimental results backed by scanning electron microscope examination revealed that, the reinforcement volume fractions as well as orientation have considerable effect on the friction and wear of polyester composites. An increase in fiber volume fraction to 33% increased the coefficient of friction of the tested material by about 14% and decreased its wear rate by about 95% at both low and high values of pressure velocity product (P V limit) when the fibers were oriented normal to the specimen surface. The same increase in volume fraction of the fibers when oriented in the longitudinal and transverse directions resulted in almost the same increase in the coefficient of friction (16%) while the wear rate decreased only by 65% at a low PV value. For the same orientations at high PV values, the results showed no significant effect on the coefficient of friction while the wear rate decreased by 72% (Parikh & Gohil, 2017).

In the case of GFRP, the coefficient of friction increases with increasing sliding velocity at low pressure, but at high pressure it is independent of the sliding velocity. The highest value of the coefficient of friction is obtained when the fibers are oriented normal to the sliding surface and the sliding direction. On the other hand, the highest value of the wear rate is obtained when the fibers are oriented longitudinal to the sliding surface and the sliding direction. The length of coir fiber and number of glass fiber layers affected the tensile and flexural strength of the developed composite by the technique of the hand layup method. The small sized coir fibers were found to be more effective as reinforcement and presented the highest tensile strength owing to the absence of curling effect that facilitates better fiber matrix bonding. The tensile and flexural strength of composites increased with an increase in number of glass fiber layers up to 3 layers; beyond which it decreased, possibly because of improper fiber matrix bonding (Sallam et al., 2007).

Particulate filled polymers in large quantities in all kinds of applications and despite the overwhelming interest in advanced composite materials. Considerable research and development are done on particulate filled polymers. Fillers increase stiffness, fracture toughness, and high temperature load-bearing capability, decrease shrinkage and improve the appearance of composites. The major parameters that influence mechanical properties of the particulate composite are volume fraction or filler concentration, kind of the particles reinforcement, and particle size, shape of the particles and the interfacial adhesion between the matrix and the particles (Purohit et al., 2017). The study of woven bamboo natural fiber with polyester resin having 0/90-degree orientation and the bamboo natural fiber (2-4 mm length) with epoxy resin having random orientation. Tensile test was conducted on bamboo polyester resin composite whereas for bamboo epoxy resin composite, IZOD test, CHARPHY test, FTIR test and Hardness test were conducted. Both the composites i.e. , Bamboo polyester resin composite and bamboo epoxy resin composite shows significant results as compared to manmade fiber composites (Ramachandran et al., 2015). The addition of jute fiber and glass fiber to epoxy, increases the density, the impact energy, the tensile strength and flexural strength, but decreases the loss mass in function of temperature and water absorption (Braga & Jr, 2015). It was observed that both flexural and compressive properties of the hybrid composite increase with glass fiber content. These properties were found to be higher when alkali-treated bamboo fibers were used in the hybrid composites. The elimination of amorphous hemi-cellulose with alkali treatment leading to higher crystallinity of the bamboo fibers with alkali treatment may be responsible for these observations (Rajulu & Reddy, 2010). During the fabrication of the composites, specimens were tested by hand layup technique and the specimens were prepared according to the ASTM D3039 and D3410 standards for tensile and compressive tests respectively. Different fiber orientations were used to investigate the effect of fiber orientation and, the best rest was the fiber orientation of 0 °/90° provides higher strength and stiffness than other fiber orientations selected from the given orientations (Dash et al., 2013).

2.6 Optimization of fabrication parameters

The Taguchi method is a statistical approach that is widely used to optimize process parameters and to improve the quality of components that are manufactured (Athreya & Venkatesh, 2012).

The method has been employed with great success in experimental designs for problems with multiple parameters due to its practicality and robustness. Taguchi methods of experimental design provide a simple, efficient and systematic approach for optimizing testing parameters and finding out their contribution to target parameters. This method uses a unique design of orthogonal arrays to provide a reduced variance for the experiment with the optimum setting of process parameters (Prabhu et al., 2019). Taguchi method is used to determine and optimize the fabrication parameters, namely fiber length, fiber content, and fiber diameter of the reinforced vinyl ester (RFRVE) composite material with mechanical properties. The results show that the fiber content is the most significant fabrication parameter which greatly affects the mechanical properties of reinforced vinyl ester (RFRVE) composite compared to the fiber length and the fiber diameter. It was proved that the multiple performance characteristics of the plant based natural fiber and particle reinforced polymer composites can be effectively improved by this method (Navaneethakrishnan & Athijayamani, 2015).

The optimization of alkaline treatment variables; including sodium hydroxide concentration, soaking time, and curing time that influences the mechanical behavior of bamboo fiber-reinforced epoxy composites. Untreated bamboo fiber and treated bamboo fiber comparison was done and great performance was observed by treated bamboo fibers. In the study, a Box–Behnken design (BBD) of the response surface methodology (RSM) was employed to design an experiment to investigate the mercerization effect of bamboo fiber-reinforced epoxy composites. The evaluation of predicted tensile strength as a variable parameter of bamboo fiber (Bambusa vulgaris) reinforced epoxy composite structures was determined using analysis of variance (ANOVA) of the quadratic model (Jenarthanan et al., 2019) and (Hassan et al., n.d.) Optimizing the input parameters of the glass fiber and coir fiber reinforcement epoxy hybrid composite results in the optimized output response values of tensile strength and strain (Kumar et al., 2019). Optimizing the alkaline treatment variables, including sodium hydroxide (NaOH) concentration, soaking, and drying time, that influence the mechanical behavior of bamboo fiber-reinforced epoxy composites. The evaluation of predicted tensile strength as a variable parameter of bamboo fiber (Bambusa vulgaris) reinforced epoxy composite structures was determined using analysis of variance (ANOVA) of the quadratic model. It was found that the optimum mercerization condition lies at 5.81 wt. % of the NaOH, after a soaking time of 3.99 h and a drying time of 72 h. This optimum alkaline treatment once again had a great effect on the structures whereby all the treated composite cores with square and triangular structures impressively outperformed the untreated bamboo structures (Hassan et al., n.d.).

2.7 Adhesion properties of Hybrid composites

Natural fibers reinforced polypropylene composites are a renewable material with effective degradability as compared to non-renewable petroleum-based products. Both Polypropylene and natural fibers are hydrophilic in nature and it is assumed that this property will facilitate a better adhesion. Natural fiber reinforced PLA composites are a renewable material with an effective degradability as compared to non-renewable petroleum-based products. Both PLA and natural fibers are hydrophilic in nature and is assumed that this property will facilitate better adhesion (Tripathi & Yadav, 2017a). A study showed the physical and chemical treatment methods that improve the fiber matrix adhesion, their results and their effects on the physical properties of composites. These different treatments change, among others, the hydrophilic character of the natural fibers, so that moisture effects in the composite are reduced (Bledzki & Gassan, 1999).

Scratch resistance of continuous carbon–fiber-reinforced PEI composites was determined as a function of fiber orientations by means of CSM micro scratch tester. The relation between scratch direction and fiber orientation is inspected as a function of scratch hardness, penetration depth, and coefficient of friction. A close relationship between penetration depth and the contact angle (between the indenter's scratch direction and the top ply's fiber orientation of polymer composite) is observed. In the case of higher contact angles, higher penetration depths are achieved. Based on scratch depth, one can conclude that resistance to scratch deformation of composite samples follows the sequence, which has a close relationship between the fiber orientations. The penetration-depth values are found to be different due to the angle between indenter's scratch directions and first laminate is fiber direction. It can be concluded that the angle between first laminate's fiber direction and indenter's scratch direction is the main parameter which determines the scratch deformation of the composite (Bora et al., 2014).

SEM analysis revealed the morphological features. E-glass fiber-reinforced epoxy composite exhibited better mechanical properties than other composite samples. The cross-linking density of monomers of the epoxy resin and addition of the short chopped E-glass fibers enhanced the properties of E-glass epoxy fiber-reinforced composite(Jenarthanan et al., 2019).

Bamboo fiber has the potential to replace glass fiber in some applications that do not require very high load bearing capabilities. However, while fabricating a composite of specific requirements, there is a need for the choice of appropriate fiber and filler material for optimizing the composite system (Mahesh et al., 2017).

2.8 Effect of Acidic solutions on fiber reinforced composites

The interest in composite materials for hostile environments, as an alternative to stainless or coated steel ones, is becoming common. Composite materials are exposed to a range of hostile environments with consequent degradation in terms of mechanical properties (Šimůnek et al., 2020). This concern is because of high specific strength, low density and weight, and better corrosive resistance the properties of the composite material than stainless steel and coated steel. Composite materials can be used in very corrosive environment like composite pipes in chemical industries, high-speed flow and cyclic loading. In a hostile environment the mechanical properties of the composite are affected, the matrix of the composite may reduce its hardness and degradation will happen. An investigation deals with the effect of an acidic environment on the mechanical properties of a Glass Fiber Reinforced Polymer (GFRP) grid. GFRP composites are prone to the absorption of surrounding media that are either of a liquid or gaseous state, and this may result in the degradation of their mechanical properties. The experiment demonstrated the effect an acidic environment can have on the properties of GFRP material (Šimůnek et al., 2020). The composite material exposed to a range of corrosive environment during their service life, which causes degradation in terms of the mechanical properties. The flexural properties and the impact strength of a glass fiber/epoxy composite after immersion in hydrochloric acid (HCl) and sodium hydroxide (NaOH) were analyzed. Independently of the solution, the flexural strength and the flexural modulus decrease with the exposure time. However, alkaline solution promotes higher decrease of the flexural properties than the acid solution that shown in Table1.1 (Šimůnek et al., 2020).

Table 2.1 Effects of corrosive environment on bending properties

Samples		Aver. flexural stress (MPa)	Std Dev (MPa)	Aver. flexural modulus (GPa)	Std Dev (MPa)
Control samples		416.0	2.84	20.5	1.75
H_2SO_4	12days	398.4	3.77	19.6	1.92
	24 days	389.0	5.03	18.4	3.05
	36 days	367.6	6.94	16.9	4.31
HCl	12 days	403.9	6.01	18.1	2.74
	24 days	378.0	7.14	16.9	5.01
	36 days	348.6	8.11	15.9	6.77

The chemical resistance of the glass/bamboo fibers reinforced polyester composites to acetic acid, sodium hydroxide, ammonium hydroxide, sodium carbonates, benzene, toluene, carbon tetrachloride, and water was studied. The chemical resistance of the composite was studied as per ASTMD 543-87 method. For chemical resistance test, the acids namely concentrated hydrochloric acid (10%), concentrated nitric acid (40%), and glacial acetic acid (8%), the alkalis namely aqueous solutions of sodium hydroxide (10%), ammonium hydroxide (10%), and sodium carbonate (20%) and the solvents benzene, carbon tetrachloride, toluene, and water were selected. In each case, the pre-weighted samples were dipped in the respective chemicals under study for 24 h, removed and immediately washed thoroughly with distilled water and then dried by pressing them on both sides by filter paper. The final weight of the samples and % weight loss/gain were determined. The resistance test was repeated for 10 samples in each case and the average is reported (E. Reddy et al., 2010).

2.9 Applications of fiber reinforced composites

Composites are highly beneficial because of the many benefits that can be realized because of their mechanical behavior. A composite offers the ability for light weighting, multi functionality, creativity of design, innovative solutions, etc. and thus offers the greatest near-term growth opportunities especially in Automotive, Infrastructure and Aerospace and other industries. Thermoplastic composites are increasingly deployed for potential decreased cycle times and increased recyclability. The choice of materials used in composites manufacturing is driven by industry requirements and government investments and regulations. Industrial requirements for materials focus foremost on cost reductions enabled by lower raw material costs, as well as attractive processing parameters, such as short cycle times, low processing temperatures and zero scrap rates. Primary focus is to increase sustainability via recycling efforts and bio-derived material sourcing and to substantially reduce embodied energy. These factors have propelled modern designers to develop newer composite materials which are sustainable and replace synthetic materials (K.G Prakas et al.,, 2019). Natural Fiber Composites applications in Interior Cars: Most of the car companies in the world have done a lot of investigation in order to insert the Natural fiber polymer composites into their products.

Concrete beams

A significant improvement in flexural strength and load-carrying capacity is observed in fiber-reinforced polymers (FRP) sheets bonded to the tension face of concrete beams, even when subjected to the harsh environment of wet and dry cycling (Toutanji & Gómez, 1997). To achieve higher means of strain levels, the anchorage of externally bonded FRP materials is applied prior to the premature deboning failure of reinforced concrete (RC) structures.

Mechanical Gear pair

For the application of gear pair, polyoxymethylene (POM) with 28% glass fiber reinforcement revealed significant enhancement of about 50% in the load-carrying capacity, with lower specific wear rate when compared to unreinforced POM (Mao et al., 2019). Gear pair made of carbon–epoxy prepared laminate was comparable to steel for the evaluation of static transmission error (STE) and mesh stiffness curves.

Pressure vessel

In the automobile industry, there has been remarkable growth in the demand for lightweight materials to increase fuel efficiency and reduce emissions. FRP composites are serving these demands, for example, for safe and efficient storage and transportation of gaseous fuels such as hydrogen, and natural gas pressure vessels are used (Holmes, 2017). Pressure vessels made of FRP composite materials, when compared to metallic vessels; provide high strength and rigidity, improved corrosion resistance, and improved fatigue strength, besides being light (Schäkel et al., 2019) and (Wilson, 2017).

Hydraulic cylinder

For the transportation of soil material, a dump truck uses a hydraulic system consisting of an actuator made of a telescopic hydraulic cylinder. There is a 96% weight reduction when the steel cylinder is replaced with a carbon fiber-reinforced epoxy resin composite. When this telescopic cylinder made of composite was installed. There was a 50% reduction in the hydraulic system (Solazzi & Buffoli, 2019).

Headstock material

During a typical machining operation, there is interference between the machine tool and the work piece, which produces high vibration in the cutting tool relative to the work piece. Nearly half of the deflections in cutting tools comes from the headstock; therefore, headstock demands a high degree of damping property. A hybrid steel–composite headstock adhesively manufactured by glass fiber epoxy composite laminates served a 12% increase in stiffness and 212% increase in damping property for the application of a precision grinding machine (Chang et al., 2001).

Braking system

In an automobile braking system, the temperature can reach up to thousands of degrees centigrade. A monolithic metal fails to perform well as it is not able to withstand these higher temperatures. Therefore, carbon fiber-reinforced silicon carbide (C-Si) finds applications in brakes materials for heavy vehicles, high-speed trains, and emergency brakes in cranes (Panda, n.d.).

Automobile body parts

Automobile body parts, such as engine hoods, dashboards, and storage tanks, are manufactured by using reinforcements of natural fibers such as flax, hemp, jute, sisal, and ramie. For these composite structures, VARTM manufacturing method was employed and liability was tested with structural testing and by using impact stress analysis. The result showed a reduction in the weight of the material with the enhancement in stability and strength. The improvement in safety features was measured under head impact criteria (HIC), and it was found that composite structures comprised of natural fiber reinforcements are reasonable for automobile body parts (Kong et al., 2016).

For marine applications, mechanical properties of materials get deteriorated in all types of metals, alloys, or composites due to seawater aging. Hybrid glass–carbon fiber-reinforced polymer composite shows a high flexural strength of 462 MPa with the lowest water absorption tendency. (Jesthi & Nayak, 2019).

Aircraft parts

Hybrid kenaf/glass fiber-reinforced polymer composites showed enhanced mechanical properties with rain erosion resistance, suitable for aircraft application (Arockiam et al., 2018). Carbon fiber-reinforced silicon carbide is applied to aircraft brakes to withstand temperatures up to 1200 $^{\circ}$C (Fan et al., 2016).

Summary

The effect of alkali treatment of the natural fiber gives better tensile, compressive and flexural strengths than untreated natural fiber-based composites. As the studies showed, the amount of alkali concentration and fiber length affect the mechanical properties of the composite material. However, those studies did not show the exact amount of alkali concentration used to treat the natural fiber composites. Depending on the studies, I conclude that the alkali concentration from 4% to 10% is preferred and showed optimal tensile and flexural properties. A very important input parameter of the composite material is the amount of fiber of both the natural and artificial composites and the type of matrix and matrix concentration. Depending on the mechanical properties to be studied, normal, 15° and 0/90°-fiber orientation results in better tensile and flexural strength of the developed composites. When hybrid composite is done, the amount of glass fiber concentration used to make the composite plays a great role in the strength and optimization of composites. Increasing the amount of glass fiber up to three layers increases the strength of the developed composites.

Research Gap

Composite materials can be manufactured by combining natural and synthetic fibers. However, there has not been much work conducted yet on optimizing the parameters and characterization of the mechanical properties of the hybrid composite. The investigation into using the products of natural fiber composites is increasing daily. Natural fiber-based composites with optimization of the input parameters can be further used in many application areas. As the previous studies showed, composite materials have been used in household, automotive and aircraft applications. Hybrid composites are applicable in shipping container basements, automotive bodies like windows, doors, dashboards and for decorative purposes (Kong et al., 2016). Their applications also extend to manufacturing industries with chemical pipelines, corrosive environments and areas with high pressure and high-speed vessels (Jesthi & Nayak, 2019). Chemical treatment of bamboo fiber is very important and has a significant effect on the mechanical properties of the composite material. Therefore, optimization is required to determine the chemical composition, fiber length and amount of filler material to be added. In addition, resistance to water absorption is also another mechanical property of the composite material required to be investigated.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Materials and Extraction Methods

In this work, materials such as bamboo fibers, E-glass fibers and epoxy resin with its hardener were utilized directly for hybrid composite preparation. E-glass fibers and epoxy resin with its hardener were obtained from a local market in Addis Ababa, Ethiopia; whereas bamboo fiber is extracted from bamboo culms coming from Gurage zone, in the South West part of the country, which is obtained from Addis Ababa in a green form.

3.1.1 Bamboo Fiber

Bamboo plant is either naturally grown or farmed in a farmyard in the countryside of Ethiopia. The Ethiopian natural bamboo forest covers about 1 million hectares, which is about 7% of the world total and 67% of the African bamboo forest area (S. George, 2010). Because of this fact, the availability of this plant for the fiber extraction process is not a problem. Such a situation causes for the relying on this plant alone for different studies in the past. This in turn causes the unavailability of sufficient research carried out in the past on the potential and presence of different natural plants in Ethiopia beyond the bamboo plant. The bamboo which was used in this study was taken from the Gurage area grown in the farmyard. Bamboo was taken from this area because of available of suppliers and much amount of bamboo timber present in Addis Ababa. The Presence of information about plants, such as age and that it has good mechanical properties. The bamboo type is from the highland bamboo species. The single bamboo timber has an average length, diameter and wall thickness of 8m, 180mm and 50mm, respectively. The average unit price was 200 Ethiopian birr for a single bamboo timber. The fiber length and fiber wall thickness increase with the increase in age of bamboo (S. George, 2010). According to (Amada et al., 2001) research findings on the properties of bamboo, the strength of bamboo increases with an increment of age. The optimum strength value occurs between 2.5 and 4 years. Then it becomes less at a later age. However, as age increases, the extraction of bamboo fiber from the culm is more difficult. From these aspects, for this study, a green bamboo three years old, which is the highest age of. However, as age increases the extraction of bamboo fiber from the culm is more difficult. From these aspects, for this study a green bamboo with three years old, which is the highest age of bamboo timber available on suppliers, was taken for fiber extraction. The fiber obtained from this plant is whitish in color after drying, in average 200mm to 400mm length and 300 up to 400 μm in diameter.

