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Program of Mechanical Design and Manufacturing Engineering

Synthesis and Characterization of Bamboo Fiber Reinforced Epoxy Composite

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Candidate Declarations

I hereby declare that the work which is being presented in this thesis entitled by "**Synthesis and Characterization of Bamboo Fiber Reinforced Epoxy Composite**", in partial fulfillment of the requirements for the award of Masters of Science in Manufacturing Engineering is authentic record of my own work carried out during session of September to May 2018 under the supervision of Dr. Desalegn, Assistant Professor, Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality. All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Dr. Desalegn (PHD) _____________________ __________________

Advisor Signature Date

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Abstract

Composite materials are dominant among all emerging materials because of its advanced mechanical properties. While focusing on composite materials, the main points to be considered are cost effectiveness and environmental friendliness. In recent years, due to environmental concerns and growing cost of synthetic materials, the focus of research on natural fibers as an alternative reinforcement in polymer composites have created an enormous interest of many researchers and scientists. The natural fibers are fibers which consist of animal, plant fibers and minerals such as flax, hemp, jute, coir, cotton, wool, bamboo, banana, sisal and etc. The aim of this work is to synthesize and characterize the lowland bamboo fiber reinforced epoxy composite material mechanical properties under different fiber orientation. The fiber extraction can be done using mechanical extraction (retting) technique. The mechanical test result reveal that the uni directional bamboo fiber has high Vickers hardness value 116HN. While the multi directional bamboo fiber reinforced epoxy composite show high flexural strength 190.2MPa. The water absorption capability of the fabricated composite material was tested and result reveal less amount of water is absorbed than the natural lowland bamboo.

Key words: Composite, Natural fiber, Lowland bamboo, Synthesis, Fiber orientation, Retting, Mechanical test

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Abbreviations

ASTM	American Society for Testing and Methods
BBHGC	Bio Based Hybrid Green Composite
BFRPC	Bamboo Fiber Reinforced Polymer Composite
CM	Composite Material
EPDM	Ethylene Propylene Diane Monomer
FEM	Finite Element Method
GF	Glass Fiber
ILSS	Inter laminar shear strength
LBFRC	Lowland Bamboo Fiber Reinforced Composite
MFC	Mineral Filled Composite
NFRC	Natural Fiber Reinforced Composite
OM	Optical Microscope
PFRC	Plant Fiber Reinforced Composite
PLA	Poly Lactic Acid
PP	Polypropylene
RBSC	Reinforced Bamboo Scrimber Composite
SFRC	Synthetic Fiber Reinforced Composite
TCR	Thermoplastic Composite Reinforced
UTM	Universal Testing Machine

Acronyms

ρf	Density of the fiber
M_f	Mass of the fiber
V_i	Initial volume of the water before floating immersed
V_f	Final volume of the water with the floating object
Wa	Weight in air
W_1	Weight in fluid or liquid
M_1	Weight of dry piece
M_2	Weight of wet piece
Wa	Percentage of water absorption
Hv	Vickers hardness value
F	Applied force for indentation
D	Indentation surface
δ	Bending (Flexural) strength
l	Length of the specimen
b	Width of the sample
d	Thickness of the sample
t	Thickness of sample

CHAPTER ONE

INTRODUCTION

1.1. Back ground of the Study

Composite materials are dominant among all emerging materials because of its greater mechanical properties. The utilization of composite materials proved that it overcomes new markets inflexibility. While focusing on composite materials, the main points to be considered are cost effectiveness and environmental friendliness [1]. In recent years, due to environmental concerns and growing cost of synthetic materials, the focus of research on natural fibers as an alternative reinforcement in polymer composites have created an enormous interest of many researchers and scientists. The natural fibers are fibers which consist of animal, plant fibers and minerals such as flax, hemp, jute, coir, cotton, wool, bamboo, banana, sisal and etc. Natural Fiber-Reinforced Polymeric (NFRP) composites are quickly springing up in terms of research and industrial applications because they are abundantly available, economical, renewable, and biodegradable and possess comparable high mechanical properties. In addition, natural fiber as reinforcement in composite has several advantages over synthetic fibers like glass, carbon and boron fibers etc. like lower processing price, lower density, higher strength to weight ratio, higher specific ratio. Lingo cellulosic plant fibers like bamboo, sisal, kenaf, cotton, jute, pineapple, banana etc. are mainly used as reinforcement for NFRP composites. Nowadays they are used in various applications like transportation, defense, civil engineering applications, packaging, consumer products etc [2].Bamboo fiber also has higher tensile strength and modulus than natural fibers such as jowar, banana, sisal and coir fibers. Bamboo fiber is a naturally existing composite material as it is unidirectional reinforced by fibers in structure [3].

1.2. Statement of Problem

Bamboo has been traditionally perceived in Ethiopia as a plant having negligible value in comparison to other forest products. However, many studies indicated that bamboo is a plant having good mechanical properties, biodegradable, renewable and versatile material. Ethiopia has a surplus amount of bamboo plant, which has a great potential that can be used as structural materials for different applications [4]. But the contribution of bamboo plant on in industrial sector of the country is negligible as compared to other countries. Moreover, due to lack of awareness about this plant, un availability of experimental tools and low manufacturing process capability, the performance and applications of Ethiopian bamboo fibers and its composite materials are not investigated well. On the other hand, large amount of synthetic fibers are used in different construction, house hold products and manufacturing processes. However, these synthetic fibers can cause environmental pollution during manufacturing, fiber extraction, and during disposal of the used composite materials. Furthermore, the cost of different construction and manufacturing of products from metals and other synthetic composite materials are higher and tedious compared to natural fibers [1-4]. Therefore the composite material manufactured by reinforcement of bamboo fiber with epoxy matrix material is expected to reduce and alleviate all the above mentioned problems. In addition a proper synthesis and characterization of the bamboo fiber reinforced composite materials are very essential for different application as engineering materials and construction materials.