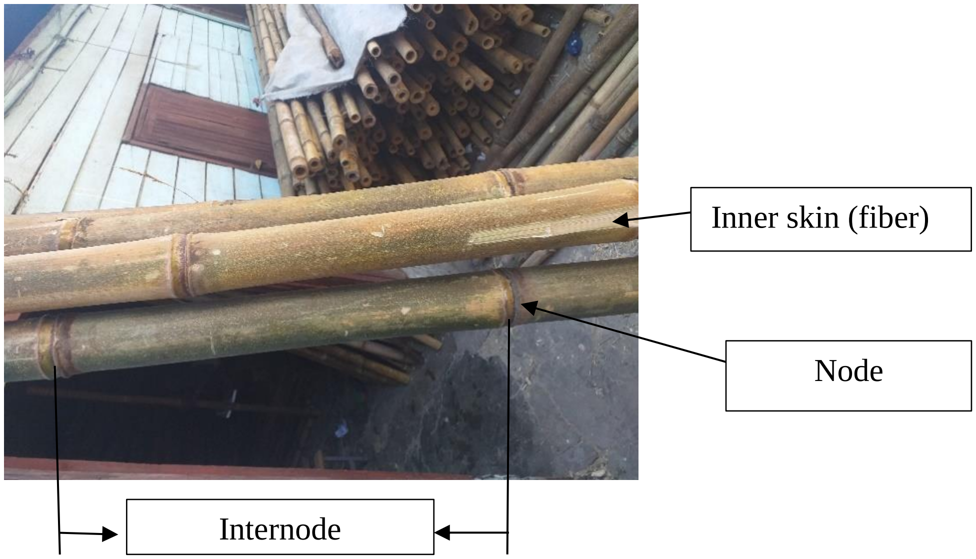

Figure 3.1 Bamboo fiber and its parts

Extraction process of bamboo fibers

Bamboo fibers can be extracted from the bamboo culm through different ways. By mechanical means using different machines such as advanced rollers & mechanical dryers; by chemicals, applying different chemicals and or by the steam explosion technique, using steam (Reinforced, 2013). However, in this work, bamboo fiber was extracted using a manual extraction technique due to the following reasons.

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

In general, the extraction process of the bamboo fibers is concisely summarized as below. Nodes, most inner parts and a very thin layer of mesoderm of the highland bamboo have been removed and remaining parts have been cleaved in the longitudinal direction into thin slabs by using a circular band saw. The strips are bundled and are kept in water for five days in order to soften them. After removing, they are beaten gently at a slow, constant impact load using rubber hammer in order to loosen and separate the fiber. The resulting fiber bundle is combed using a wire comb. The process of beating and combing is repeated until individual fibers are separated.

Finally, these fibers were soaked in NaOH chemical for 24 hours at 60°C in the induction furnace in order to remove excess fat from individual fibers.

Figure 3.2 Manual extraction process of bamboo fibers.

In Figure 3.2(a), the cleaved bamboo strips are socked under the water in the bath. Figure 3.2 (b) shows that wetted bamboo strips are hammered with a rubber hammer, whereas Figure 3.2 (c) illustrates the outcome of the extracted bamboo fiber. Even if the fiber is extracted from the stem of the culm, still excess fatty like material known as lignin and celluloses is not removed, which is shown visually. Therefore, to remove this remnant, alkaline treatment has been undertaken in Figure 3.2 (d).

3.1.2 Sodium Hydroxide (NaOH)

Sodium hydroxide, also known as caustic soda, has the molecular formula NaOH and is a highly caustic metallic base and alkali salt. Pure sodium hydroxide is a whitish solid that is available in pellets, flakes, granules, and as a 50% saturated solution (Greenwood, 1997). Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and willingly absorbs moisture and carbon dioxide in air. Although molten sodium hydroxide keeps properties similar to those of the other forms, its high temperature comparatively limits its applications.

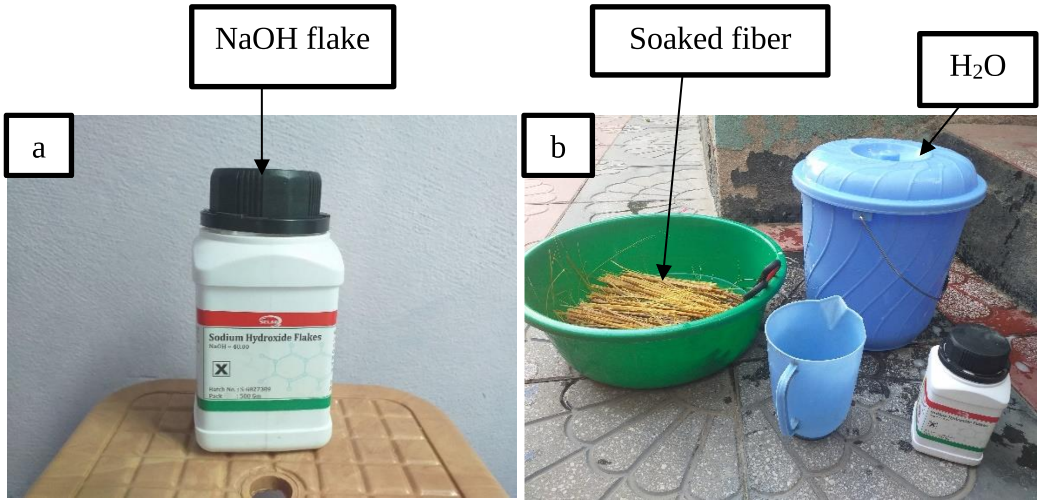

Figure 3.3 (a) Sodium Hydroxide flakes (b) apparatuses for soaking the fiber

Sodium hydroxide is used in many industries, typically as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents (Greenwood, 1997). I used flake form of Sodium hydroxide in my work, purchased from local suppliers with a brand name and batch number of SELAB, S-6827389 respectively.

3.1.3 Glass Fiber

Fiberglass materials usually have a laminate structure with different fiber orientations in the reinforcing glass layers. Various glass fiber orientations result in anisotropy of the material properties in the plane parallel to the laminates. E-glass fibers are, by far, the most common types found in composites. These types have good combinations of chemical resistance, mechanical and insulating properties. Furthermore, E-glass offers more attractive economics. E-glass have advantages as compared to other types of glass fibers. E-glass fiber is cheap in price, has good electrical insulating characteristics, has higher mechanical strength than other glass fiber and has low susceptibility to moisture (resists attacks from water). Due to the above promising characteristic; E-glass fiber has been taken as bamboo fiber reinforcement for this study. E-glass fibers usually exist in three principal types including, continuous glass fiber, chopped glass fiber and unidirectional glass fiber. The type of E-glass fiber that was used in this study is unidirectional (UD) E-glass type. UD fiber type has good mechanical properties as compared to other fiber types and most of the time it uses in the fabrication of wind turbine blade structure (Reinforced, 2013).

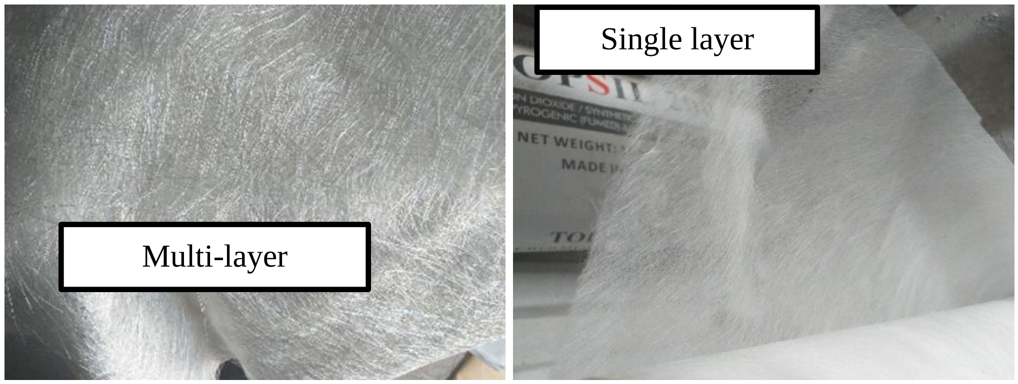

Figure 3.4 Random oriented Fiberglass

3.1.4 The Reinforcement

Fiber reinforced composites are the most widely used class of polymer composites. Recently, fiber reinforced polymer matrix composites have found applications in various areas, such as automotive, marine, aerospace etc. due to their high specific stiffness and strength. The fibers are the most important constituents of the FRCs. They occupy the largest volume fraction of the laminate. Thus, they bear a major portion of the load acting on the composite structure. The fibers in a fiber reinforced composite, density, tensile Strength and modulus, compressive strength and modulus, fatigue strength and failure mechanisms, Electrical and Thermal conductivities Cost of the composite structure.

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

The properties of the fiber reinforced composites depend on various fiber parameters, the most important being fiber length, fiber orientation and fiber loading. Fiber orientation is one of the crucial parameters of the composite material. Fibers show excellent tensile properties in the longitudinal direction. Thus, the direction of orientation enables us to squeeze the anisotropic properties of the composite material. The material will show better ductile properties along the direction of orientation of the fibers. Similarly, it can be safely assumed that the randomly oriented fibers have isotropic properties, as the fibers are then oriented in all possible directions. Another important parameter is the fiber loading. Fiber loading refers to the percentage of fiber present in the composite. The amount of fiber present in the composite is an important parameter as with the increasing volume of fibers, we can get an increase in strength and stiffness. However, with increasing amount of fiber, there is also a chance of it not bonding properly with the matrix base. Thus, the fiber-loading ratio needs a special attention during their design. Similarly, fiber length is also an important parameter, which can influence various properties of the composite.

3.1.5 Epoxy Resin and its Hardener

Among the main groups of the matrix materials, thermoset resins are the major ones, which include polyesters, phenolics, melamine, silicones, polyurethanes and epoxies. The resin used for this study is Epoxy Resin with the brand name of Epoxy floor coating clear, which is manufactured by Abay Esdee Paints Jelaram Esdee Manufacturing plc. It has superior flexural strength, tensile strength, bond strength, adhesive characteristics and fatigue resistance than other types of resins**.** Although epoxy is costlier than other polymer matrices, it is the most popular PMC matrix. More than two-thirds of the polymer matrices used in aerospace applications are epoxy based. The main reasons why epoxy is the most used polymer matrix material are:

• High strength

• Low viscosity and low flow rates, which allow good wetting of fibers and prevent misalignment of fibers during processing

• Low volatility during cure

Low shrink rates, which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement• Available in more than 20 grades to meet specific property and processing requirement (Autar K. Kaw, 2013).

Figure 3.5 Epoxy clear

Hardener (catalyst)

Epoxy resin is cured by adding a catalyst, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the epoxy resin and monomer ingredient from liquid to a solid state. The curing agent applied in this work for the liquid epoxy resin is hardener with brand name of Abay hardener Manufactured by Abay Esdee Paints Jelaram Manufacturing plc.

The ratio of epoxy resin to hardener used for this study is three to two. In general ratio is calculated based on manufacturer guidelines and that was 66.7% hardener for 100% epoxy. According to manufacturer guide lines, better mechanical properties of composites after curing process are attained if & only if the above-mentioned ratio is correctly applied irrespective of any environmentally determined conditions (Reinforced, 2013).

3.1.6 Epoxy Coating Resins Vs Casting Resin

The most obvious difference between the two is the intended use. Epoxy resins are meant for coating applications whereas casting resins are meant for casting applications such as molds, figurines, & jewelry. However, that is not to say that either would not work for their opposite intended uses, but more on that later.

Viscosity- The Thickness of the Material

Casting Resins are normally much thinner mixtures when compared to epoxy coating resins. That is because casting resins are usually slower to cure, thus produce less heat, which in turn, allows them to be poured thicker. However, this presents a problem when casting resins are used in coating applications. Because the mixture is thinner, it will often run off the edges of the project or require a dam/frame to be built to hold the material in.

Cure Times: Casting resins cure much slower than epoxy resins. Casting resins typically cure in 36-48 hours and epoxy resins cure in 12-24 hours. However, epoxy resins will begin to gel in as quickly as 20 minutes, whereas casting resins may take upwards of 18 hours to gel. Because casting resins are typically capable of thicker pours, they dissipate heat (exothermal) much slower than coating epoxy. If some coating epoxies are left in a mixing container beyond 5-10 minutes, they will react in an accelerated fashion, producing excessive heat. Pouring a coating epoxy too thick (as in a river table) could ruin a project as the epoxy could heat up, and potentially crack.

Working Time: Not to be confused with curing time is working time. Sometimes called gel time or pot time, working time, as the name implies, is the amount of time before the material begins to gel/set up. Past this time, the mixed material can not be moved easily or bubbles easily popped. Because casting resins cure much slower, they have much longer worked times. Coating epoxies often have working times of 20 +/- 5 minutes. 20 minutes is often less time than many people need to properly prepare a project. This time can also be significantly reduced if pouring in hot environments or by leaving large amounts of epoxy in the mixing container too long before pouring.

Maximum Pour Depth: Many coating epoxies require thin pours of no more than 1/8-1/4 inch per application. If poured thicker than the recommended max pour depth, then an accelerated reaction could occur. Some casting resins, on the other hand, can be poured as thick as several inches per application. This property makes casting resins suitable for river tables, molds, figurines, and deep encapsulation projects.

Hardness: Generally, (but not always) coated epoxy resins are harder than cast resins. Casting resins often have the ability to vary mix ratios that ultimately allow a variance in hardness. The best example of this is seen in casting resin used as faux water for a vase. If casting resin is used with no flexibility, the vase will ultimately crack as the glass expands and contracts. Therefore, more mixtures that are flexible are necessary for these types of applications, which can usually be accomplished by varying the amount of hardener (curing agent) used. However, every casting resin is different; research each as to the suitability for your individual project. Lastly, coating epoxies usually offer superior scratch resistance compared to casting resins.

Mix Ratios: In a very broad generalization, most casting resins vary in mixing ratios, such as 2:1, 3:1 and even 1:1. A vast majority of available coating epoxies utilize a 1:1 by volume mixture. Many users find working with a 1:1 by volume the easiest. Varied ratios like 2:1 and 3:1 require graduated mixing containers to ensure accurately measured material. In either case, mixing rations must be measured accurately or the resin may not cure properly.

Ultraviolet (UV) Resistance: Both casting resins and epoxy coating resins are capable of containing UV inhibitors. However, yellowing due to UV exposure can be more noticeable on thick, standalone casting projects. Because these projects are not backed by the color of wood grain, paint, stain etc., yellowing can be more noticeable. As with both, some epoxy resins resist yellowing better than others do. Coating epoxies often had better hide/distort yellowing when backed by the grain of wood or darker colored paints and stains on the substrate of the project. Most casting resins and coating epoxy systems are not recommended for permanent outdoor use or direct exposure to UV.

Susceptibility to Bubbles: Both materials are equally susceptible to bubble formation on the substrate and encapsulated items. Bubbles may be less noticeable with casting resin, as it is a thinner material, which allows bubbles to rise to the surface and ultimately pop easier. However, with both materials, bubbles can be drastically reduced by properly preparing a project. Porous surfaces, such as wood, should be initially coated with a thin seal coat. A thin seal coat allows the epoxy to flow into (and seal) all porous areas and air to easily rise to the surface. Items, which will be encapsulated, should also be sealed prior to being placed in a project. Items with many grooves, corners and open areas are prone to holding/trapping air in an epoxy project. Finally, this proper amount of epoxy & hardener is mixed and stirred for few minutes using deep stick material.

Before fabrication of the composite, bamboo fiber was treated with chemicals like alkaline to increase stiffness properties. There will be different orientations of bamboo fiber preparation. The amount of fiber and matrix will be determined to make composite using optimization techniques

Table 3.1 List and Amount of material required

No	Item	Unit	Quantity
1	Bamboo fiber (short fiber)	Kg	1.5
2	Glass fiber(E-glass)	Kg	1
3	Epoxy resin	Liter	3
4	Hardener	Liter	2
5	Sodium hydroxide (NaOH)	kg	1
6	Wax	Kg	0.25
7	Glove	Packet	1pack
8	Water	Liter	25

Table 3.2 Equipment Used

No	Items	Quantity/unit
1	Molds	1
2	Brush	1
3	Mixing container	3
4	Steel rule	1
5	Weighting balance	1
6	Beaker	4

3.1.7 Fiber and Matrix volume content of the composite

In design, fabrication and analysis of composite materials, determination of ingredient percentages such as fiber and matrix (resin) fraction presence in laminate is an important task. These components are microstructural elements of the composite laminate in which composites strength and properties, are determined and limited by these values (Clyne & Hull, 2019).

Fiber and matrix weight fraction (WF, WM)

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

$$WF = \frac{W_f}{W_f + W_m} \tag{3.1}$$

$$\text{Matrix Weight Fraction} = \frac{\text{Weight of matrics}}{\text{Total Weight}}$$

$$W_M = \frac{W_M}{W_f + W_m} \tag{3.2}$$

$$W_c = W_f + W_m \tag{3.3}$$

Fiber and matrix volume fraction (VF, VM)

Volume of fibers, matrix and composite is given by:

$$V_f = \frac{W_f}{\rho_f}; \qquad V_m = \frac{W_M}{\rho_m}$$

$$V_C = V_f + V_m \tag{3.4}$$

$$Fiber\ Volume\ fraction = \frac{Volume\ of\ fiber}{Total\ volume}$$

$$V_f = \frac{V_f}{V_m + V_f} = \frac{V_f}{V_c} \tag{3.5}$$

$$Matrix\ Volume\ Fraction = \frac{Volume\ of\ matrix}{Total\ Volume}$$

$$V_m = \frac{V_m}{V_m + V_f} = \frac{V_m}{V_c} \qquad (3.6)$$

VM+VF= 1

Let ρ_f and ρ_m are density of fiber and matrix respectively. Then we have

$$V_f = \frac{W_F * \rho_m}{W_f * \rho_m + W_m * \rho_f} \qquad (3.7)$$

Similarly: $V_m = \frac{W_m * \rho_f}{W_f * \rho_m + W_m * \rho_f}$

(3.8)

where: V_m, V_f = volume of matrix and fiber

W_F, W_m= weight of fiber and matrix

ρ_{f}, ρ_{m} = density of fiber and density of matrix

W_F, W_m = matrix weight fraction and fiber weight fraction

W_c, V_c= weight of composite specimen and volume of composite specimen

3.2 Methods of Experimentation

3.2.1 Alkali treatment

The hybrid fibers of bamboo/glass fibers were alkali treated to improve adhesion property between fiber/resin. Initially, bamboo reinforcements were cleaned with proper distilled water for three to four times. Then these fibers were dipped into 4, 6% and 8% NaOH diluted in water and stirred in every 25 minutes. After 24hrs of alkali treatment, these treated fibers were properly cleaned to avoid more NaOH particles in the fibers and dried in room temperature for 48hrs. In order to dry the fibers completely, reinforcements were kept in sunlight for two days. Finally, after the whole treatment and heating process, these bamboo fibers were cropped with at lengths of 10 mm.

Figure 3.6 (a) Soaking of the bamboo fiber with NaOH (b) kept in sunlight (c) Cropped fibers

3.2.2. Composite Preparation and Fabrication Mechanisms

In this work, the hand layup method is used for fabricating composite laminates and this technique is the simplest method of hybrid composite.

The processing steps are very simple. First, a release gel (wax) is sprayed on the mold surface to avoid the sticking of fiber to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get a good surface finish on the product.

The reinforcement in the form of chopped structure with thermosetting polymer in liquid form is mixed thoroughly. Suitable proportion with a prescribed hardener and poured onto the surface of glass fiber, already placed at the mold prepared by the mechanical stirring method to make it uniform distribution of the fibers throughout the fabricated sample as per the mold size and placed at the mold surface after Perspex sheet has been placed over it. The process is repeated for each layer of polymer and mat, until the required layers are stacked.

After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate, which is then kept on the stacked layers, and the pressure is applied. After curing, either at room temperature, the mold is opened and the developed composite part is taken out and further processed. The fabrication of the hybrid composite of bamboo-glass reinforced with epoxy was carried out using the hand layup method, having a mold of (300 ×300×3.5) mm^3 dimensions. The combinations of bamboo fiber (A) and E-glass fiber (B) hybrid fiber combinations in various fiber wt. % were fixed in the mold and the required amount of epoxy resin (C) was poured into it. The whole working process was carried out using DOE and the Taguchi optimization method.

Figure 3.7 (a) Open mold and (b) stir casting (c) fabricated composite (d) fabricated composite with required size

3.2.3 Taguchi Optimization and Experimental Design

Taguchi optimization is a DOE approach for optimizing the experiments with a smaller number of trials. All the tabulations are done using Minitab 19 software. In this approach, three important factors are taken with three levels of experimentation. An experiment of nine samples was fabricated using L9 orthogonal array arrangement. The fiber weight percentage of bamboo, NaOH treatment and epoxy resin are the factors. Bamboo weight percentage varies from 10% to 20%, NaOH treatment varies from 4% to 8 %, and epoxy weight percentage varies from 60% to 70%. The percentage composition of glass fiber is set to be 20% for all the nine experimental runs. All the samples were done with three layers of glass fiber. Impact strength (toughness), tensile strength, compressive strength, hardness and flexural strength are the responses.