1.3 Objectives

1.3.1 General Objective

The general objective of the study is to synthesize and characterize the mechanical properties namely tensile, flexural and hardness properties of bamboo fiber reinforced epoxy composite material for different fiber orientation.

1.3.2 Specific objectives

- To extract bamboo fiber from the lowland bamboo tree using appropriate technique.
- To analyze lowland bamboo fiber natural structure and orientation using optical microscope (OM).
- To characterize the properties (density) of extracted bamboo fiber.
- To fabricate the composite material for different experimental conditions.
- To evaluate the effect of fiber orientation on mechanical properties of composite (flexural strength, hardness and water absorption).
- To compare the results with different equivalent plastic materials.

1.4 Scope of the Study

In order to achieve the objectives specified earlier the following scopes were setted

- The bamboo plant considered for this study was limited to those found in the lowland areas of Ethiopia.
- The fiber extraction method was limited to mechanical extraction (retting) method of fiber from the bamboo plant.
- The fabrication of composite material was conducted by using hand lay-up technique.
- The study was also limited to the evaluation of mechanical properties namely flexural strength, hardness and water absorption.
- The micro structural analysis of these composite materials was carried out using optical microscope (OM).

1.5 Research Motivation

Different bamboo species are available in Ethiopia. Ethiopia has Africa's biggest bamboo resource. 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 covers 15% and the monotypic genus lowland bamboo (Oxythenantera Abyssinica), with solid culms at maturing age, 5cm diameter and 7m high covers 85%. 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 [4]. In Ethiopia, in the past and even in present, the economic potential of bamboo has not been explored and the role of bamboo resources in national economies is negligible. However, now a day, bamboo has been used in traditional way in the country side. A little bit for the scaffolding, construction of houses, fuel feed houses, beehives, hats, mats, baskets, handicrafts, small furniture and other countless products. Hence to add values to the bamboo plant, it is essential to develop the fiber extraction method, characterizing the prominent properties of fibers and convert the bamboo fiber into more valuable form of composite products which can be used in several industrial applications.

1.6. Significant of the Research

There has been great interest in using natural fiber composites instead of synthetic fibers because of their low density, abundant availability, low cost and biodegradability. Natural fibers are getting high popularity as a replacement in place of synthetic fibers [1-3]. Bamboo fibers have significant potential in composite making due to its high strength and environmentally friend in nature. Bamboo fiber has higher ultimate tensile strength and higher tensile modulus than most of natural fibers such as jowar, banana, coir and sisal [3]. This bamboo resource is abundant in our country; such that the identification and description of these abundantly occurring resource mechanical and other properties aid to be profitable from the resource. The research aim is to synthesize and characterize the properties bamboo natural fibers reinforced composite polymers in which the bamboo fiber will be collected from lowland areas of Ethiopia for different fiber orientation and, it also evaluate the properties of lowland bamboo fiber found in Ethiopia. The effective characterization of bamboo fiber as well as bamboo fiber based composites will be carried out. In general the benefits and beneficiaries of this research are:

- Bamboo plant producer namely local farmers in Ethiopia.
- Bamboo fiber based composite manufacturing industries.
- The manufactured composite material can be used by construction industries, automobile industries, household products, manufacturing industries, etc.
- Researcher who is interested to work on natural fiber reinforced composite.

1.7Arrangement of the thesis

This thesis work is organized in six chapters. The first chapter is deal brief about the description of composite material, type of composite material as well as the reinforcement used, the thesis background, problem of the statement and general and specific objectives. The second chapter presents literature review on composite materials, bamboo plants, bamboo fiber, fiber extraction technique, the matrix material used to bind the fiber and composite fabrication technique. The third chapter deals with the experimental which focused on raw material preparation, test piece preparations, experimental methods, conditions and test set up for mechanical tests of lowland bamboo fiber reinforced epoxy composite. The fourth chapter addresses the analysis and interpretation of data gathered from mechanical test results. The fifth chapter deal with result and discussion on the data gathered from mechanical tests, interpret the data in using different technique and verify the result gain with different literatures. The sixth chapter describes the conclusions, recommendations and future works of the thesis.

CHAPTER TWO

LETERATURE REVIEW

2.1 Introduction

Now-a-days interest in natural fiber reinforced polymer composites are increasing rapidly due to their many advantages. These composites are more eco-friend and frequently used in many engineering applications worldwide such as in automobile, aerospace, construction (ceiling, partition boards etc.) and other household applications

2.2 Bamboo plant resources and properties

Different bamboo species are available in Ethiopia. Ethiopia has Africa's biggest bamboo resources and this plant can be harvested in sustainable cycles on 30%-40% of the mature culms every two years. 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 are in Africa. The highland bamboo (Yushania Alpina), 8cm diameter and 17m height covers 15% and the monotypic genus lowland bamboo (Oxythenantera Abyssinica), with solid culms at maturing age, 5cm diameter and 7m high covers 85%.

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. In Ethiopia, in the past and even in present, the economic potential of bamboo has not been explored and the role of bamboo resources in national economies is negligible. From the figure 2.1 Assosa, Injibara, Gimbi, Ambo, Gurage, Bale, Masha, Chencha and Hagere-Selam are rich in bamboo sources. The largest source of bamboo plant present in Assosa was presented by Siyoum [4].

Figure 2. 1 Diversity of Bamboo in Ethiopia [5].

A recently developed mechanical method for extracting long bamboo fibers opens the possibility to exploit new material as reinforcement in composite materials for high end uses was investigated. Bamboo has many culms. There is a variety between different culms on stiffness, strength and fracture toughness. The Culm of a bamboo plant is a ligno-cellulosic natural functionally graded composite material. Fibers are densely located around the outer cortex and similarly on the top of the Culm. The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%). The strength distribution of the fibers was characterized in a novel approach to evaluate the effect of defects introduced by the extraction process as function of different scale variables of fiber length, fiber surface area and fiber volume. They state that a practical model requiring only three parameters described accurately the fiber strength distribution of the fibers at different gauge lengths. The average fiber strength decreased with increasing gauge length, from 943 MPa at L = 1 mm to 733 MPa at L = 40mm and it was nearly independent of the mean fiber volume was stated by Trujillo et.al [6].

The bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin. Therefore, a devised process should be adopted to extract the bamboo fibers for reinforcement of composite materials. However once proper method of fiber extraction is selected, the result obtained is comparable even with glass fiber.

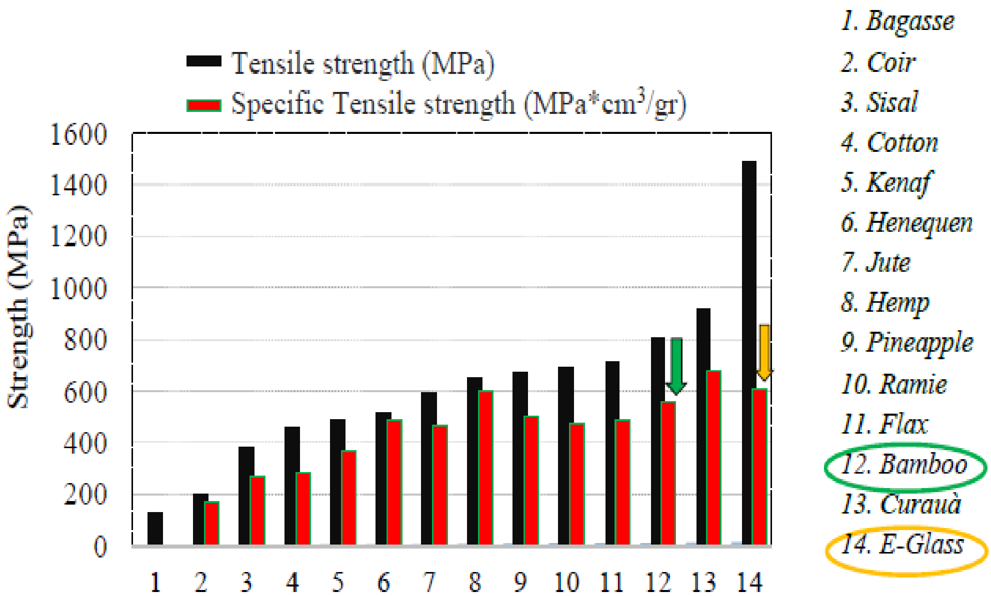


Figure 2. 2 Comparison of Natural fibers strength and specific strength [7]

The reduction in harmful destruction of ecosystem and to produce low cost polymeric reinforced composites, the researchers are emerging with policies of manufacturing the composites using natural fibers which are entirely biodegradable was described. These policies had generated safe strategies to protect our environment. The utilization of bamboo fibers as reinforcement in composite materials increased tremendously and undergoes high-tech revolution in recent years. Bamboo fiber is stronger as well as can be utilized in generating high quality sustainable industrial products were presented Abdul Khalil et.al [7].

The advantages of natural fibers over synthetic fibers comprise low density, low cost, availability, recyclability and biodegradability was investigated. Due to their numerous advantages they are supposed to be analogous to those of synthetic fibers used as reinforcements was stated by Begum et.al [8].

2.3 Bamboo fiber extraction, composite fabrication and matrix materials

The properties of bamboo fiber, jute fiber and coir fiber with different volume of epoxy resin having random orientation were studied under Comparative analysis of bamboo using jute and coir fiber reinforced polymeric composite. Hybrid was prepared from Bamboo, jute and coir fiber mixture with epoxy resin having volume percentage of 90:10 (epoxy: bamboo fiber) 90:5:5 (epoxy, bamboo, jute fiber) 90:5:5 (epoxy, bamboo, coir fiber).

The test was conducted and, bamboo–coir-epoxy resin composite show highest impact result 4 and 5 joules in IZOD and CHARPY test. Bamboo –epoxy show lowest values of 2 and 3 joules, according to FTIR test. Hardness result Bamboo –coir epoxy resin composite had the highest RHT value of 38 RHN and bamboo epoxy composite has the lowest 20 RHN was described by Sahas Bansal et.al [2].

Natural fiber reinforced polymer composite (NFRC) is the composite material in which natural fibers are used to reinforce the polymer matrix so as to improve its mechanical properties. These are eco- friendly and cost effective to synthetic fiber reinforced composites (SFRC). The availability of natural fiber, low cost and ease of manufacturing have urged researchers worldwide to try locally available inexpensive fiber and to study their feasibility for reinforcement purposes. Natural fibers (NF) need to be treated chemically so as to improve interfacial adhesion between fiber surface and polymer matrix. The chemically treated natural fibers show better improvement in properties than untreated fibers. This can be attributed to the removal of waxy layer from the surface of natural fibers and making it rougher. Natural fiber reinforcements have resulted in improved impact toughness and fatigue strength was studied by Tushar Sonar et.al [9].

The application of alkali treatment and elevated temperatures on the mechanical properties of bamboo fiber reinforced polyester composites (BFRPC) was investigated. Laminates were fabricated using untreated and sodium hydroxide (NaOH) treated (4-8% by weight) randomly oriented bamboo fibers and tested at room and elevated temperature (40, 80 and 120^{0}c). An improvement in the mechanical properties of the composites was achieved with treatment of the bamboo fibers. NaOH concentration of 6% was found optimum and resulted in the best mechanical properties. The bending, tensile and compressive strength as well as the stiffness of this composite are 7, 10, 81, and 25%, respectively higher than the untreated composites. When tested up to 80 ^{0}C, the flexural and tensile strength are enhanced but the bending stiffness and compressive strength decreased as these latter properties are governed by the behavior of resin.

At 40 and 80^{0}C, the bond between the untreated fibers and polyester is comparable to that of treated fibers and polyester which resulted in almost same mechanical properties. However, a significant decrease in all mechanical properties was observed for Composites tested at 120^{0}C was investigated by Allan C et.al [10].