The experimental investigation data such as bamboo weight percentage, NaOH treatment percentage and epoxy weight percentage are transformed into a Signal-to-Noise (S/N) ratio.

Signal to noise ratio is interpreted as the ratio of the mean value of the signal to the standard deviation of noise value. It is used to arbitrate the rank of input process factors or parameters. There are three types of quality indicators: namely, “larger is better”, “smaller is better” and “nominal is best” (Shah, 2019). These results were converted into a signal to noise (S/N) ratio. For mechanical property enhancement “larger the better” S/N ratios were used and the formula is given below:

$$\frac{S}{N} = -10log_{10}\, sum\left(\frac{1}{Y^2}\Big/n\right) \quad \text{higher- is- better} \quad (3.9)$$

$$\frac{S}{N} = 10\log_{10}(\frac{y^2}{S^2}) \quad \text{Nominal is the best} \quad (3.10)$$

$$\frac{S}{N} = -10\log_{10} \text{sum}\left(Y^2/n\right) \quad \text{smaller -is- better} \quad (3.11)$$

Where, y is the required data (bamboo weight percentage, NaOH treatment weight percentage and epoxy weight percentage) and n is the number of observations. The process parameters and their levels used for development of bamboo-glass fiber hybrid composites have been shown in Table 3.3 (Prabhu et al., 2019) , (Goud & Rao, 2011) and (Braga & Jr, 2015).

Table 3.3 Control factors and levels for bamboo/glass fiber hybrid composite

Control factors	Notation	Level 1	Level 2	Level 3
1. Bamboo fiber (wt.%)	A	10	15	20
2. NaOH treatment (wt.%)	B	4	6	8
3. Epoxy resin with hardener (wt.%)	C	70	65	60

3.2.4 Design of experiment

In the Taguchi DOE concept, the preference of an orthogonal array depends on the total degrees of freedom of the process parameters. The degree of freedom was accounted or defined as the number of comparisons in between the parameters required to optimize each parameter (factor) with the selected levels. The Degree of freedom for the orthogonal array must be greater than or equal to the preferred number of control factors (Dharmalingam et al., 2013). In this study, the degree of freedom required was eight. To study the influence of these three factors at different three levels on the mechanical property of the composite, design of experiment (DOE) was used for modeling and analyzing the influence of the control factors on the performance output. The selection of control factors was the most important stage in the design of the experiment. Three parameters, namely, fiber content (A), NaOH% (B), and epoxy content (C), each at 3 levels, were considered in this study in accordance with L9 OA shown in Table 3.4.

3.2.5 S/N Ratios in the Taguchi Method

The Taguchi method employs orthogonal arrays to reduce variance and optimize process parameters. In the Taguchi method, the signal to noise ratio (S/N) is used as a performance characteristic to measure process robustness and to evaluate deviation from desired values (Sylajakumari & Ramakrishnasamy, 2018). The S/N ratio a logarithmic function, were computed by assessing the proportion of signal (mean) to the noise (standard deviation). In order to diminish noise and the effects of uncontrollable factors, higher values of S/N ratios are preferred (Navaneethakrishnan & Athijayamani, 2015a). High S/N ratios indicate improved quality of the product.

Table 3.4 The L9 orthogonal array (OA) and its level of control factors

Test runs	Bamboo fiber (wt.%)	NaOH treatment (wt.%)	Epoxy resin (wt.%)
1	10	4	70
2	15	4	65
3	20	4	60
4	10	6	65
5	15	6	60
6	20	6	70
7	10	8	60
8	15	8	70
9	20	8	65

3.3 Taguchi Analysis

3.3.1 Analysis of variance

ANOVA is conventionally used to investigate whether the experimental design parameters have a significant effect on the responses. The ANOVA table was also widely used to analyze the interactions between factors and the effect of such interactions on the dependent variables (Sylajakumari & Ramakrishnasamy, 2018). Generally, the F-test was employed as a measure to evaluate the extent of factors controlling the test results. For a 95% confidence level, if the value of 'Prob > F', commonly known as 'p-value', was less than 0.05, the factors and interactions were considered significant (Şahin, 2015). Additionally, a large F-value was an indication of a process parameter having a significant effect on the performance characteristic. In ANOVA, the adjusted correlation coefficient, R^2_{adj} was used to evaluate the validity of the fitted model. R^2_{adj} measures the percentage of variation explained exclusively by those independent factors and interactions which predominantly affect the response variables. Further, to conclude that the created models fit the performed experiments well, it was desired that the values of R^2 and R^2_{adj} should be high and close to each other (Şahin, 2015).

3.4 Mechanical characterization

3.4.1 Tensile Strength

Tensile strength is a measurement of the force required to pull something such as rope, wire, or a structural beam to the point where it breaks and therefore tensile properties indicate how the material will react to forces being applied in tension. Tensile tests were used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties (Ramachandran et al., 2015). The tensile test was generally performed on flat samples. The tensile strength test was done using universal testing machine (UTM) and the test is carried out in such a way till the sample gets fractured by gradually applying the load and the ultimate tensile strength, elongation at the peak load and ultimate stress are found out. The load Vs displacement graph is auto generated by the machine.

Tensile test samples

The dimension of the specimens was 200 mm ×13 mm × 3.5 mm with a shape of dog bone type as shown in the Figure 3.2, and a uniaxial load was applied through both the ends. The ASTM standard test method for tensile properties of fiber-resin composites was conducted with UTM according to (ASTM D3039). All samples were equipped with 200 mm long and 3.5 mm thick, leaving 55 mm specimen gauge length. The crosshead speed was 1mm/min, the specimens were subjected to a controlled tension until they failed. The elongation up to the breaking point, the load taken by the samples until the point of breaking and the ultimate tensile stresses were calculated by the machine.

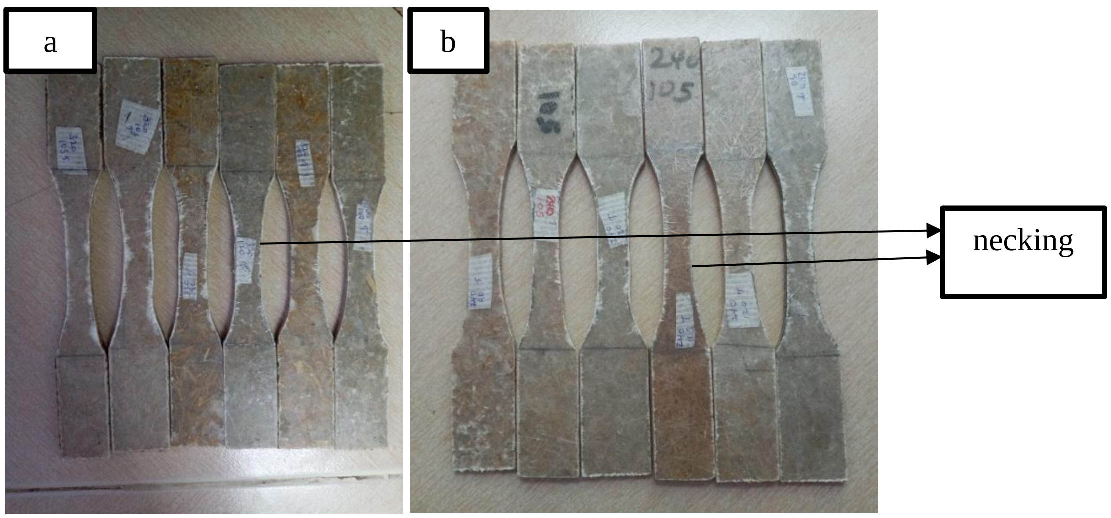

Figure 3.8 Tensile test specimens (a) front side (b) on the back side

The tests were performed on the universal testing machine HUT-1000 series of microchip controlled Electro-hydraulic servo universal testing machines at Ethiopian Technical University material testing lab, Addis Ababa, Ethiopia as shown in (Figure 3.3). At a crosshead speed of 10 mm/min and the results were used to calculate the tensile strength of composite samples. Here, the test is repeated three times on each composite type and the mean value was reported as the tensile strength of the composite.

3.4.2 Flexural Strength

The flexural strength of a composite is the maximum tensile stress that it can withstand during bending before reaching the breaking point. The three-point bend test was conducted on all the composite samples in the universal testing machine at Defense Collage of Engineering, Debrezeit Ethiopia. The specimens prepared according to ASTM standard (D790-2010). The dimension of each specimen was 60 mm ×10 mm × 3.5mm Span length of 40 mm and the crosshead speed of 10 mm/min were maintained. The loading arrangement is shown in Figure 3.4. For flexural strength, the test was repeated three times for each composite type and the mean value was reported.

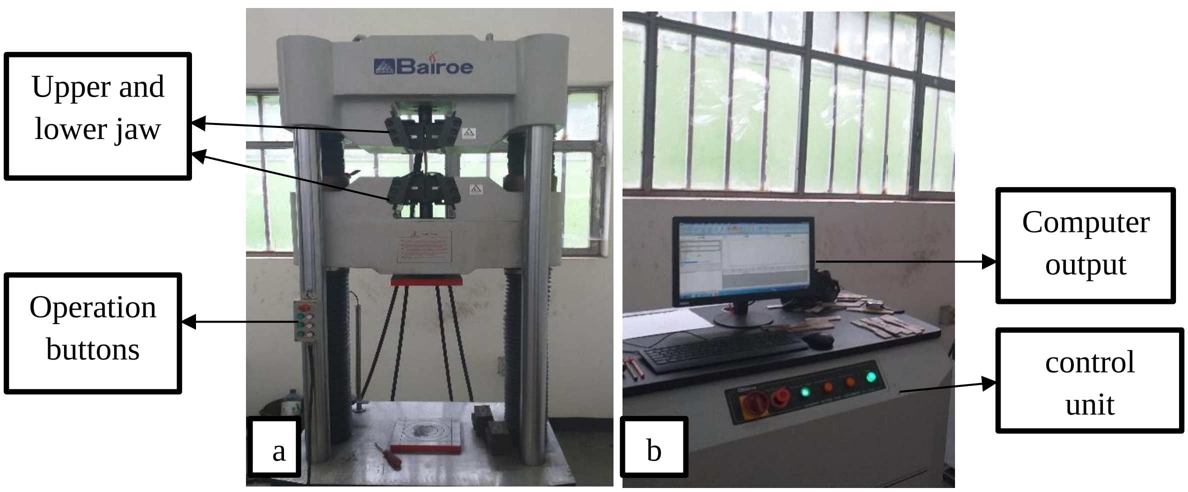

Figure 3.9 Universal Testing Machine (a) operating part (b) control unit

The flexural strength of the composite specimen is determined using the following equation.

$$\text{Flexural Strength} = \frac{3PL}{2bh2} \qquad (3.12)$$

where P is the maximum load applied on test specimen (N), L is the support span (mm), b the width of specimen tested (mm), h is the thickness of specimen tested (mm).

Figure 3.10 Universal Testing Machine for Flexural strength

The flexural test was carried out in a UTM on Samples cut in accordance with ASTM D-790 standard the testing procedure was as per the three-point bending test method by placing the specimen on the universal testing machine and applying load till the specimen fractures. Specimens were cut from the composite laminates with a length 200 mm and width 25 mm using the power hacksaw machine. Three specimens of each laminate were tested for accuracy and then, mean of the flexural strength was reported on the same machine used for tensile testing. the results are compared and flexural strength of the materials was identified.

3.4.3 Impact Strength

Impact energy is the energy that the specimen absorbs once a sudden load is applied. Izod impact testing is an ASTM standard method of determining the impact resistance. (Meenakshi & Krishnamoorthy, 2018). Material specimens were prepared to confirm to ASTM D4812. A pendulum from a particular height was released which strike the specimen and breaks it. From the amount of energy spent to break the specimen. Low velocity instrumented impact tests are carried out on the composite specimens. The pendulum impact-testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy.

The impact energy required to fracture a sample was measured with Izod impact strength test. All the samples were prepared with thickness of 3.5±0.5mm. The composite materials got capability to resist a sudden applied force. The most important factors were molecular distribution and crystal structure of the composite. The intrinsic factors were temperature speed, notch shape and size and geometry of the composite was constant for all the samples. The standard specimen size as per ASTM D 256 was 55 mm× 12.7 mm × 3.2 mm and the depth under the notch is 10 mm. but, Impact strength tester machine done as per (ISO 9001:2001) of Length 55 mm, width 10 mm & thickness 5.5 mm. The impact test was performed over the samples 55mm length, 10mm width and 3.2 mm thickness. This will change the value of the toughness of the composite material since the thickness of the composite was prepared as per the ASTM D256.

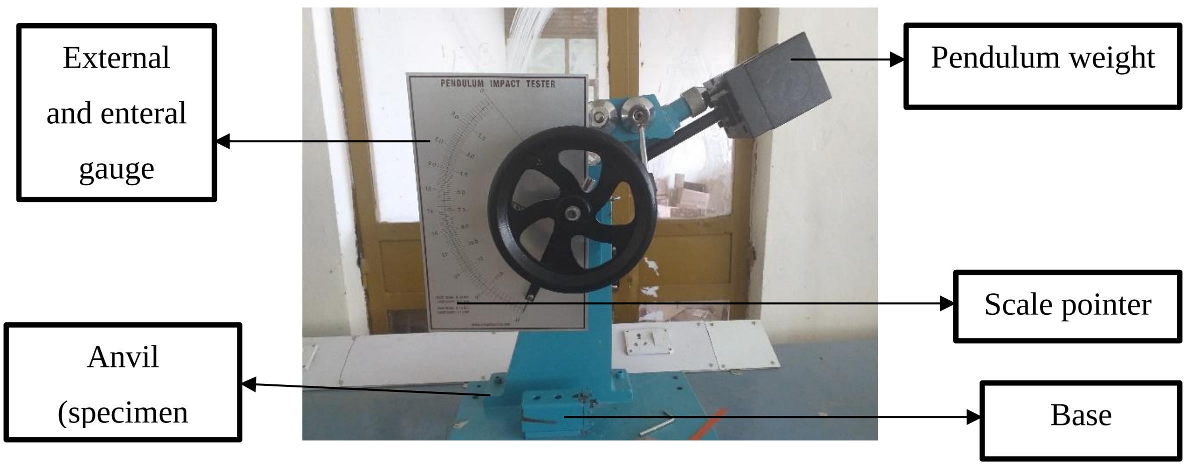

Figure 3.11 Pendulum Impact testing machine and its parts

The impact speed of the hammer was 3.8 meters per second with a 30-kilogram weight mounted pendulum. The respective values of impact energy of different specimens were recorded directly from the dial indicator.

Figure 3.12 Impact test specimens

3.4.4 Hardness Measurement

Hardness test was conducted by using a Rockwell hardness tester as per specimen standard ASTM D785 shown in Figure 3.13. A standard specimen of 3.5 mm thick-hardness tester as per specimen standard (ASTM D785) was shown in Figure 3.13. A standard specimen of 3.5 mm thickness was cut from the plate irrespective of its size. The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond/ball indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, was applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load was then released and the final position was measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number (Ramachandran et al., 2015). In this study the Rockwell indenter having a spherical diamond and a contact radius of 300μm was used. The samples were fixed on a leveling platform attached to a displacement stage and normal load was applied by placing dead-weights on the indenter holder. Mechanically induced surface damage in the form of a scratch was introduced on the surface of the samples using loads at 60 N. The scratch velocity was 60 mm/min and the length of scratch was 3mm.

Load was applied for 15 s and the hardness was measured. All the values were taken as the average of three samples each (Li et al., 2007).

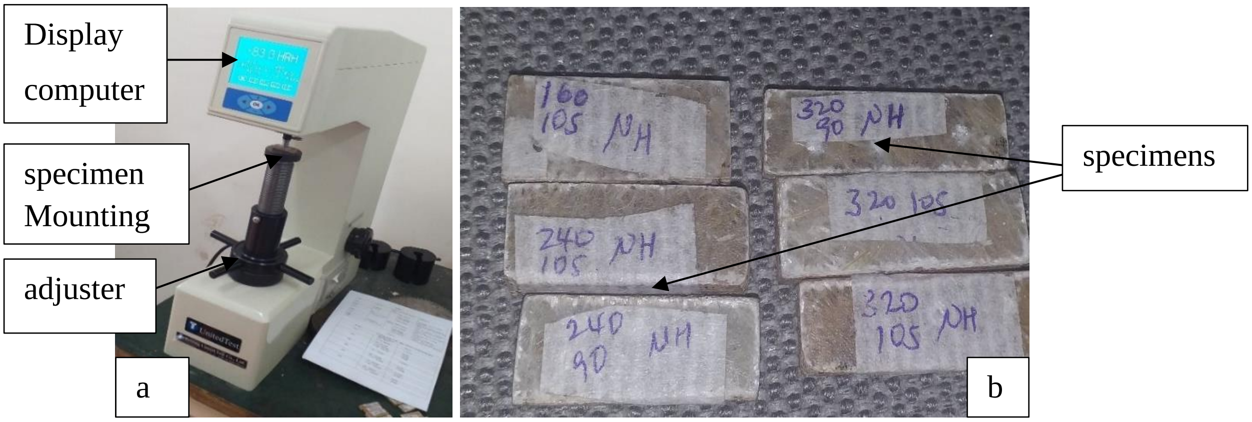

Figure 3.13 (a) Rockwell hardness Machine (b) specimens before test

3.5 Water Absorption test

The water absorption tests were performed on immersing samples into normal water. Sample preparation and water absorption studies was carried out as per (ASTM D570) standard. The samples dimension was (30x28x3)mm^3. Specimens were immersed in normal water (pH=7) shown in Fig 3.8, water at room temperature, i.e., 23°C. After specific time intervals (every 24 hours), samples were removed from the container and their surface moisture was removed by tissue paper. The content of water absorption by the sample was measured using a precise digital balance machine. The percentage of water uptake was calculated by the following equation (Dan-Mallam et al., 2013).

$$W\,(\%) = \frac{W1 - W2}{W1} * 100\% \qquad (3.13)$$

Where: W% = is percentage of water absorption

W1 = is initial weight of sample before immersed

W2 = is final weight of sample after immersed

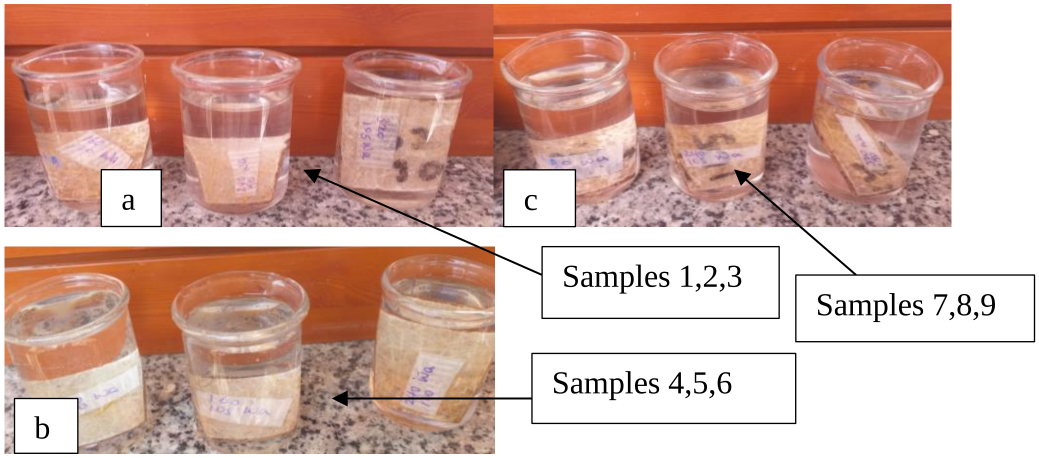

Figure 3.14 Water absorption (a) Test-1 (b) Test-2 (c) Test-3

3.6 Microstructural Analysis

By using SEM (Scanning Electron Microscope) analysis, the qualitative information on the distribution of particles, size and morphology of hybrid composite specimen after polishing process can be observed. The microstructure analysis of the examined composites indicated that the mechanical properties were related to the proportion of fibers in the matrix. They were affected by defects (voids, holes, pores, cracks) in the structure. Voids and pores were formed during production incomplete infiltration of the matrix between the fibers. This is the reason for the lower strength parameters of the material (Kalova & Rusnakova, 2019).