Bio-based hybrid green composites (BBHGC) in unidirectional configuration were prepared by using kenaf, bamboo and coir fibers to reinforce polylactic acid (PLA) polymer matrix. Three types of hybrid green composites: kenaf-coir/PLA, bamboo-coir/PLA and kenaf-bamboo-coir/PLA composites were investigated by tensile and flexural tests. Scanning electron microscopy and optical microscopy were used to observe their micro structural failures. Tensile strength of kenaf-bamboo-coir/PLA composites achieved 187 MPa, approximately 20 and 78% higher than bamboo-coir/PLA and kenaf-coir/PLA, respectively. Young’s modulus of the three composites was low, ranging from 6.0 to 7.5 GPa. High flexural strength was obtained in both kenaf-bamboo-coir/PLA (199 MPa) and bamboo-coir/PLA (206MPa) composites, approximately 16and 20% higher than that of kenaf-coir/PLA, respectively. However kenaf-coir/PLA composites showed the highest flexural modulus, approximately 70% higher than other combinations.

Higher strain energy per unit volume required to break (toughness) was characteristic of kenaf-bamboo-coir/PLA composites. It was found that the combination of high strength and stiffness of bamboo and kenaf fibers and high ductility of coir fiber improved tensile and flexural strengths compared to those of single fiber green composites was presented by Rosini Bint Yusoff et.al [11].

The abundant availability and accessibility of plant fibers are the major reasons for an emerging new interest in sustainable technology. While focusing on the composite materials (CM), the main points to be considered are environment friendliness, light weight and specific properties. Plants fibers (PF) are a kind of renewable resources, which have been renewed by nature and human ingenuity for thousands of years were investigated by M. Ramesha et.al [12].

The greatest challenge in working with plant fiber reinforced composites (PFRC) is their large variation in properties and characteristics. Properties are influenced by a number of variables, including the fiber type, environmental conditions, processing methods, and modification of the fiber. Overall characteristics of plant fibers used in bio-composites, including source, type, structure, composition, as well as properties will influence the mechanical properties. To meet the material requirements of a large span structural beam, a newly designed reinforced bamboo scrimber composite (RBSC) beam combining the bamboo element and the reinforcement element was developed. The RSBC beam was compared with other un-reinforced beams to evaluate its bending properties. Results indicated that the reinforcement and the bamboo elements could firmly form an integrated composite cross-section. The failure modes, ultimate load and cross-section stiffness of the RBSC beams were significantly correlated to the diameter of reinforcement as well as the heat treatment of bamboo bundle. Both the ultimate load capacities and bending stiffness of the RBSC beams could be significantly improved and had a maximum increase of 58% and 82%, respectively, compared with the un-reinforced bamboo scrimber composite beams.

For the whole cross-section of RBSC beams, the ratios of bending stiffness and ultimate load capacity contributed by the reinforcement element ranged from 23% to 45% and from 15% to 31%, respectively, when the reinforcement diameter was increased from 12 mm to 20 mm were presented by Yong Zhong et.al [13].

Thermoplastic composites reinforced (TCR) with natural fibers (NF) have attracted the attention of many researchers, not only for environmental concerns, but also for economic reasons, recyclability, ease of processing and etc. One promising application is in the automotive industry due to their low cost and weight. This industry is increasingly pressured to produce vehicles that consume less fuel and are less polluting. Therefore, plastics reinforced (PR) with fibers are required to produce lighter parts to replace the much more abrasive glass fiber (GF) and mineral filled composites (MFC). One of the most widely used polymers in the automotive sector for manufacturing interior and exterior vehicle components is talc filled EPDM (ethylene propylene diene monomer) toughened polypropylene (PP) Addition of bamboo fiber significantly increased tensile and bending strength, modulus and fatigue life, and decreased elongation at break and impact strength. On the other hand, addition of the compatibilizer had a positive effect only on tensile and flexural strength, and fatigue life whereas the effect was negative on elongation at break and impact strength. The addition of fiber and compatibilizer did not appreciably affect the matrix melting temperature, but slightly increased crystallization temperature and in some cases the degree of crystallinity was investigated by Andre L. et.al [14].

Bamboo fiber, banana fiber& linen fiber with epoxy composite having random orientation with Epoxy resin, bamboo fiber with ratio of 90:10-Epoxy resin, bamboo fiber & banana fiber 90:5:5 Epoxy resin, bamboo fiber & linen fiber:90:5:5. Using the Hand lay-up moulding process, And Banana, epoxy resin composite show better result in impact test with value of 4joules for IZOD test and 5joule for CHARPY test. In FTIR test compatibility of fiber with polymer in bamboo-banana epoxy resin composite are the best. Bamboo–linen epoxy resin composite shows better result in rock well hardness test with value of 40 RHN was studied by Ramachandran et.al [15].

Replacement of bamboo fiber and bamboo powder in place of plastic products and reduce the environmental impact of expensive plastic use and the; Bamboo fiber percentage volume 0%, 50%, 100%. Molding temperature 160^0c, 180^0c, and 200^0c. Fiber orientation. Length of bamboo fiber, by extracting the fiber using steam explosion technique, Composite fabrication by Hot press technique, Tensile and flexural strength nearly increase with increasing fiber content, in case of 100% bamboo fiber molded at 160^0c tensile and flexural strength were 169.9 MPa and 211.1MPa. Strength of all powder specimen increase with rising molding temperature otherwise strength of 50% and 100% bamboo fiber decrease with increasing molding temperature. Was described by Shingi Ochi [16].

Analysis of Bamboo Fiber Composite with Polyester and Epoxy Resin were studied properties of woven bamboo natural fiber with polyester resin having 0/90 degree orientation and the bamboo natural fiber with epoxy resin having random orientation. Fiber orientation Polyester resin Epoxy resin they obtain tensile strength of bamboo composite PE 21.22N/mm^2. Impact test bamboo composite (epoxy resin) IZOD test 2 joule & CHARPY test 3joule. Rockwell hardness for bamboo composite (epoxy resin) 20RHN was done by M. Ramachandran et.al [17].