X-Ray Diffraction (XRD): was used in the experimental science determining the atomic and molecular structures of a crystal, in which the crystalline structure causes abeam of incident X-rays to diffract into many specific directions (Modification & Polylactic, 2018).

Energy Dispersive X-ray Analysis (EDX): Analysis is an x-ray technique used to identify the elemental composition of materials. X-ray analysis is an analytical technique used for the elemental analysis or chemical characterization of a sample.it relies on an interaction of some source of X-ray excitation and a sample.

CHAPTER FOUR

4. RESULTS AND DESCUSSION

4.1 Introduction

In this analysis part, the results of the experimental work have been discussed in detail in different sections and subsections. The mechanical properties of the hybrid composites such as: tensile strength test results, toughness, flexural strength test results, hardness test results, compressive test results were reported. Water observation behavior was analyzed. Optimization of those mechanical properties also made by using the Taguchi Techniques. The Design mechanism of experiment method identifies the experiment have been done for enhancing the mechanical properties.

4.2 Analysis of the Tensile strength

The tensile strength test was done using a dog bone shaped sample under a universal testing machine. The samples fracture point was developed in the gage area at the center of the sample, but some of samples also failed at various gage areas due to the weak fiber-matrix bond created by the matrix material with a lower amount of fiber volume and fiber treated with lower amount of alkali. Some technical adjustments of the UTM machine were also limiting factors for the fracture point that developed in the gripper area. Since the machine gripper was moving in hydraulic system, it hold and elongated the samples automatically.

In order to analyze Taguchi's L9 OA using design of experiment, the experimental data in Table 4.1 were converted to S/N ratios. In this study, the effect of varying the control factors; bamboo fiber, NaOH treatment and Epoxy resin on the responses of mechanical properties were analyzed. As higher values of mechanical properties were desirable, larger the better-quality characteristic was selected to investigate the influence of factors on the multiple responses. Table 4.1 shows the separate signal to noise ratio of each sample in the design experiment. The largest values of the S/N ratios were indicated in sample number nine and the lowest value in sample number one with S/N ratios of 47.31 and 39.05 respectively. The respective highest and lowest tensile strength values were 232.1MPa and 89.6 MPa. This results in, when the bamboo fiber weight percentage increased and alkali treated with 8wt.%, the tensile strength of the composite increased. in contrast the lowest tensile strength was recorded as the epoxy weight percentage was much higher even the bamboo fiber weight percentage was higher.

Figure 4.1 Tensile test samples after test

From the previous work analysis, alkali treated and untreated natural fiber-reinforced epoxy composites were done. Alkali-treated fiber composites have shown superior tensile properties than untreated composites. Tensile strength increased with an increase in fiber content and was highest at 20 wt.% (Goud & Rao, 2011).

Figure 4.2 shows the tensile strengths of composites with different amounts of epoxy resin, treated with three levels of NaOH wt.%. When epoxy resin was 60% and treated with 4%, the tensile strength of the composite fiber increased but decreased at the points of 65 and 70%. This was because the amount of fiber decreased from 20% to 15% and to 10%. Similarly, for 8% of NaOH concentration, except the peak value was on the 60% of epoxy resin. This could be because alkali treatment increased surface roughness (exposes hydroxyl groups) of the fibers to the matrix due to the removal of lignin, amorphous hemicellulose and other impurities from the fiber surface, thereby improving fiber-matrix adhesion and leading to higher crystallinity (Venkata Subba Reddy et al., 2010). However, when the alkali treatment was 6%, surface impurities were possible and the amount of alkali treatment was less. The graph shows a linear increment of tensile strength with increased epoxy resin weight percentages. This was due to, increasing the amount of crystalline cellulose bamboo fiber in the fiber- matrix bond made the tensile strength higher.

Table 4.1 Taguchi L9 OA results with signal to noise (S/N) Ratio

Exp. Run	Bamboo fiber wt.%	NaOH wt.%	Epoxy wt.%	Exp. 1 (Flat specimen)	Exp. 2 (dog bone)	Av. Tensile strength (MPa)	S/N Ratio
1	10	4	70	89.1	90	89.6	39.05
2	15	4	65	243.4	90.12	166.7	44.44
3	20	4	60	317.7	197.86	210.3	46.46
4	10	6	65	224.0	74.73	149.4	43.49
5	15	6	60	202.3	68.13	135.2	42.62
6	20	6	70	293.7	94.5	194.1	45.76
7	10	8	60	280	94.5	187.0	45.44
8	15	8	70	162.3	94.5	128.4	42.17
9	20	8	65	354.3	109.89	232.1	47.31

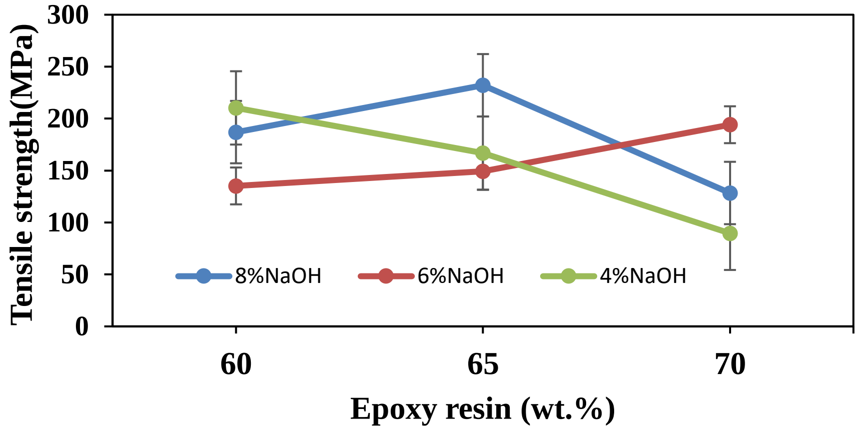

Figure 4.2 Tensile strength vs Epoxy resin with different levels of NaOH (wt.%)

Figure 4.3 shows that with an increase in the weight percentage of bamboo fiber, the tensile strength of the composite increased due to the reinforcement of bamboo fiber from 10% to 20%, the tensile strength of the composite increased from 89.6MPa to 210.3MPa. This could be explained by the fact that the low content fibers cause non-uniform distribution, thus acting as potential defects, resulting in the decline of tensile strength. As the bamboo fiber content increased, epoxy could not effectively penetrate the bamboo fiber bundles, and the possibility of fiber agglomeration was increased, which was detrimental to the macroscopic, mechanical properties of the composites (Composites, 2018).

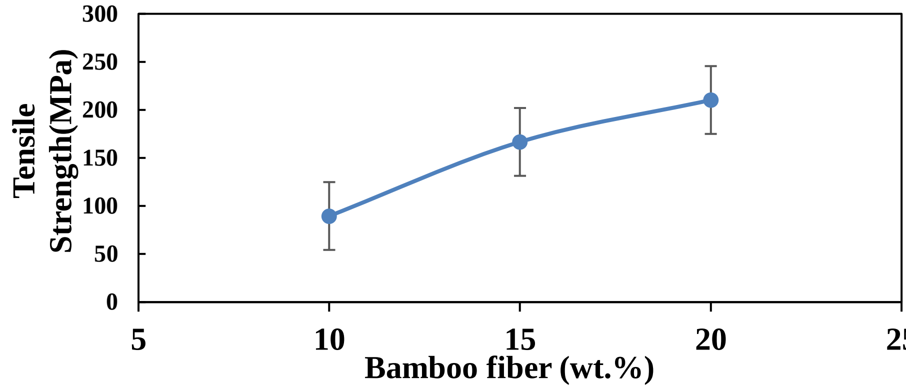

Figure 4.3 Tensile strength vs Bamboo fiber (first three samples)

4.2.1 Effect of the Control Factors on Tensile strength

The experimental data for tensile strength in Table 4.2 was converted into S/N ratios using Minitab® 19 statistical software. The dominant control factors were identified from the delta statistics in the response table for means as shown in Table 4.2. The delta statistics were computed based on the difference between the highest and the lowest average value of each factor. Ranks were then assigned according to the delta value. The highest value of delta was assigned the first rank and represents the predominant factor affecting tensile strength. Table 4.2 indicates that the bamboo fiber(wt.%) with a delta value of 3.85 was the most influential factor. The second most contributing factor was the epoxy resin with a delta value of 2.75, followed by the NaOH (wt.%) of 1.66.

Table 4.2 Response table for S/N Ratio of Tensile strength

Level	**NaOH (wt.%)**	**Bamboo fiber (wt.%)**	**Epoxy resin (wt.%)**
1	43.31	42.66	44.84
2	43.96	43.08	**45.08**[1]
3	**44.97**[1]	**46.51**[1]	42.33
Delta	1.66	3.85	2.75
Rank	3	1	2

From the responses in Table 4.2, the main effects plot for S/N ratios was generated as depicted in Figure 4.4. The trend of the plot indicates that tensile strength is greatly influenced by variations in the amount of bamboo fiber. As can be seen from Table 4.2, particularly in the case of natural fiber reinforced composites, the tensile strength normally increases with an increase in the fiber weight percentage. Why? The reason was the formation of a strong bond between fibers and orientation of the fibers that resisted tensile elongations at high loads. The steeply increased trend of S/N ratios for tensile strength from 10% to 20% in Figure 4.4 was due to the strong crystalline bond between the fibers. The relationship between epoxy resin concentration and S/N ratio in Figure 4.4 shows an increasing trend from 60% to 65%. Subsequently, the value considerably decreased when the epoxy percentage was increased to 70%. In S/N ratio analysis, regardless of the quality characteristic, a higher S/N ratio corresponds to better values of experimental results. The response table presented in Table 4.1 and main effects plot for S/N ratios in Figure 4.4 suggest that bamboo fiber (A=3), epoxy resin(C=2) and NaOH (B=3) were the desired factor levels in order to achieve high S/N ratios and higher values of tensile strength.

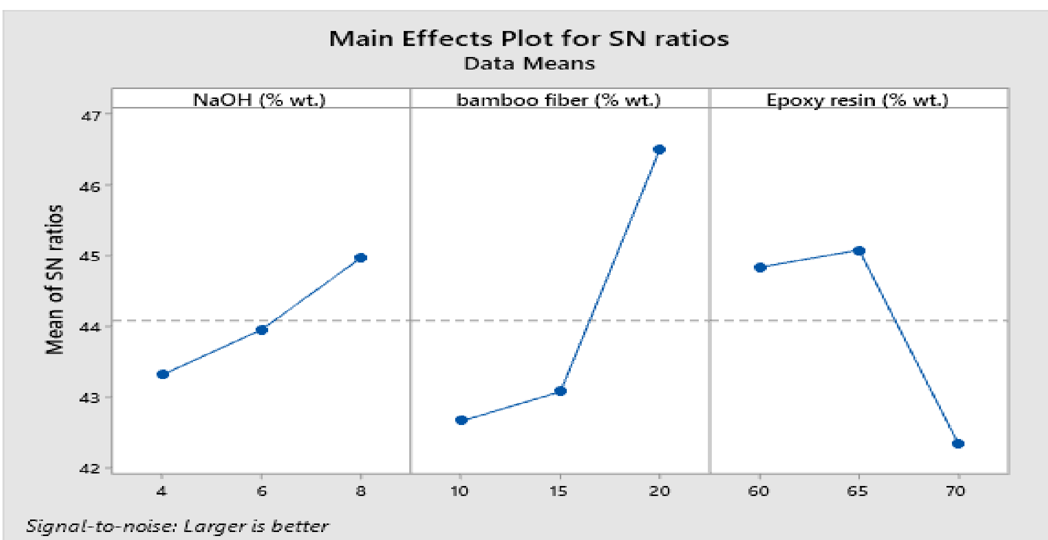

Figure 4.4 Main effects Plot for S/N ratios of tensile strength

Determining the factor levels an ANOVA (shown in Table 4.3) was performed to obtain the percentage contribution of each factor's effect on the tensile strength of the composite. It can be observed that the bamboo fiber with a contribution of 60.17%, has the highest effect on the tensile strength of the composite followed by epoxy resin wt.%, with 23.05%, and then NaOH treatment with 7.91%. At 95% confidence level, factors having a p-value less than 0.05 are considered significant (Sylajakumari & Ramakrishnasamy, 2018). Since the p-values of bamboo fiber was less than 0.05, it is impossible to accept the null hypothesis. The parameter had significant effect on the tensile strength at 95% confidence level.

Table 4.3 Analysis of variance (ANOVA) for tensile strength

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**PC**
NaOH (wt.%)	2	1269	634.7	0.89	0.528	7.91%
Bamboo fiber (wt.%)	2	9650	4824.8	6.78	0.028	60.17%
Epoxy resin (wt.%)	2	3696	1848.1	2.60	0.278	23.05%
Error	2	16038	711.1			4.43%
Total	8	54077				100%

S=26.67 R^2 =91.13 R^2(adj) = 64.53

4.3 Analysis of Compressive Strength

Table 4.4 demonstrated the arrangements of the input parameters with response of compressive strength of the samples. From the samples, the highest compressive strength recorded was 76.97MPa and the lowest recorded value was 23.35MPa. The maximum compressive strength value indicated that, the composite bears the maximum compressive load on its cross section before the material reached the fracture point. When the amount of fiber was higher and the fiber was treated with 8% of alkali concentration, the force required to push the material closer becomes higher. The interlocking bond between fibers and the matrix got strong, the higher the force to break the bond.

The graphical representation of the compressive strength of composite was dipicted in Figure 4.5. Bar graphs of the first three samples revealed a linear increament of the compressive strength. The first sample with compositions of 10% bamboo fiber, treated with 4% of NaOH and 70% of epoxy resin was added. The lowest compresssive strength of the sample shows a weak bond existed between the fibers and the matrix.

Table 4.4 Taguchi L9 OA and results with signal to noise (S/N) Ratio

Exp. Run	**Bamboo fiber wt.%**	**NaOH wt.%**	**Epoxy wt.%**	**Compressive strength (MPa)**	**S/N Ratio**
1	10	4	70	14.70	23.35
2	15	4	65	28.53	29.10
3	20	4	60	31.87	30.07
4	10	6	65	34.22	30.68
5	15	6	60	49.11	33.82
6	20	6	70	39.19	31.86
7	10	8	60	53.87	34.62
8	15	8	70	40.22	32.08
9	20	8	65	76.97	37.72

When the amount of epoxy resin was higher and the amount of bamboo fiber was small, the compressive strength value found to be 14.70MPa. As the amount of bamboo fiber increased from 15% to 20%, the compressive strength increased from 28.53MPa to 31.87MPa respectively. However, the fiber content was not the only parameter increased the compressive strength. The amout of NaOH alkilization determined the the compressive properties. In the samples 4 and 5 clearly shows 6% of NaOH concentration increased compressive strength of composites as shown in Figure 4.5. This was due to the reason alkilization enabled the stiffness and reduced the fracture of fiber bond, when compressive load was applied to the material. The impact of the amout of epoxy resin used as a matrix was shown in sample 6, and 8. The peak value of the compressive strength was recorded in sample nine in the Table 4.4. with optimal fiber, epoxy resin amounts and bamboo fiber treatments. In order to determine the factors influencing the compressive strength, the S/N ratios of the experimental data of compressive strength were calculated as shown in Table 4.4. Similar to tensile strength analysis, “larger-is-better” characteristic of the Taguchi method was selected to investigate factor effects. The response table for the S/N ratios of compressive strength was then generated as shown in Table 4.4. The results indicate that the amount of NaOH wt.%, with a delta of 7.31, has the highest effect on compressive strength, followed by epoxy resin wt.% and bamboo fiber with deltas of 3.74 and 3.67, respectively.

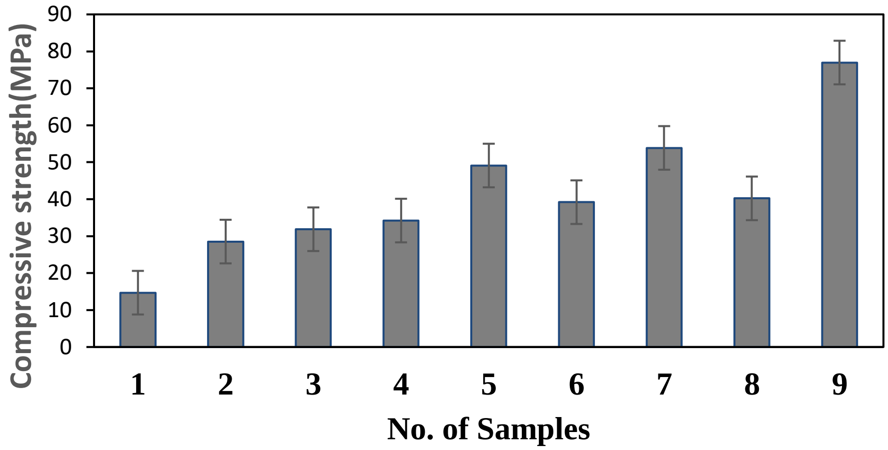

Figure 4.5 Compressive strength vs No. of samples

Table 4.5 Response Table for S/N Ratio of Compressive strength

Level	**NaOH (wt.%)**	**Bamboo fiber (wt.%)**	**Epoxy resin (wt.%)**
1	27.51	29.55	**32.84**
2	32.12	31.67	32.51
3	**34.81**	**33.22**	29.10
Delta	7.31	3.67	3.74
Rank	1	3	2

The response table for S/N ratios was then used to obtain the plot of main effects for Compressive strength, as showed in Figure 4.6. It can be interpreted that the S/N ratio increased with an increased in the amount of alkali treatment concentration and with the amount of bamboo fiber. In the case of epoxy resin concentration, there was a slight decrease from 60% to 65% and then a sharp decrease from 65% to 70%. Figure 4.6 shows that desirable values of S/N ratios of compressive strength achieved at the third level of NaOH (B=3), the third level of bamboo fiber (A=3) and the second level of epoxy resin wt.% (C=2). The results of S/N ratios in

Table 4.5 also specify the same levels for the variables. Further, the delta statistics in Table 4.5 revealed that compressive strength was primarily affected by amount NaOH wt.%, followed by amount of epoxy resin and bamboo fiber. Alkali treated composite fibers had the ability to resist the compressive load due to crystallinlity of the fibers and the closness of particles inside the composite.

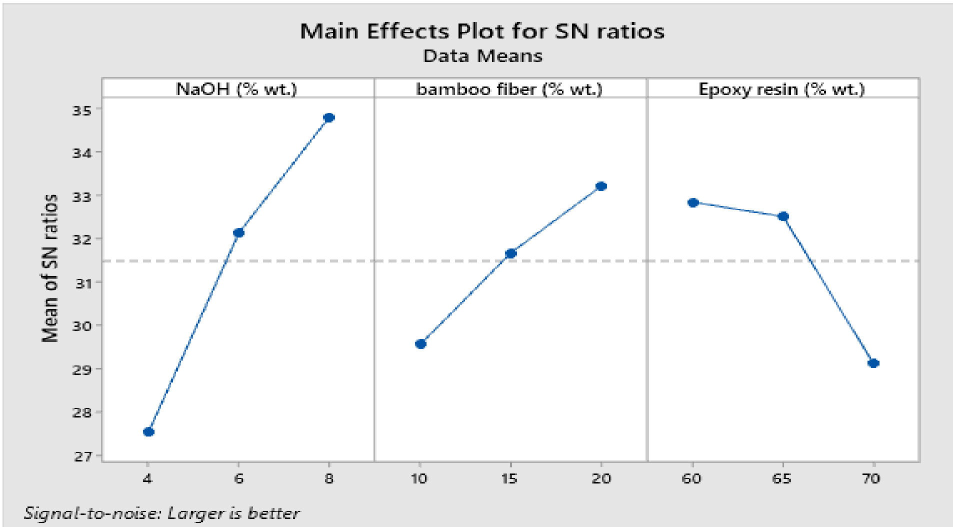

Figure 4.6 Main effects plot for S/N Ratio of Compressive Strength

To determine the significant factors and the percentage contribution of each factor to the response compressive strength, an ANOVA was performed in Table 4.6. At 95% confidence level, the amount of alkali treatment had the highest percentage contribution of 61.25%, followed by epoxy resin of 16.69%. Further, as the p value of the applied load was less than 0.05, it was the sole significant factor.

Table 4.6 Analysis of Variance of compressive strength

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Contribution**
NaOH (wt.%)	2	1534.8	767.39	7.72	0.115	61.25%
Bamboo fiber (wt.%)	2	353.80	176.89	1.78	0.360	14.12%
Epoxy resin (wt.%)	2	418.20	209.10	2.10	0.322	16.69%
Error	2	198.90	99.44			7.9%
Total	8	2505.6				100.00%

S=9.97% R^2 = 92.06% R^2(adj) = 68.25%

4.4 Analysis of Rockwell Hardness test

The results obtained during hardness test on composite specimen of different fiber content are summarized in Table 4.7. It can be noted from the graph that the hardness of composite increases with increases in bamboo fiber contents. Thus, the bamboo fibers helped in increasing the hardness of the hybrid composite. Fiber content in the matrix plays a major role in determining the mechanical performance of the fiber- reinforced polymer composites. As the fiber content is increased to the highest level, the properties gradually improve to give strength higher than that of the matrix. The fiber content beyond which the properties of the composite improve above the matrix strength is known as optimum fiber content. The lower fiber content gives lower mechanical properties (Navaneethakrishnan & Athijayamani, 2015b).

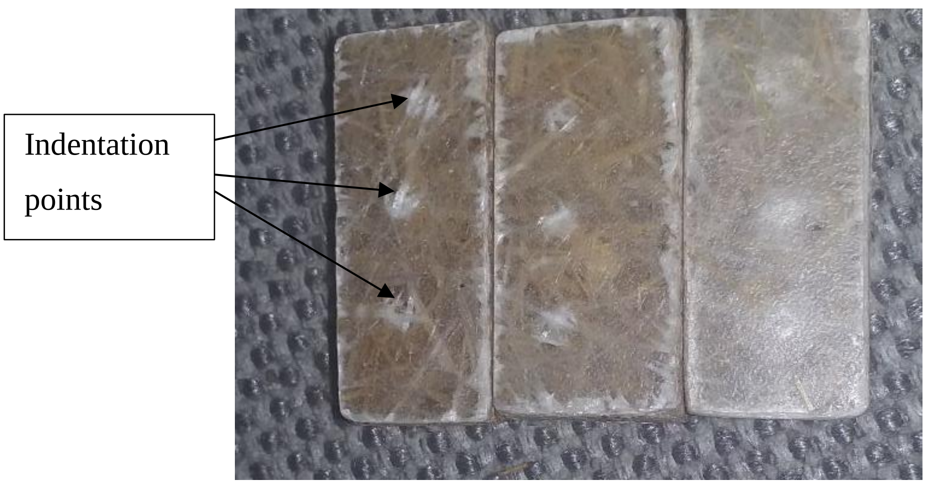

Figure 4.7 Permanent Depth of indentation of Samples

Table 4.7 Taguchi L9 OA and results with signal to noise (S/N) Ratio

Exp. Run	B. fiber wt.%	NaOH wt.%	Epoxy wt.%	Hardness Trial-1	Trial-2	Trial-3	(Average)	S/N ratio
1	10	4	70	22.6	23.3	38.2	28.03	28.95
2	15	4	65	59.8	48.9	34.7	47.8	33.58
3	20	4	60	55.2	70.3	44.9	56.8	35.08
4	10	6	65	34.5	43	32.6	36.7	31.29
5	15	6	60	47.6	34.1	38.4	40.03	32.05
6	20	6	70	15.7	28.6	28.6	24.3	27.71
7	10	8	60	53.5	34.5	62.6	50.2	34.01
8	15	8	70	23.2	22.2	18.9	21.43	26.62
9	20	8	65	59.7	73.6	70.5	67.93	36.64

From the graph, it can be noticed that the surface hardness increases initially with increase in weight percentage of bamboo fiber up to 20%, then there was decrease in surface hardness with decrease in the amount of bamboo fiber from 20% to 10%. The decrease in surface hardness of the samples with increase in epoxy resin weight percentage from 60% to 70% was due to smooth surface created by the epoxides. Figure 4.7 shows the surface indentation of the composite.it can be inferred from the indentation areas that the amount of epoxy resin increases with possible shrinkage of the surface areas. The maximum surface hardness of sample was shown with a well-treated and with a maximum amount of bamboo fiber weight percentages.

The response table for S/N ratios was used to obtain the plot of main effects for hardness, as exhibited in Figure 4.9. It can be shown that the ratio decreased with an increased in the alkali treatment from 4% to 6% and the ratio increases from 6% to 8%. The fiber content decreases from 10% to 15% and increases from 15% to 20%. In the case of epoxy resin, there was an appreciable decrease in the ratio between 65% to 70% and then a slight increase from 60% to 65%. Figure 4 shows that desirable values of S/N ratios of Rockwell hardness were achieved at the first level of alkali treatment (B=1), the third level of fiber content (A=3) and the second level of epoxy resin (C=2). The results of S/N ratios in Table 4.8 also specify the same levels for the variables. Further, the delta statistics in Table 4.8 revealed that hardness was primarily affected by amount of epoxy resin used, followed by bamboo fiber and amount of alkali treatment of bamboo fiber.

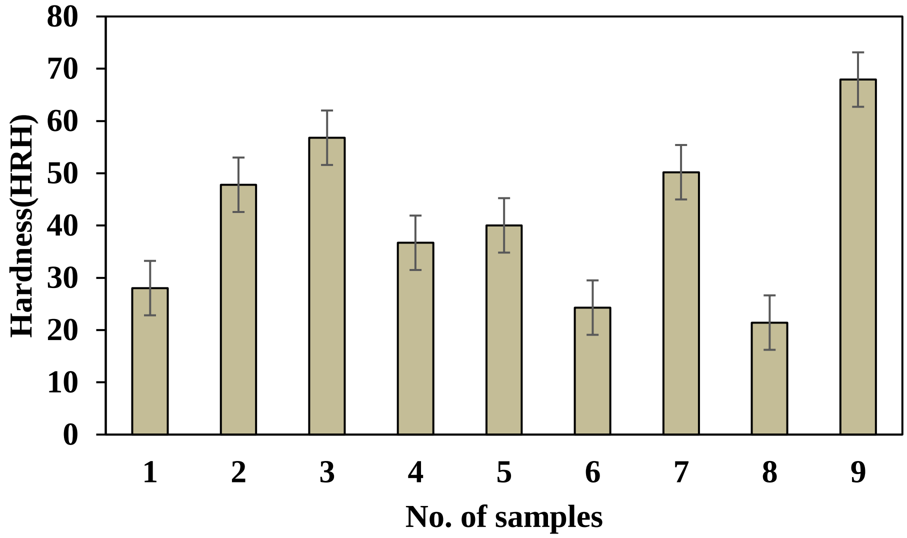

Figure 4.8 Hardness vs Composition of samples

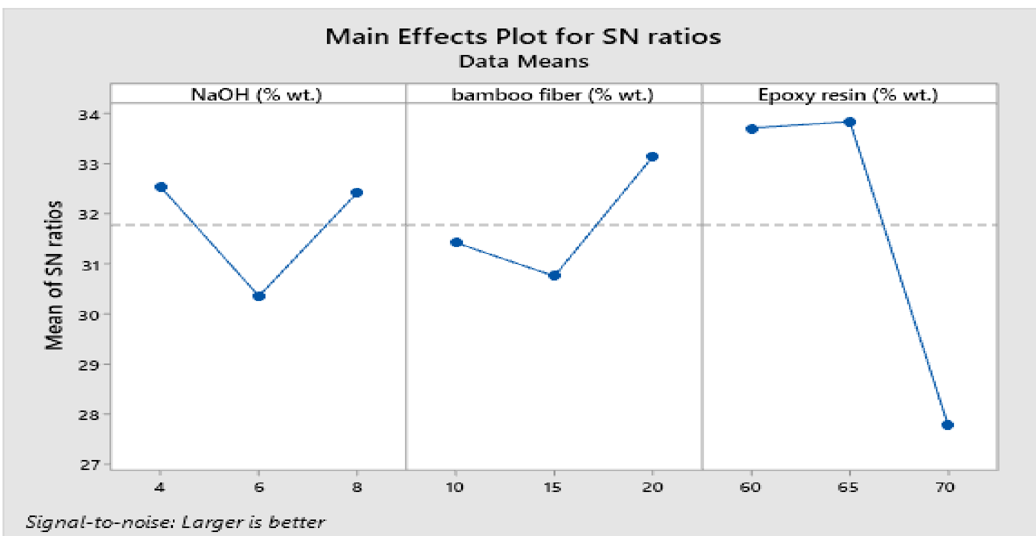

Figure 4.9 Main Effects Plot for S/N Ratios of hardness

The response Table for the S/N ratios of hardness was then generated as shown in Table 4.8. The result indicated that the epoxy resin with a delta of 6.08 has the highest effect on hardness, followed by bamboo fiber and NaOH solutions with deltas of 2.39 and 2.19 respectively.

Table 4.8 Response Table for Signal to Noise Ratios

Level	NaOH (wt.%)	Bamboo fiber(wt.%)	Epoxy resin (wt.%)
1	**32.54**[1]	31.42	33.72
2	30.35	30.75	**33.84**[1]
3	32.43	**33.15**[1]	27.76
Delta	2.19	2.39	6.08
Rank	3	2	1

ANOVA was done (Table 4.9) and, it can be concluded that at 95% confidence level, the epoxy resin has the highest percentage contribution of 82.88%, followed by bamboo fiber of 15.79% and 14.40% of NaOH solutions. The higher "R values" indicate that 96.10% of the variability can be explained by the model and hence, affirms the validity of this model.

Table 4.9 Analysis of Variance of noise to ratio of hardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
NaOH (wt.%)	2	281.24	140.62	3.69	0.213	14.40%
Bamboo fiber (wt.%)	2	308.51	154.26	4.05	0.198	15.79%
Epoxy resin (wt.%)	2	1287.40	643.70	16.91	0.046	82.88%
Error	2	76.14	38.07			3.89%
Total	8	1953.29				100.00%

S = 6.17% $R^2 = 96.10\%$ R^2 adj = 84.41%

4.5 Analysis of Flexural strength

Previous studies show that, increasing the amount of alkali treated natural fibers in the composite resulted in a resistant to the force required to bend the material. The flexural strength increased with the increase in fiber volume fraction. This concludes that the increased amount of fibers in concrete makes the concrete effective in withstanding the greater flexural loads (Kapoor & Nasier, 2018). In figure 4.10 (a), the composite sample shows, the random arrangement of the bamboo/glass fibers before the test was done. Fiber content in the matrix plays a major role in determining the mechanical performance of the fiber- reinforced polymer composites. As the fiber content was increased to the highest level, the properties gradually improved to give strength higher than that of the matrix. The fiber content beyond which the properties of the composite improve above the matrix strength is known as optimum fiber content. The lower fiber content gives lower mechanical properties (Navaneethakrishnan & Athijayamani, 2015b).

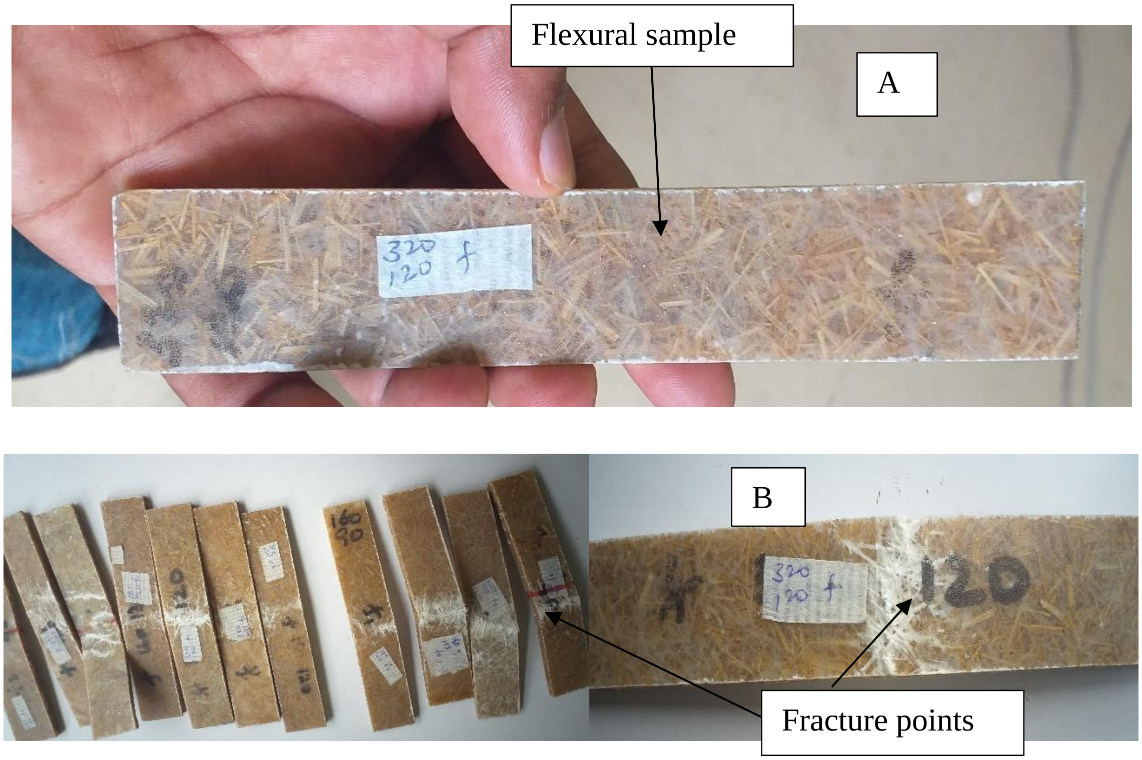

Figure 4.10 Flexural Specimen(a) before and (b) after test

Table 4.10 Taguchi L9 OA and results with signal to noise (S/N) Ratio

Exp. Run	Bamboo fiber wt.%	NaOH wt.%	Epoxy wt.%	Flexural str. (MPa)	S/N ratio
1	10	4	70	146.94	43.34
2	15	4	65	242.45	47.69
3	20	4	60	286.53	49.14
4	10	6	65	117.55	41.4
5	15	6	60	205.7	46.26
6	20	6	70	330.61	50.39
7	10	8	60	271.84	48.68
8	15	8	70	127.35	42.10
9	20	8	65	536.33	54.59

Figure 4.11 indicates that the effect of alkali treatment of the bamboo fibers on flexural properties was observed. Flexural properties of the hybrid composite increased with increased in fiberglass content. These properties were found to be higher when alkali-treated bamboo fibers were used in the hybrid composites with concentration of NaOH solution (4,6,8%) by weight. It was easy to understand that higher fiber content and fiber length could provide higher bending stiffness during the flexural test. A report found from ANOVA indicated that fiber content is the most significant factor effecting tensile and flexural strength, followed by fiber length and NaOH% (Prabhu et al., 2019).

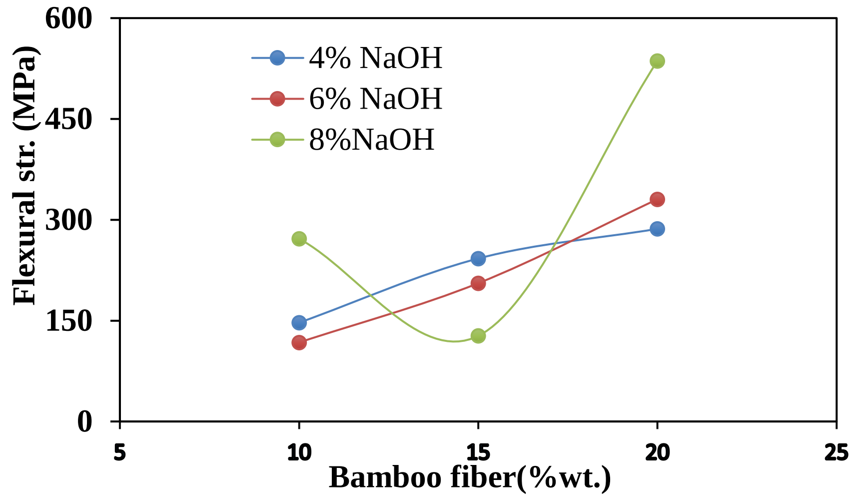

Figure 4.11 Flexural Strength vs Bamboo Fiber wt.%

The effect of epoxy resin of the bamboo fibers on flexural properties of the hybrid composites increased with bamboo fiber weight percentages. These properties were found to be higher when alkali treated bamboo fibers were used in the hybrid composites. The elimination of amorphous hemi-cellulose fibers with alkali treatment leading to higher crystallinity of the bamboo fibers would be responsible for these observations. Figure 4.12 indicates the graph effects of the control factors on flexural strength. As the amount of fiber increased, the flexural strength increased. The highest flexural strength found at the 65% epoxy resin concentrations. This was due to the fact that, the strong bond between fiber and matrix has been created when the amount of fiber was higher and the amount of epoxy resin concentration was enough to bind the fibers together.

The response table for S/N ratio was indicated in Table 4.11, from which it can be determined that among all the factors, fiber content was the most significant factor followed by epoxy resin wt.%, and NaOH% for flexural strength. Analysis of the results leads to the conclusion that as far as maximization of flexural strength is concerned, factors fiber content, epoxy resin wt.% and NaOH wt.% have significant effect. In order to validate the insignificant factor ANOVA was carried out.

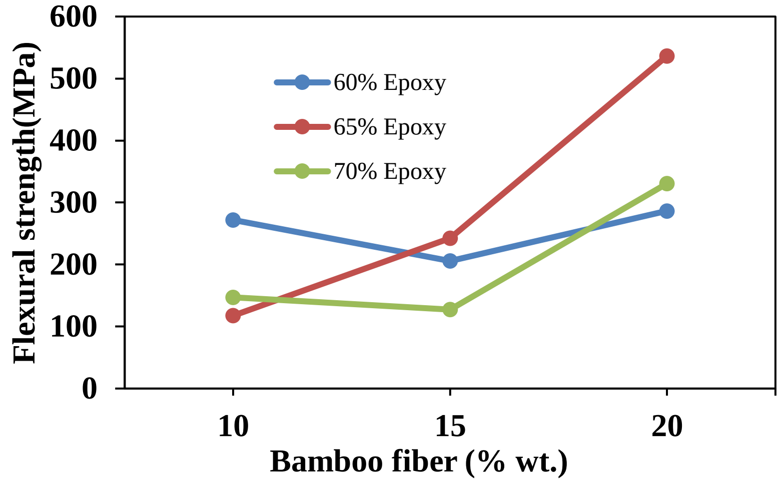

Figure 4.12 Flexural strength vs Bamboo Fiber

Table 4.11 Response Table for S/N Ratio of Flexural Strength

Level	**NaOH (wt.%)**	**Bamboo fiber (wt.%)**	**Epoxy resin (wt.%)**
1	46.73	44.48	**48.03**[1]
2	46.02	45.35	47.90
3	**48.46**[1]	**51.37**[1]	45.28
Delta	2.44	6.89	2.76
Rank	3	1	2

Figure 4.13 indicates the graphical effect of the control factors on a flexural strength. The graph shows the variation of the S/N ratio as the control factors changed from one level to the other. The lines in the main effect plot had nearly horizontal for the factor which has least effect and, for the factor which has a greater effect highest inclination. From the plot it can be observed that, fiber content was the most significant parameter, while epoxy content and NaOH% had relatively less significant influence. It can be observed from the main effect plot that Flexural strength of

the composites increased with the increased in filler content from 10% to 15% and to 20% of bamboo fibers. Why? Because of the strong fiber matrix bond formed. The force applied to the composite resisted fracture and not easily bend the material. It was observed that the alkaline treatment of fiber has improved the flexural strength of the composite. The composite prepared using fiber treated with 8% NaOH gives ultimate properties, but further increased above 8% and decrease below 6% in percentage of NaOH resulted in decrease in flexural strength. It was observed from main effect plot that, as we increased the content of epoxy resin from 60% to 70% the flexural strength decreased, and it gives maximum strength at 60% of epoxy resin. However, further increased in an amount resulted in weak bonding of fiber with matrix which resulted in weak of property of the composite. From the graph it was observed that factor combination of (B=3), (A=3) and (C=1) gives maximum flexural strength.