Characterization of natural fiber reinforced composite To obtain good mechanical properties of NFRC Orientation of fiber Strength of fiber Interfacial adhesion of fiber Glass Fiber Reinforced Composite has highest Tensile strength, Flexural strength, Flexural modulus than compared to natural FRC. Hybrid FRC consisting of Sisal and Pineapple has superior elastic modulus. Whereas FRC with date palm is having superior impact strength was studied by P.Hema Aditya et.al [18].

Characterization of natural fiber reinforced composites-bamboo and sisal Mechanical characterization, the mechanical properties of the natural fiber composites (bamboo, sisal) primarily depend upon the fiber/matrix interfacial adhesion. Though the natural fibers are superior in properties, but due to its hydrophilic nature, it possesses poor bonding nature with the hydrophobic polymer matrix. This has resulted in the degradation of its mechanical properties. The fiber length, loading and its moisture absorption capacity also influence the mechanical properties of the natural fiber reinforced composites Thermal Characterization, Electrical Characterization for both bamboo & sisal was studied by Thingujam Jackson Singh et.al [19].

Bamboo fiber as the reinforcement materials and matrix materials such as epoxy, urea formaldehyde resin, polyester, phenolic, poly lactic acid, polypropylene, polyester, poly (butylene succinate) and different filler materials was carried out. The result reveals that the bamboo fiber reinforced epoxy composites has a better tensile strength, flexural strength compared with other polymer materials. The impact strength is increased by adding bamboo fiber with matrix materials as compared with pure matrix materials the composites materials which shows the higher mechanical properties by adding filler materials with polymer composites. Tensile strength of some bamboo fiber reinforced polymer composites is more or less to the tensile strength of mild steel These composites materials can be used for the applications such as car bumpers, panels, railway window frames, doors, etc studied Nanda Kumar. et.al [20].

Bamboo Fibre Extraction and Its Reinforced Polymer Composite Material to gain a better understanding of a bamboo Culm's advantages as a natural plant fibre and its benefits over glass fibre was studied. Bamboo fibre has several advantages over other plant natural fibers such as high growth rate, strength, and fixing the carbon dioxide. It also can be compared with glass fibre because of its light weight, biodegradability, and low cost was described by P. Zakikhani et.al [21].

Optimizing the delamination failure in bamboo fiber reinforced polyester composite emphasizes on the critical parameters by varying its speed, feed, and diameter of the cutting tool was discussed, their contribution to delamination Speed (500,860 and 1360) feed (18,26 and 34)and Diameter of the drill bit (4,6and 8) was investigated and, delamination failure effect can be minimized by controlling the feed rate at 18 mm/min with a minimum speed of 500 rpm with 4 mm diameter drill bit, whereas the optimal condition for glass and royal fiber composite is around 2000 rpm with same size of drill and at a feed rate of 200 mm/min. Analysis of variance which gives the influence of input parameters and feed rate is known to have a maximum contribution followed by the drill diameter and spindle speed which has a minor part in delamination. By analyzing the mean squares the error percentage is found to be 3.09 percentages which is within the acceptable range was done by N. Abilash et .al [22].

Tensile Properties of Bamboo Fiber Reinforced Biodegradable Plastics describes tensile properties of bamboo fiber reinforced biodegradable plastics. The tensile strengths of the composites increased with increasing fiber content up to 70%. The composites possessed extremely high tensile strengths of 265 MPa. The fabrication with emulsion-type biodegradable resin contributed to reduction in voids and fiber contents in the composites was done by Shinji Ochi [23].

Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites was covered. Investigation of physical, mechanical and thermal properties of jute and bamboo fiber reinforced epoxy resin unidirectional void free composites it is observed that bamboo fiber reinforced epoxy composites showed good results in terms of tensile strength, while jute fiber reinforced epoxy. Composites had higher Young's modulus values. Bamboo fiber reinforced epoxy composites showed good flexure strength in the longitudinal distribution. On the other hand, jute fiber reinforced epoxy composited had better flexural strength with transverse fiber distribution in the composites. Fiber distribution was not uniform for both bamboo and jute fiber reinforced unidirectional epoxy composites were stated by Subhankar et.al [24].

Tensile Testing of Bamboo Fiber Reinforced Epoxy Composite Experiment was carried out on bamboo epoxy reinforced composite and it is found that its tensile strength is 26.417 MPa at 2.4kN. It is assumed that, composite is free of voids. But in reality, there are few voids present in the composite. Hence theoretically calculated value of modulus of elasticity is greater than the practically calculated value. In this case, theoretical Modulus of elasticity is 3456 MPa, while practical Modulus of elasticity is 2930 MPa. Percentage error is less than 15% between theoretical and practical value investigated by Wani et.al [25].

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials used in the research work

For this study the natural fiber which was used for fabrication of composite was bamboo plant fiber obtained from the low land bamboo plant. This plant abundantly found in Assosa, Ethiopia. The matrix material used was epoxy resin and its hardeners and surface treatment chemicals were used during the composite material preparation such as wax.

3.1.1 Equipment

The instruments and tools used for fabrication and characterization of composite material beginning from fiber extraction up to composite material fabrication were given as follows.

3.1.1.1 Optical microscope (OM)

Optical microscope is the most widely used type of instrument which is used for characterization of micro structure of materials. It examines microscopic structure by using visible light on the surface of materials. Optical microscope can be used for visualization and characterization of the fiber microstructures and others [26].

3.1.1.2 Band saw and Rubber hammers

Band saw was used to split the bamboo plant or trees into separate pieces, and rubber hammer was used while extracting the retted strip of bamboo Culm and also used to separate the fiber from the matrix material. This hammer was selected due to it advantage of protecting damage from fiber.