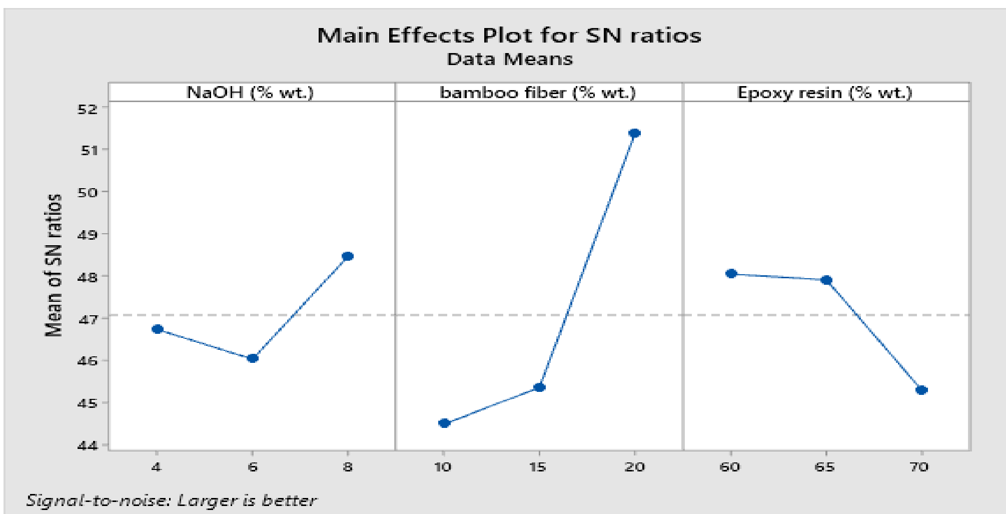

Figure 4.13 Main effects plot for signal-to-noise ratio of flexural strength

ANOVA is a statistical design technique used to break up the individual effects from all control Parameters (Prabhu et al., 2019). Tables 4.12 displays the results of the ANOVA with the flexural strength of the bamboo fiber reinforced epoxy composites. The weight percentage influence of each parameter was shown in the last column of the Table 4.12. The fiber content (P = 59.32%), epoxy resin (P = 25.26%) and NaOH % (P = 12.34%) were the controlling factors and the error in the ANOVA was (P=3.08%). The values of R^2 and R^2adj were higher and comparable with each other. This indicates the goodness of fit of the model (Navaneethakrishnan & Athijayamani, 2015b).

Table 4.12 Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**PC**
NaOH (wt.%)	2	16716	8358	4.00	0.200	12.34%
Bamboo fiber (wt.%)	2	80371	40186	19.23	0.049	59.32%
Epoxy resin (wt.%)	2	34227	17113	8.19	0.109	25.26%
Error	2	4180	2090			3.08%
Total	8	135494				100%
S=47.72%	R^2=96.91		$R^2(adj)$=87.66			

4.6 Analysis of Impact strength

Table 4.12 shows the response of the impact strength test results and the energy values of all the samples were nearly same. Among the given experimental samples, composition of bamboo fiber with 20 wt.%, NaOH 8 wt.% of and epoxy 70 wt.% of was the largest. The corresponding largest signal to noise ratio from the Minitab analysis was 14.03. The pattern of failure observed in impact testing was fiber breakage and delamination (Meenakshi & Krishnamoorthy, 2018). The value of impact resistance for each composite laminate was given in Table 4.13. Generally, higher cellulose content in natural fiber allows for more fracture to happened. Long fibers increased the impact strength of the composites as compared to short fibers when reinforced in a POM matrix. This was due to the mechanics of load transfer in the short fiber composites, which is between the fibers and the matrix. The poor interfacial bonding between the fiber and the matrix caused the initiation of microcracks at the point of contact, which then propagates into the matrix thereby reducing the impact strength of the composite (Dan-Mallam et al., 2013).

Figure 4.14 demonstrates the graphical representation of impact strength, which the optimal impact strength from the nine experimental run was displayed with bamboo fiber of 20 wt.% treated with 8 wt.% of sodium hydroxide solutions and 65 wt.% epoxy resin concentrations. linear increment of impact strength was found from sample six up to sample nine, due to the increased in fiber amount and alkali treatment. Since strong interfacial bond was created between the fiber and matrix, when the composite had substantial amount of fiber and epoxy resin. There was no chance to get initiation of micro cracks within the composites.

Table 4.13 Design of experiment of samples and impact strength test result

Exp. Run	Bamboo fiber wt.%	NaOH wt.%	Epoxy wt.%	Impact Str. (J/m)	SN ratio
1	10	4	70	4.17	12.40
2	15	4	65	4.35	12.77
3	20	4	60	4.90	13.80
4	10	6	65	4.57	13.20
5	15	6	60	4.50	13.06
6	20	6	60	4.78	13.59
7	10	8	70	4.77	13.57
8	15	8	60	4.65	13.35
9	20	8	65	5.03	14.0

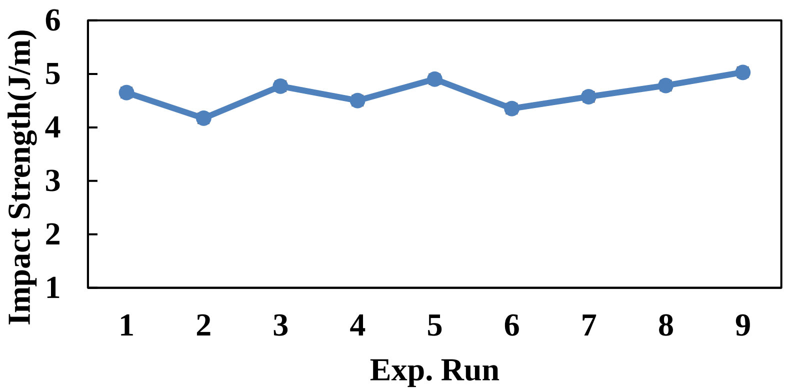

Figure 4.14 Graphical representation of Impact Strength

The composite materials crystal structure would be strong enough to resist the sudden applied force. From the given parameters natural bamboo fiber was the main reinforcement material to yield such properties. Delta value of the signal to noise ratio of the response table shows, bamboo fiber 0.75 wt.% was ranked first followed by epoxy resin 0.61wt.% (Table 4.14).

Table 4.14 Response Table for SN ratio

Level	**NaOH (wt.%)**	**Bamboo fiber (wt.%)**	**Epoxy resin (wt.%)**
1	13.19	13.06	**13.48**[1]
2	13.28	13.06	13.53
3	**13.46**[1]	**13.81**[1]	12.92
Delta	0.27	0.75	0.61
Rank	3	1	2

The data of S/N ratio shows, the optimal level for impact strength. Importantly, the inclination of data means shows the optimum point. The optimum point of bamboo fiber was 20 wt.%, followed by NaOH 8 wt.% and optimum point of epoxy resin was 60 wt.% shown in Figure 4.15. From the graph, NaOH weight percentage line graph inclination was less and close to the horizontal line. Since its effect on the impact strength was less from the main effect plot for signal to noise ratio analysis. Bamboo fiber weight percentage line graph inclination was higher from other line graphs, its effect on the signal to noise ratio was higher based on the design of experiment analysis.

The data values of 10 wt.% and 15 wt.% was almost the same and sudden increment was found for the data value of 20 wt.%. However, the signal to noise ratio of epoxy resin weight percentage increased from 60 wt.% to 65 wt.%, and dropped down to 70 wt.%. the results of signal to noise ratio reveals that, using fiber treated composite with a fiber content of 20 wt.% had resisted the energy applied on the structure of composite with minimum fracture and debonding.

Analysis of variance (ANOVA) for impact strength

Tables 4.15 displays the results of the ANOVA with the impact strength(toughness) of the bamboo fiber reinforced epoxy composites. The seventh column in the table shows the percentage of influence of each parameter. Table 4.15 shows that the fiber content (P = 55.10%), epoxy resin (P = 31.61%) and NaOH % (P = 5.54%) were the controlling factors and the error in the ANOVA was (P=7.79%).

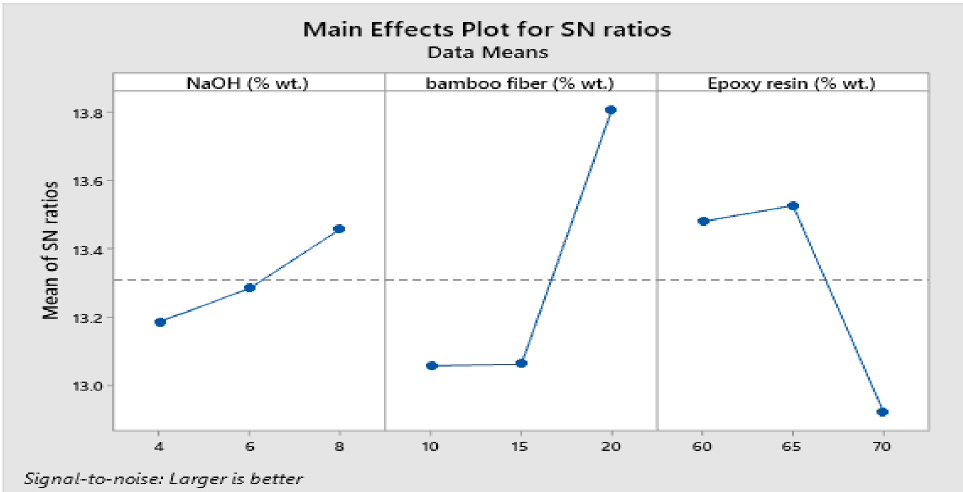

Figure 4.15 Main effects plot for SN ratio

Table 4.15 ANOVA for impact strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	PC
NaOH (wt.%)	2	0.03242	0.01621	0.71	0.583	5.54%
Bamboo fiber (wt.%)	2	0.32269	0.16134	7.10	0.123	55.10%
Epoxy resin (wt.%)	2	0.18509	0.09254	4.07	0.197	31.61%
Error	2	0.04542	0.02271			7.79%
Total	8	0.58562				100%

S=0.15% R^2 =92.24% R^2(adj) = 68.98%

4.7 Water Absorption Test

Table 4.16 illustrates the water absorption test results, the sample were immersed in normal water at room temperature for 24, 48 and 72 hours. After removal from water, the specimens have been Shaked and dried with a cloth as rapidly possibly until the free water was removed from the surface. Weight of each specimen was measured and the masses were recorded. The water absorption behavior of fibers reduced the bonding between the matrix and fibers, and leads to a decrease in the strength of composites. The amount of water absorption of Samples three and nine was small, sown in Figure 4.16. This shows that good bonding between the matrix and the reinforcement or the fibers. However, sample seven absorbed much amount of water, which was 30.29%.

Table 4.16 Water Absorption test result

Samples	NaOH (% wt.)	Bamboo fiber (% wt.)	Epoxy (% wt.)	Time (hour)	Average (Dry)	Average (Wet)	Water intake (%)
1	4	10	70	72	3.86	4.7	21.76
2	4	15	65	72	3.933	4.59	16.7
3	4	20	60	72	4.77	5.22	9.43
4	6	10	65	72	4.0	4.85	21.25
5	6	15	60	72	4.9	5.87	19.79
6	6	20	70	72	5.4	6.01	11.29
7	8	10	60	72	3.4	4.43	30.29
8	8	15	70	72	5.3	5.96	12.45
9	8	20	65	72	5.35	5.84	9.16

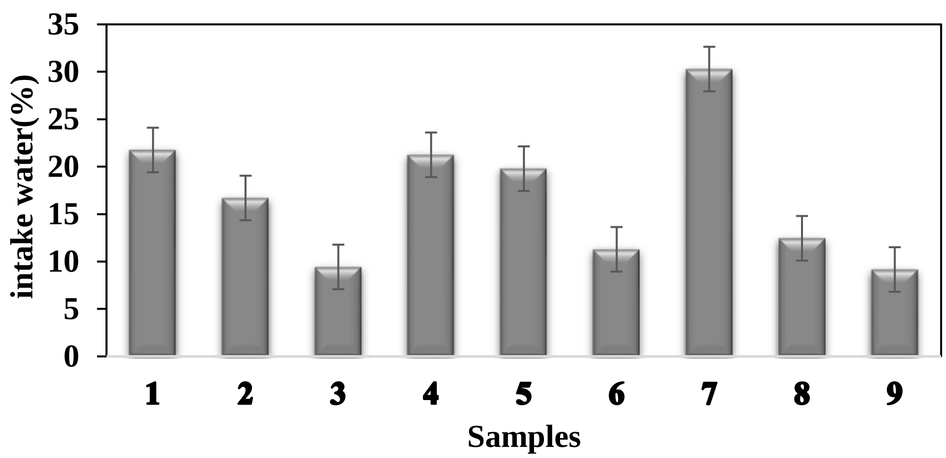

Figure 4.16 Water Absorption graphical representation

The bamboo fibers were prone to moisture and water absorption due to the presence of constituent materials such as cellulose and hemicellulose. Studies show that, the high moisture and water absorption rate of fiber-reinforced POM composites were due to the presence of a natural fiber that was generally hydrophilic in nature. Cellulose is a hydrophilic glucan polymer consisting of hydroxyl groups. The hydroxyl groups form intermolecular and intramolecular hydrogen bonds with macromolecules and polar molecules of cellulose. The water molecules formed hydrogen bonds with the hydroxyl groups of cellulose that results in high water uptake in the composite (Dan-Mallam et al., 2013).

4.8 Microstructural Analysis

4.8.1 X-ray Powder diffraction Test results

X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined (Speakman, 1902). The orientation and loading of bamboo-glass fibers in the epoxy resin and the identification of peaks of reinforced glass fiber and its characteristics in the matrix is studied using x-ray diffraction analysis. Figure 4.17 showed that the XRD of the selected composite with both bamboo and glass fiber amount of 20% wt. and epoxy resin weight was 4%. It indicated a peak at Bragg's angle $2\theta=18.42$, affirming the remnant crystalline bamboo fiber in the composite. It can be seen that the glass fiber and epoxy resin did not have any other identifiable XRD peaks and this indicates that the materials were amorphous in nature.

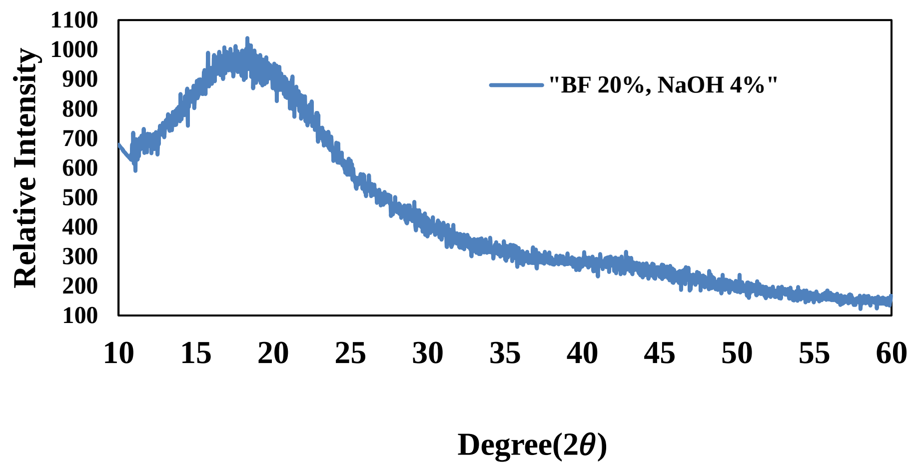

Figure 4.17 (a) X-RD graph of 20% bamboo fiber, 60% epoxy resin and 4%NaOH

Figure 4.17 (b) showed that the XRD of the selected composite with both bamboo and glass fiber amount of 20% wt. and epoxy resin weight was 6%. It indicated a peak at Bragg's angle 2θ=17.30, affirming the remnant crystalline bamboo fiber in the composite.

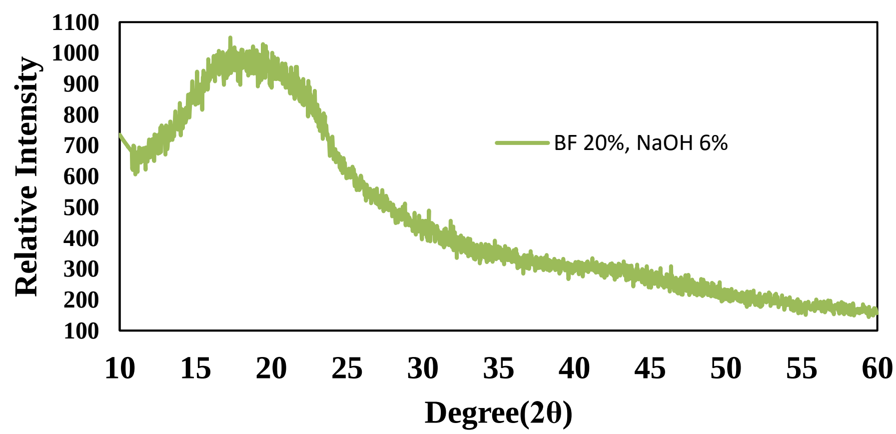

Figure 4.17 (b) X-RD graph of 20% bamboo fiber, 65% epoxy resin fiber and 6%NaOH

Figure 4.17 (c) showed that the XRD of the selected composite with both bamboo and glass fiber amount of 20% wt. and epoxy resin weight was 8%. It indicated a peak at Bragg's angle 2θ=18.34, affirming the remnant crystalline bamboo fiber in the composite.

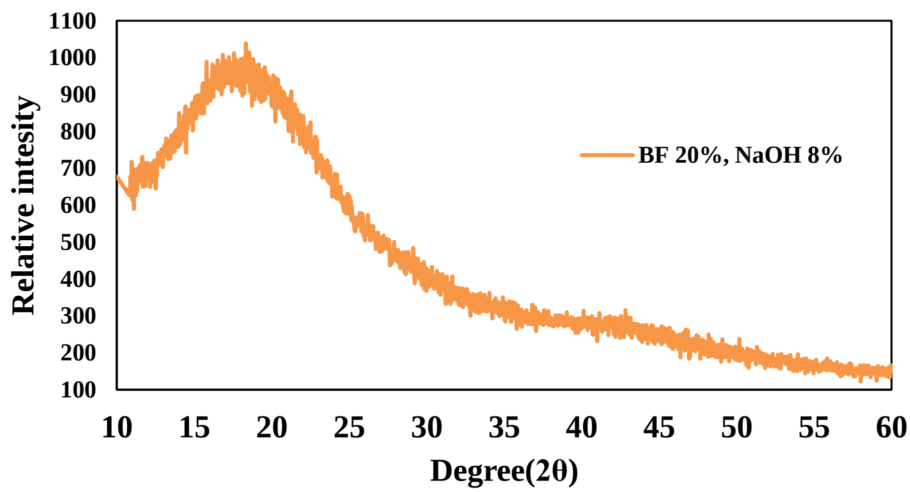

Figure 4.17 (c) X-RD graph of 20% bamboo fiber, 65% epoxy resin fiber and 8%NaOH

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

This chapter presents the summary and conclusion derived from the conduct of the study, which is optimizing the process parameters and mechanical properties of the hybrid glass/bamboo fiber reinforced epoxy composites. It also provides recommendations which can be pursued by manufacturing engineering scholars.

5.1 Conclusions

From the outcomes of statistical analysis, the following conclusions are obtained.

1. Design of experiment approach by Taguchi method enable us to analyze successfully the tensile, compressive strength, hardness, flexural strength and impact strength of the composite with NaOH%, Fiber content and epoxy resin content as test variables. From the S/N ratio analysis, the optimal combination of parameters is obtained to maximize mechanical properties of the fiber.
2. ANOVA indicates that fiber content was the most significant factor effecting mechanical properties, followed by epoxy resin content and NaOH%. The results recommend the following levels of fabrication parameters as optimal parameters for maximizing the mechanical properties of hybrid composites.
    A. Bamboo fiber (A) at level three 20 wt.%, epoxy resin (C) at level two 65 wt.% and NaOH (B) at level three 8 wt.% were the desired factor levels in order to achieve high S/N ratios. Higher values of tensile strength were found at 232.1MPa. Analysis of variance indicates that bamboo fiber, with a contribution of 60.17%, has the highest influence on the tensile strength of the composites, followed by epoxy resin, 23.05 %, and then NaOH treatment, with 7.91%. Therefore, the amount of bamboo fiber was the most significant factor effecting tensile strength, followed by epoxy resin and NaOH%.