3.1.1.3 Universal testing machine (UTM) and Vickers hardness tester

Universal testing machine (UTM) was used for testing mechanical properties of the fabricated composite materials such as tensile, flexural and other tests. The Vickers hardness tester is selected to determine hardness of the bamboo fiber reinforced composite materials

3.2 Experimental methods

3.2.1 Methods of fibre extraction and composite preparation

In this work the composite material was fabricated from natural plant typically from the Lowland bamboo. Lowland bamboos are abundantly available in the lowland part in Ethiopia. They cover around 85% of bamboo resource in our country. Specifically the bamboo was selected from Assosa, Ethiopia for investigation. The preparation of this composite material required different techniques beginning from the selection of bamboo up to the final stage in which the composite was fabricated for the investigation of different mechanical properties.

3.2.1.1 Techniques of bamboo fibre extraction

Bamboo trees have high strength and stiffness at maturating age in between 3-5 years. This property of bamboo is special from other natural polymers. Fibre extraction technique is the method in which the required fibre (reinforcing phase) for the preparation of composite material is obtained. This fibre extraction plays vital role for the composite material strength as well as different properties. To obtain this fibre from the bundle of the bamboo trees there are different techniques available in the literature as listed below

- Mechanical extraction methods (steam explosion, crushing, grinding, roll in mill and retting)
- Chemical extraction methods (chemical retting, alkali or acid retting)
- Combined chemical and mechanical extraction methods. All of the fibre extraction methods have their own advantages and disadvantages. For this work the selected way to extract the fibre is mechanical fibre extraction method (retting) [27].

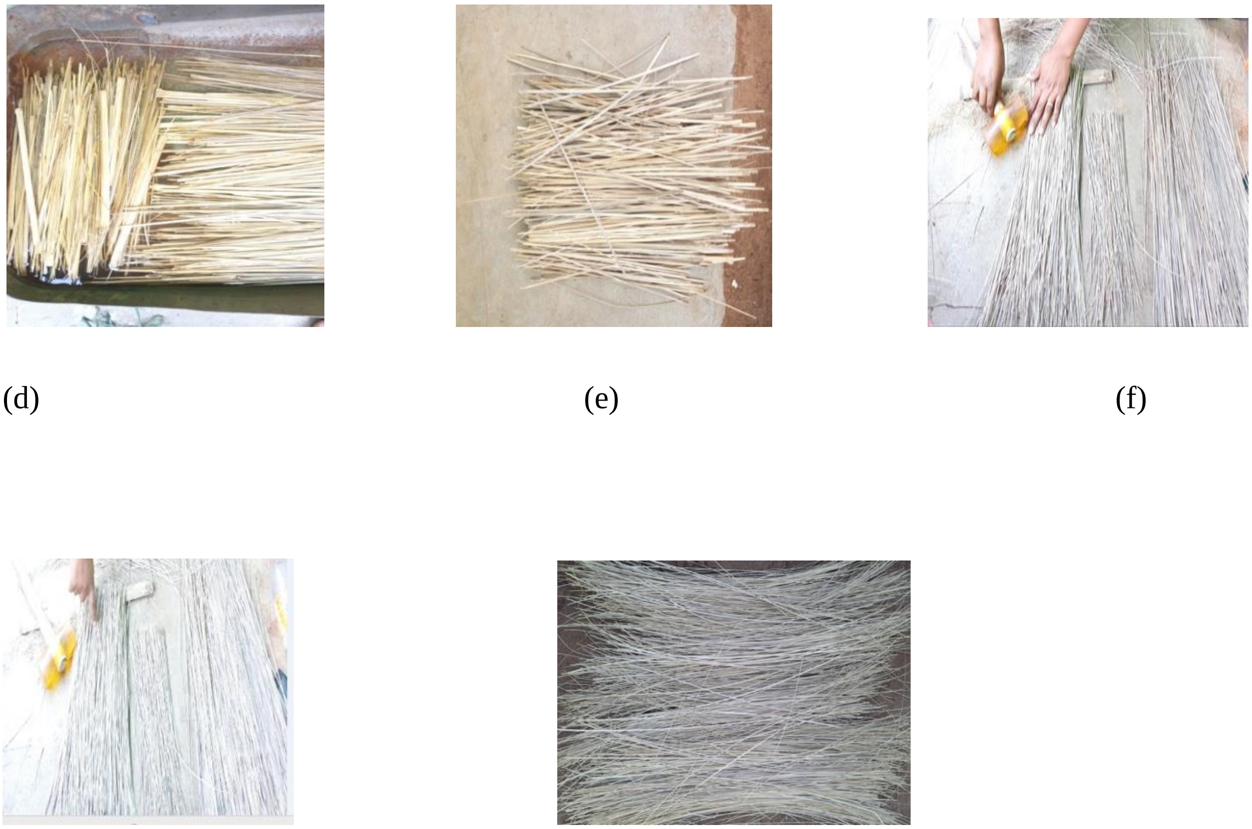
3.2.1.2 Mechanical extraction

There are many forms of mechanical extraction methods such as steam explosion, crushing, grinding, rolling in a mill and retting.

These methods are used for the extraction of bamboo fibre for application in various industries for making bamboo fibre reinforced composites. In this work, the extraction of bamboo fibre was carried out by mechanical extraction technique (retting). In general, the extraction process of the bamboo fibers is summarized as below. The lowland bamboo in maturating age was cut in its nodal. Then, scrap the outer cover of cylindrical part of the bamboo Culm and peel to obtain the strips. In order to remove the dirty particle, the bamboo Culm was cleaned using sand paper.

The bundles of strips were kept in water for seven days in order to soften and separate the non-cellulose part. The wetted strips was beaten with a rubber hammer slowly in order to avoid damage occur on the fibre, then scrap and comb the fiber using wire or metal comb. The process of beating and combing was repeated until individual fibers are separated. In this method, the process of scraping had strong effect on the fibre quality.