B. The desirable values of S/N ratios of compressive strength were achieved at the third level of NaOH(B) (8%), the third level of bamboo fiber(A) (20wt.%), and the second level of epoxy resin wt.% (C) 65 wt.%, resulted in the highest tensile strength of 76.97MPa. The results of S/N ratios and analysis of variance specify that compressive strength was primarily affected by the amount of NaOH%, followed by the amount of epoxy resin and bamboo fiber.
C. From Taguchi analysis, the desirable values of S/N ratios of Rockwell hardness were achieved at the first level of alkali treatment (B) (4%), the third level of fiber content (A) (20%) and the second level of epoxy resin (C) (65%) with an optimum hardness value of 67.93N/mm^2. At the 95% confidence level, the epoxy resin has the highest percentage contribution of 82.88%, followed by bamboo fiber of 15.79% and 14.40% of NaOH solutions using analysis of variance (ANOVA).
D. S/N ratio analysis reveals that, factor combination of (A) and (B) at level 3 and (C) at level 1 gives a maximum flexural strength of 536.33MPa. ANOVA showed, the weight percentage influence of each parameter: fiber content (P = 59.32%), epoxy resin (P = 25.26%) and NaOH % (P = 12.34%) were the controlling factors.
E. The data of S/N ratio shows, the optimal level for impact strength of 5.03J/M. Importantly, the inclination of the data means it shows the optimum point. The optimum point of bamboo fiber was 20 wt.%, followed by NaOH wt. is 8% and the optimum point of epoxy resin was 60 wt.%.

3. NaOH alkali treatment was an effective chemical treatment method for improving interfacial adhesion between bamboo-glass fibers and epoxy resin. The optimal value of NaOH was 8 wt.%.
4. Water absorption behavior of composites is significantly influenced by the fiber parameters, amount of filler, fiber content and alkali treatment of fibers. Samples with better water absorption properties were shown in samples nine and three with water intake percentages of 9.43 and 9.16.

5. Microstructural analysis through x-ray diffraction of the hybrid composite showed that, there is good adhesion between the fibers and the matrix material. Epoxy resin which was a polymer matrix (filler), was evenly distributed in the fabricated composite.

5.2 Recommendations

In this investigation, fabrication of epoxy-based glass-bamboo fiber reinforced hybrid composite had an important and a potential application. Many researchers have conducted plenty of works on natural fiber and synthetic fiber composites in recent decades due to the reason that, bamboo fiber. It was an abundant natural resource with the characteristics of its low density and weight properties. Hybridization of natural fibers with synthetic fibers results in a better mechanical property of the composite. Application areas of the hybrid composite include industrial, automotive (seat backs, doors and windows, dashboards), household like ceiling flooring, chairs, tables, partition walls and for cabinets. Therefore, I recommended the following:

- Making hybrid of the natural fibers with different synthetic fibers and fillers gives better product with higher mechanical properties, within minimum energy absorption and without environmental affection.
- It is better to use different fabrication mechanism to control the variation of thickness and presence of porosity in hand layup technique
- Using longer natural fiber as a reinforcement will results in better product with higher mechanical behavior.

5.3 Future Work

- This study was carried out using a simple hand layup technique. However, the work can be extended further by considering other methods of fabrication, like vacuum bag molding and compression molding for enhancement of mechanical characterization and having of good surface finish.
- The present study can be further extended by using different optimization techniques, like using multi response optimization and using response surface methodology with different processing parameters.

- Further extension of this study through adding characterizations of machining and wear properties that determine the developed composite in turning and drilling applications.

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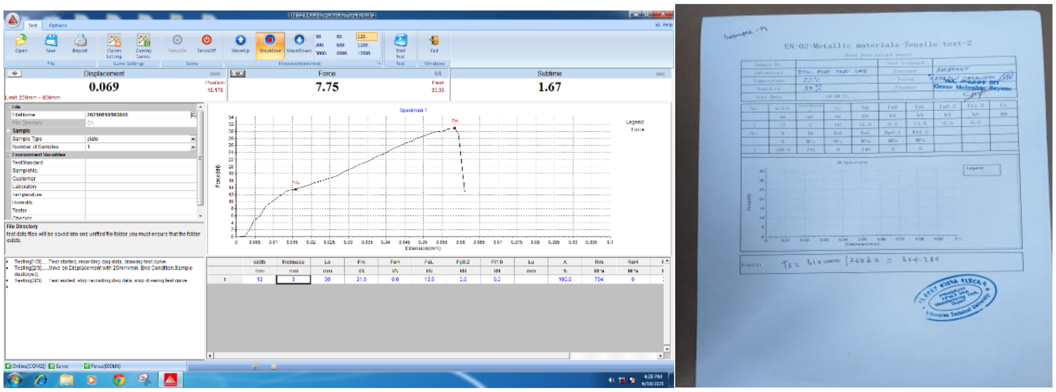
APPENDIX

Tensile strength data

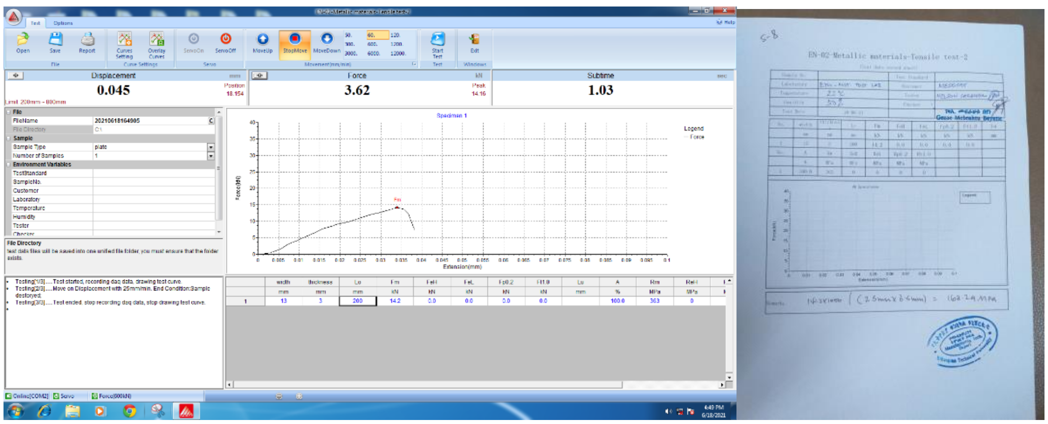
Sample-9

Tensile strength = 354.29MPa, Maximum tensile force = 31.0KN



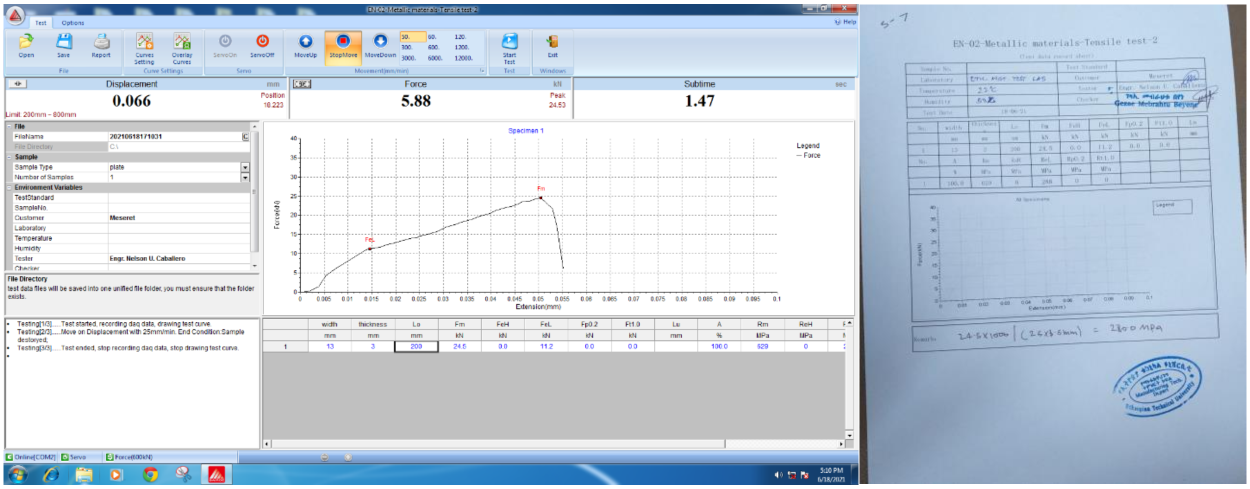
Sample-8

Tensile strength = 162.29MPa, Maximum tensile force = 14.2KN



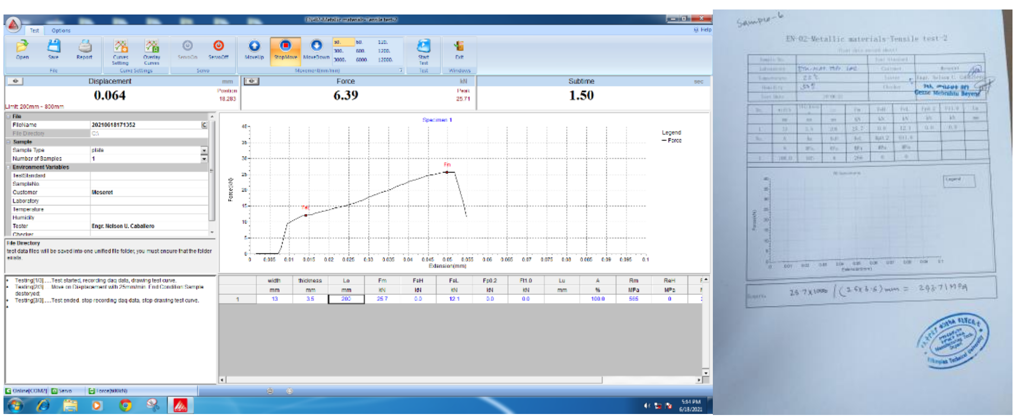
Sample-7

Tensile strength = 280.0MPa, Maximum tensile force = 24.5KN



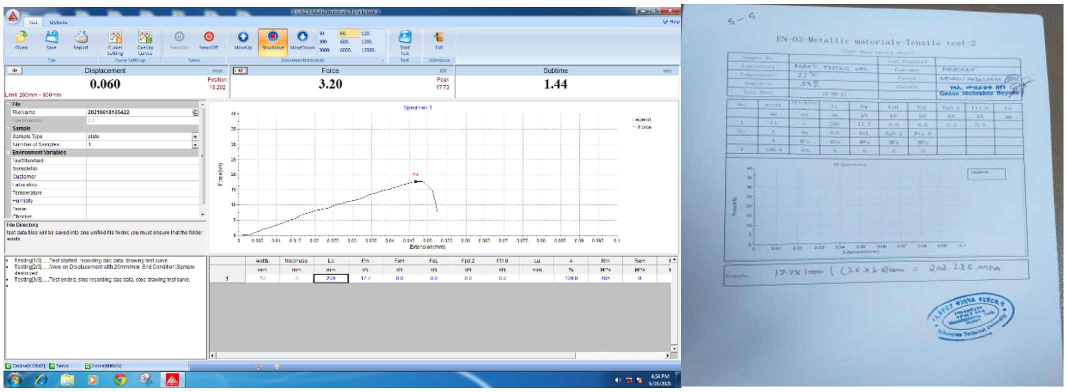
Sample-6

Tensile strength = 293.71MPa, Maximum tensile force = 25.7KN



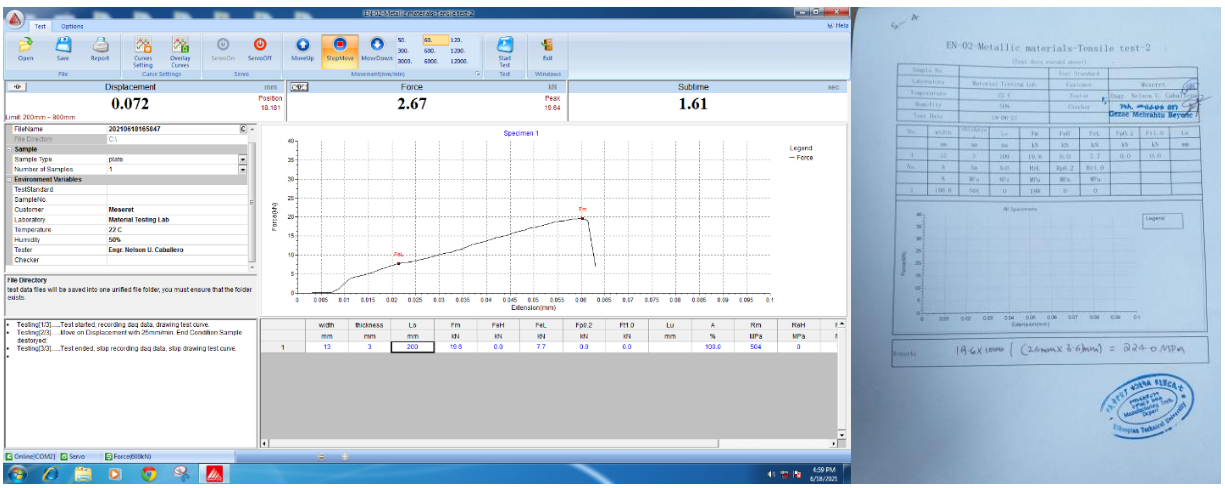
Sample-5

Tensile strength = 202.29MPa, Maximum tensile force = 17.7KN



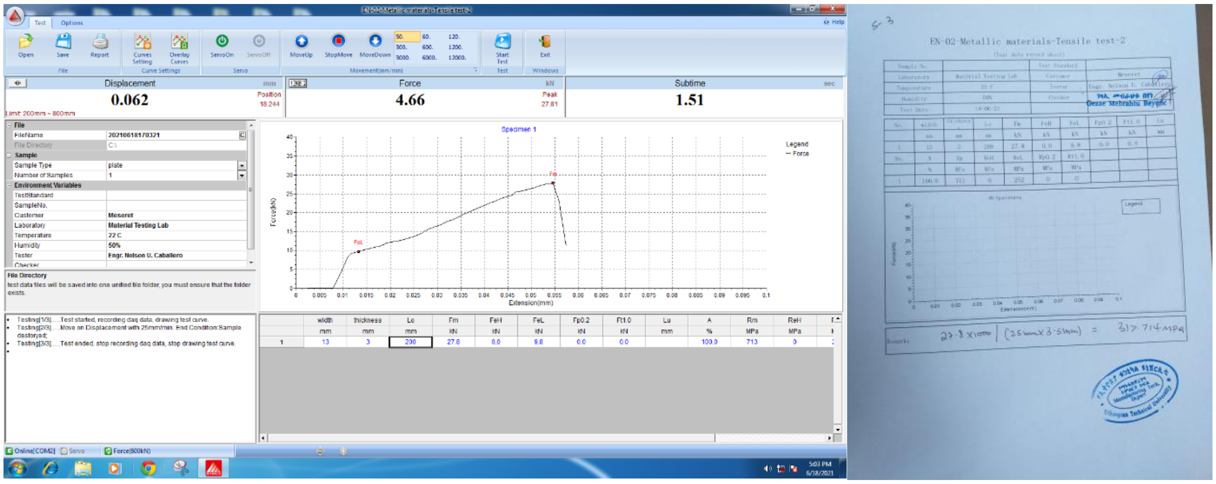
Sample-4

Tensile strength = 224.0MPa, Maximum tensile force = 19.6KN



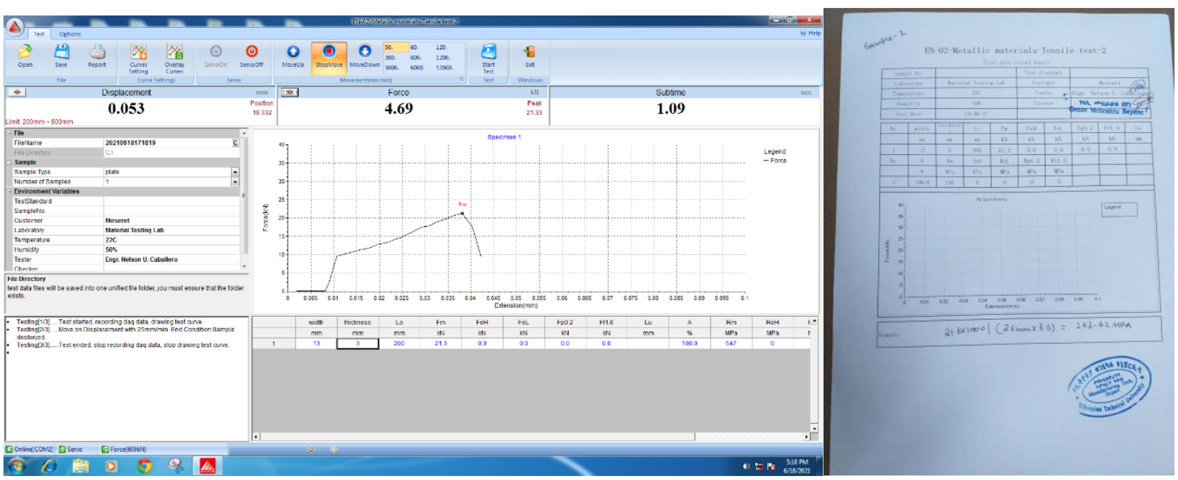
Sample-3

Tensile strength = 317.72MPa, Maximum tensile force = 27.8KN



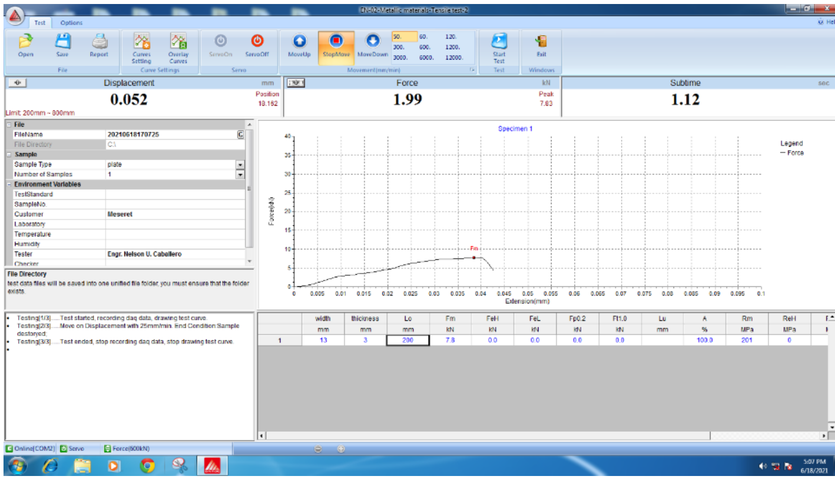
Sample-2

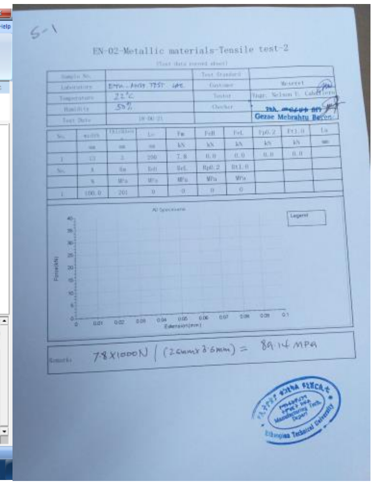
Tensile strength = 243.42MPa, Maximum tensile force = 21.3KN



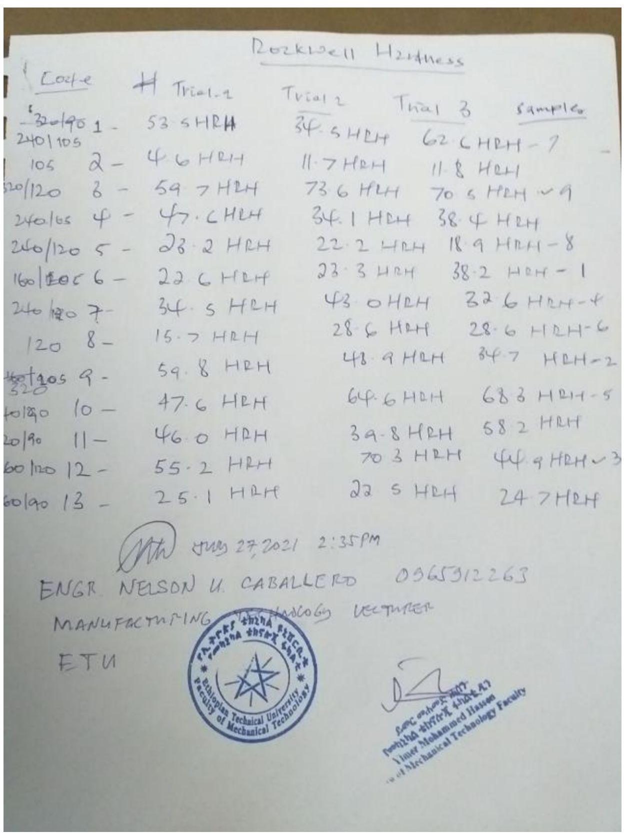
Sample-1

Tensile strength = 89.14MPa, Maximum tensile force = 3.1KN





Rockwell Hardness test



Rockwell Hardness

Code	H	Trial 1	Trial 2	Trial 3	Samples
320/90	1 -	53.5 HRH	34.5 HRH	62.6 HRH - 7	
240/105 105	2 -	4.6 HRH	11.7 HRH	11.8 HRH	
320/120	3 -	59.7 HRH	73.6 HRH	70.5 HRH - 9	
240/105	4 -	47.6 HRH	34.1 HRH	38.4 HRH	
240/120	5 -	23.2 HRH	22.2 HRH	18.9 HRH - 8	
160/105	6 -	22.6 HRH	23.3 HRH	38.2 HRH - 1	
240/120	7 -	34.5 HRH	43.0 HRH	32.6 HRH - 4	
120	8 -	15.7 HRH	28.6 HRH	28.6 HRH - 6	
520/105	9 -	59.8 HRH	48.9 HRH	34.7 HRH - 2	
40/90	10 -	47.6 HRH	64.6 HRH	68.3 HRH - 5	
20/90	11 -	46.0 HRH	39.8 HRH	58.2 HRH	
60/120	12 -	55.2 HRH	70.3 HRH	44.9 HRH - 3	
60/90	13 -	25.1 HRH	22.5 HRH	24.7 HRH	

July 27, 2021 2:35PM

ENGR. NELSON U. CABALLERO 0965312263

MANUFACTURING TECHNOLOGY LECTURER

ETU

Sample-1

Sample-2

Sample-3

Sample-4

Sample-5

Sample-6

Sample-7

Sample-8

Sample-9

Flexural strength test data

F.D.R.E Ministry of Defense
Defense University, College of Engineering

Date: June 18/2021

To: Adama Science & Technology University
Adama

Subject:- Regarding Composite Testing

Upon your request dated on June14/2021to perform Flexural Test of Composite for your post graduate student (**Meseret Tadesse**), the respective test is conducted in our Mechanical testing laboratory.