(a) (b) (c)



(d) (e) (f)

(g) (h)

Figure 3. 1 Bamboo fiber extraction technique (a) Bamboo plant, (b) dry bamboo plant, (c) Split bamboo calm, (d) retting process of bamboo split, (e) First stage of fibre extraction, (f) biting bamboo split using rubber hammer and (g) Final stage of bamboo fiber extraction (h) extracted bamboo fiber

3.2.2 Density determination of lowland bamboo fibre

Density of an object can determine the degree of compactness of that substance. Natural polymer reinforcement owns the advantage of lower density and lower weight in composite materials compared to other reinforcement phases. For this work density measuring can be conducted according to the "Archimedes' principle". Archimedes' principle can verify in experimental procedures and determine mass and density using a floating object. This is demonstrated by simple experiments using graduated beakers [28].

(a) (b)

Figure 3. 2 Measuring the density of an object (a) initial volume of water (b) after floating object immersed on it**.**

Density of composite material was measured depending on the density of the water and the volume of the water as follow:

$$\rho f = \frac{mf}{vf} \qquad [3.1]$$

$$\rho f = \frac{mf}{vi - vf} \qquad [3.2]$$

where:

ρf is Density of the fiber

M_f is mass of the fiber

V_i is initial volume of the water before floating immersed

V_f is final volume of the water with the floating object

And also using the Archimedes principle and relating the weight in air and the weight in fluid the dimension less density can be obtained

$$\rho f = \frac{wa}{wa - wl} \qquad [3.3]$$

Where:

ρf is Density of the fiber

Wa is weight of the fiber in air

Wl is weight of fiber in liquid

3.2.3 Epoxy resin and its hardener

Among main group of the matrix materials, thermo set resins is the major one which includes polyesters, phenolic, polyurethanes and epoxies. Epoxy resin belonged to a family of polymeric materials under the group of thermo set [29].

The resin used for this study was Epoxy Resin which is manufactured by Fiber Glass Development Corporation Company.

It has superior flexural strength, tensile strength, bond strength, adhesive characteristics and fatigue resistance than other types of resins.

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

- Better adhesive properties (the ability to bond to the reinforcement)
- Superior mechanical properties (particularly strength and stiffness)
- Improved resistance to fatigue and micro cracking [30].

3.2.3.1 Hardener (catalyst)

Curing agent usually react with epoxy resin in order to control or minimize its cross linking reaction, leading to reduction in inherent epoxy resin brittleness, delamination and improved fracture toughness Hardener is used to cure the epoxy resin. Generally, it is mixed with epoxy resin at normal atmospheric temperature. Epoxy resin is cured by mixing it with hardener in 10:1 ratio or according to the specification depending on the types [31]. Hardener is available in liquid form. When epoxy resin and hardener are mixed together, chemical reaction takes place and because of which, mixture starts to harden the matrix material. The curing agent applied in this work for the liquid epoxy resin is hardener Manufactured by Fiber Glass Development Corporation Company. Here, in proper amount of epoxy & hardener is mixed and stirred for few minutes using deep stick material.

3.3 Composite material preparation

The composite material was fabricated using the open mold system of hand lay-up in which the mold is open in the top direction. The materials were made in laminate form or orientation which means the fiber can be placed in the needed orientation (un-directional, bi-directional and multi-directional orientation) and the epoxy resin was mixed with its hardener was placed on the fiber. This process was repeated until the required dimension of the composite material is obtained.

3.3.1 Mold preparation

The open mold system was selected for the advantage of easy fabrication system and less cost. In order to remove easily the composite material, avoid sticking behavior as well as to provide good dimensional stability and good surface finish the mold tool was coated by coating gel or by wax.

Then the prepared bamboo fibre was placed in the mold and epoxy resin was applied with the help of roller in order to avoid crack, air bubble as well as excess resin from the prepared part; until the required thickness can be obtained the process was repeated.

3.3.2 Preparation of specimen for different mechanical test

After the constituents of the composite materials were properly identified, which means the reinforcing phases as well as the matrix phase was well defined the next work was specimen preparation. For this work specimen was prepared using the ASTM standard. The specimen preparation was made with the purpose of determining the different mechanical properties of the composite materials. The specimens were prepared to conduct mechanical properties such as flexural, hardness and water absorption properties of the composite material.

3.3.3 Specimen preparation for flexural test

The flexural specimens were prepared as per the ASTM D790 standard [33]. The three point flexure test is the most common flexural test for composite materials. For this work the flexural test was conducted by using three point bending machine, I which the applied bending load to the prepared specimens and the peak load was recorded with displacement and the force and displacement graph was plotted. Using the peak load, width and thickness the flexural strength was conducted. The specimen used for conducting the flexural test has the following dimension.

Length = 125mm, width = 12.5mm, thick = 5mm

(a) (b) (c)

Figure 3. 3 Specimen preparation for Flexural test (a) cad design (b) prepared fibre (c) prepared specimen

3.3.4 Specimen preparation for hardness test

The hardness of the polymeric composite is a critical parameter that influences the durability and lifespan of the material [34]. Hardness test was conducted using the Vickers hardness machine. Vickers hardness tester can test the hardness of the material by indenting the material by using diamond indenter tool and conduct the hardness of the materials. Size of specimen is
Length =30mm, width =30mm, thickness 10mm.