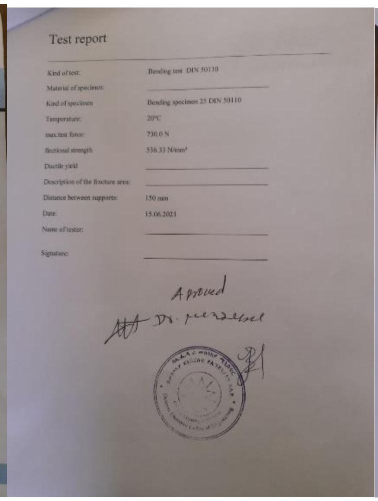
Accordingly the analysis is completed as per our request and hence, you find the report attached here.

Attachment:- 04

With Regards,

Maj. Bisrat Yosef (Dr.)
Defense University, College of Engineering
Academic Dean (Acting)

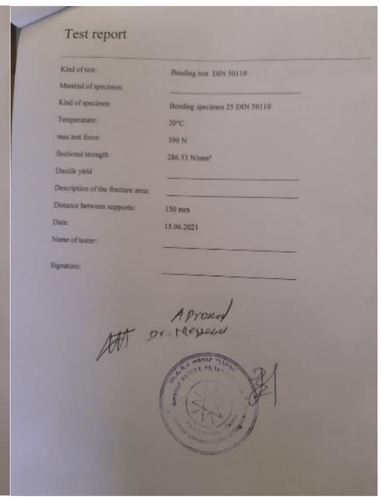
Tel 251-11433-27-11 P.O Box 1041 Fax 251-11433-86-08 Website: www.dec.edu.et Bishoftu, Ethiopia



Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
max.test force:	730.0 N
flectional strength	536.33 N/mm²
Ductile yield	
Description of the fracture area:	
Distance between supports:	150 mm
Date:	15.06.2021
Name of tester:	
Signature:	

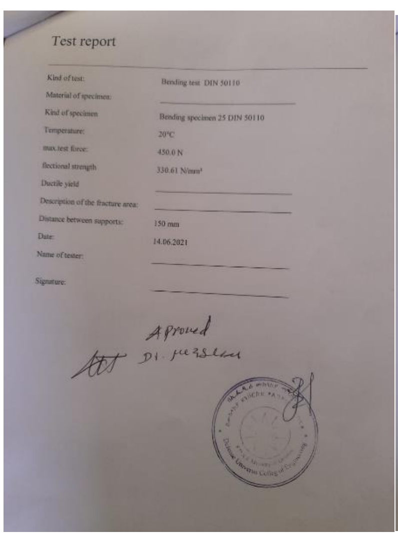
Aproved



Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
max.test force:	390 N
flectional strength	286.33 N/mm²
Ductile yield	
Description of the fracture area:	
Distance between supports:	150 mm
Date:	15.06.2021
Name of tester:	
Signature:	

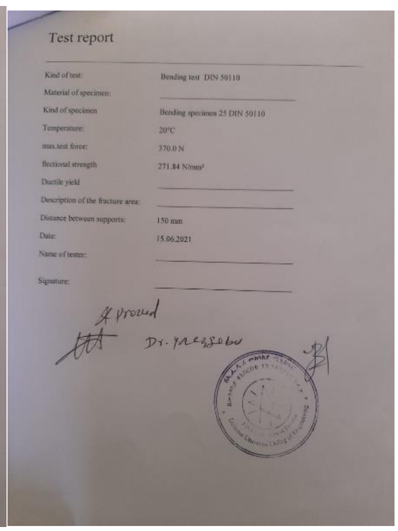
Aproved



Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
max.test force:	450.0 N
flectional strength	330.61 N/mm²
Ductile yield	
Description of the fracture area:	
Distance between supports:	150 mm
Date:	14.06.2021
Name of tester:	
Signature:	

Aproved

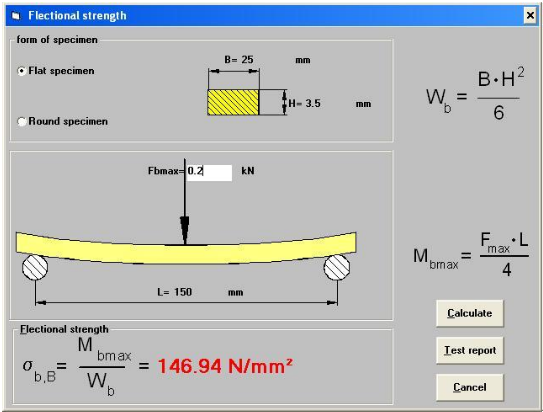


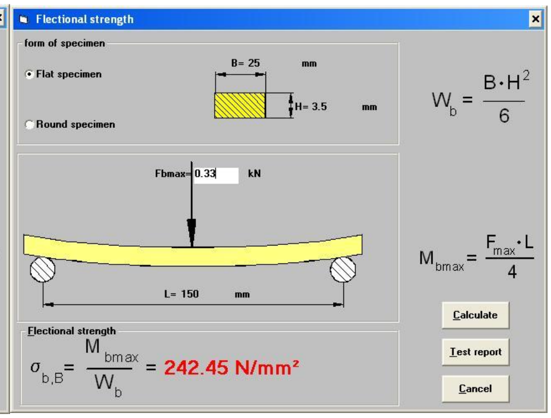
Test report

Kind of test:	Bending test DIN 50110
Material of specimen:	
Kind of specimen	Bending specimen 25 DIN 50110
Temperature:	20°C
max.test force:	370.0 N
flectional strength	271.84 N/mm²
Ductile yield	
Description of the fracture area:	
Distance between supports:	150 mm
Date:	15.06.2021
Name of tester:	
Signature:	

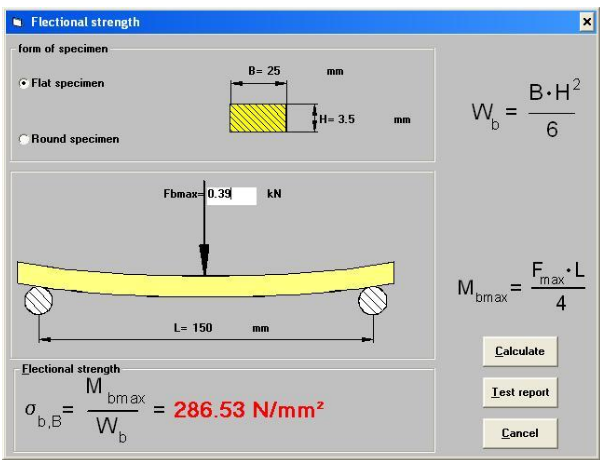
Aproved

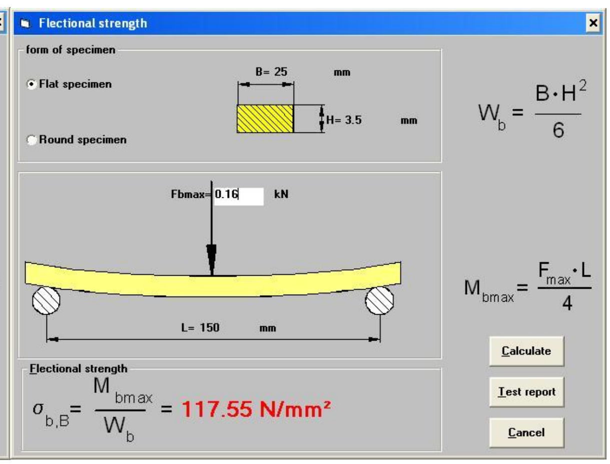
Sample 1 and Sample 2



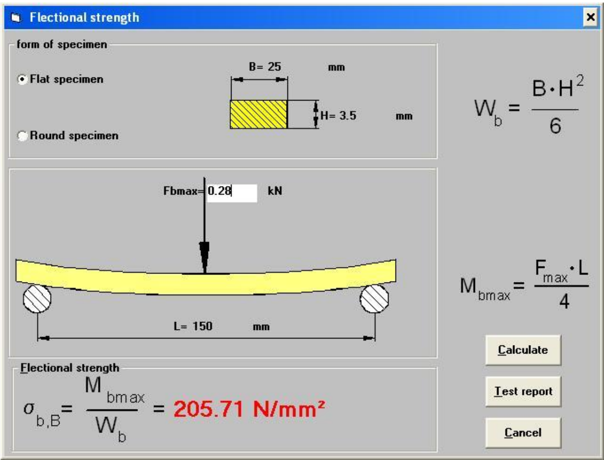


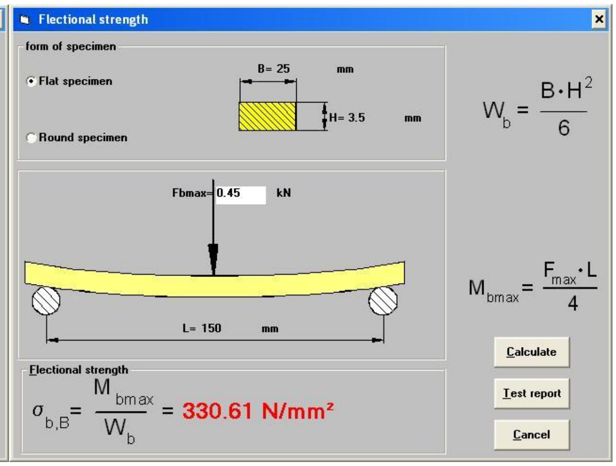
Sample 3 and 4



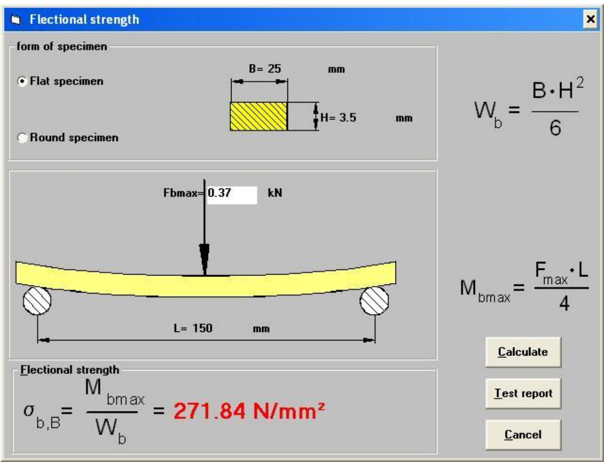


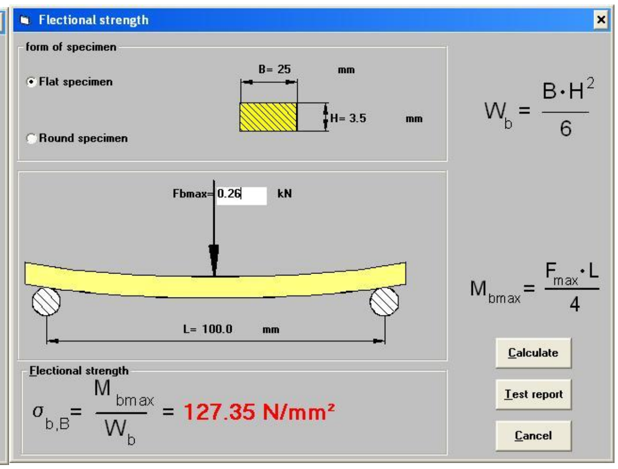
Sample 5 and 6





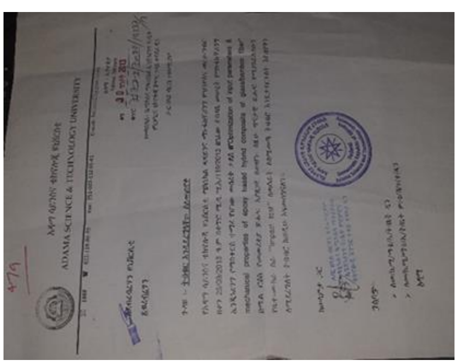
Sample 7 and 8

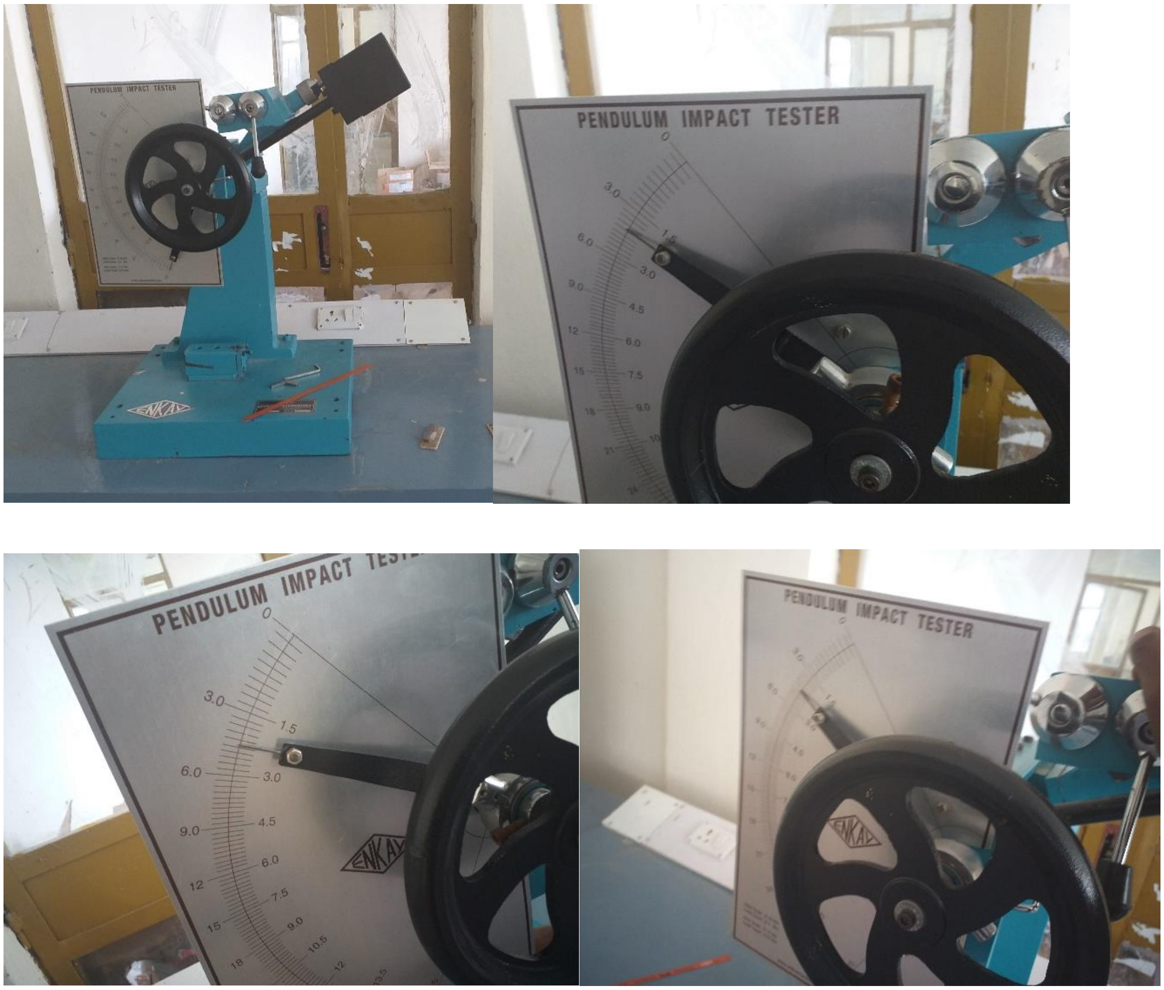




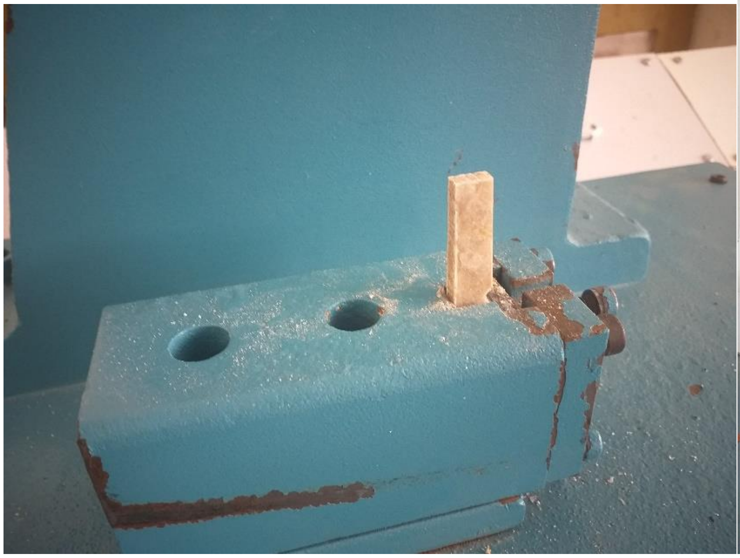
Sample 9

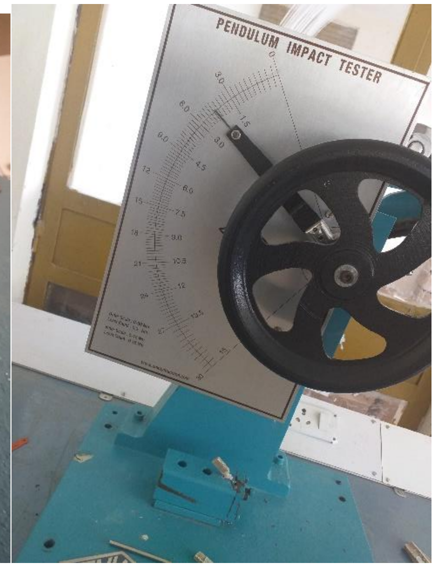
Toughness (Impact strength) test data





Adjustment and preparation of v -notch and, dial indicator after the load is applied





Specimens before and after the impact test

Front view of a specimen

Top view of the specimen

Bottom view of the specimen

Specimen view on the back

Water Absorption test data






Measurement of the weight percentage of dry and wet specimens


3.93 g

5.19 g

3.52 g

3.93 g

5.56 g

4.70 g