Figure3. 4 Specimen preparations for hardness test

3.3.5 Specimen preparation for Water absorption

Water absorption test was used to determine the amount of water absorbed by a composite material. The water absorption test followed ASTM standard test method D570 [35]. The test specimen was in the form of a bar having length of 75mm, width of 50mm and thickness of 10mm Then the specimen was immersed in water maintained at a temperature of 25°C for 24, 48, 72, 96,120,144 and other hours. After the specified hours, the specimen was removed from water and placed on blotting paper to remove excess water before weight measurement. Test specimen was prepared from the natural lowland bamboo, steam extracted and synthesized with epoxy. The water absorption percentage of the sample was calculated as percent weight change (w %) as follows:

$$\mathrm{Wa} = \frac{\mathrm{M2} - \mathrm{M1}}{\mathrm{M1}} * 100 \qquad [3.4]$$

(a) (b) (c)

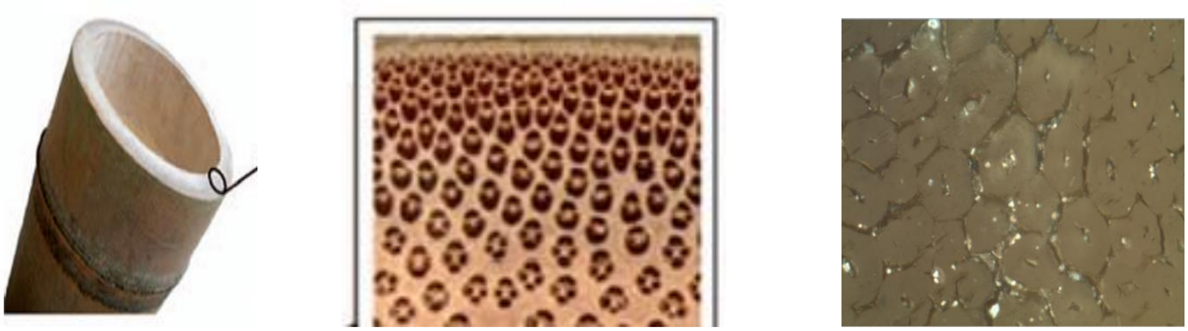
Figure3. 5 Specimen preparation for water absorption test (a) cad design (b) prepared fibre (c) prepared specimen

CHAPTER FOUR

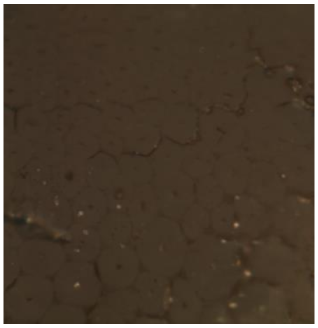
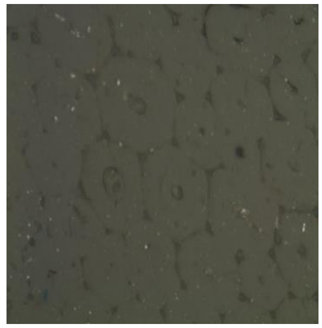
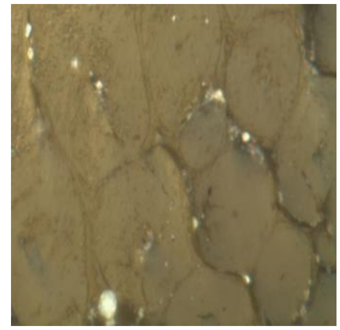
ANALYSIS AND INTERPRETATION OF DATA

4.1 Bamboo Structure

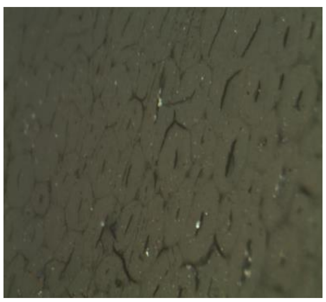
Bamboo culms are hollow, and every Culm from inner side is divided by several diaphragms which are seen as rings on the outside. The part between two rings is called "Internodes" where branches grow. Distance between each node varies and it depends on the type of the species. The microstructure of a bamboo Culm consists of many vascular bundles which are embedded in parenchyma tissue and distributed through the wall thickness. Parenchyma tissue only keeps the vascular bundles in the longitudinal direction. The number of vascular bundles is highly concentrated close to the outside of the bamboo Culm wall, and this amount reduced on the inside. The fibre strand consists of many elementary fibers with the shape of hexagonal and pentagonal, where Nano-fibrils are aligned and bounded together with lignin and hemi-cellulose. The strength of a bamboo Culm is defined by its vascular bundles. Therefore it is essential to use a suitable method to separate the parenchyma tissue from fibre strands and vascular bundles without any destructive effect on the extracted fibers.



(a) (b) (c)

(d) (e) (f)



(g)

Figure4. 1 Structure of bamboo (a) bamboo Culm (b) cross section of bamboo Culm (c) morphology of natural bamboo, (d) steamed, (e) uni directional,(f) bi directional and (g) multi directional bamboo fiber reinforced with epoxy.

The surface characteristics of the composite material used for the investigation was studied through optical microscope. The optical Microscope images were taken to observe the interfacial properties, internal cracks and internal structure of surfaces of the composite materials. All the specimens were treated by enchants before observing the surfaces through optical microscope. The etchants used to visualize the surface of the composite sample to be investigated. The etchants used was ethanol and hydrochloric acid. Figure 4.1 depict that the natural and steamed lowland bamboo shows shining characteristics which describe the occurrences of the natural matrix (wax) type of the lignin where as in the synthesized lowland bamboo composite material there is no shining characteristics which means that, the natural matrix material was removed and replaced by the epoxy.

Also this figure shows that the orientation of the fiber was enhanced in the synthesized one than the natural and steamed bamboo. In both the bi directional as well as in multi directional the fiber were arranged in different orientation as well as they were more compacted together.

4.2 Density determination

The biggest advantage of natural polymer reinforcement composite material is their low density and low weight compared to other reinforcement phases. The density was been measured according to Archimedes principle. Archimedes' principle states that an object fully or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid that the object displaces. To describe the linear density, the fiber mass measured on balance and fiber length measured with ruler is required. For density measuring the fiber it was used. In order to get weight difference the fiber, the fiber can be measured on weight balancer before immersion and after immersion in fluid. In order to avoid water absorption the fiber was covered with aluminum foil having weight of 0.095.

4.3 Hardness test

Hardness measurements quantify the resistance of a material to plastic deformation. Indentation hardness tests compose the majority of processes used to determine material hardness, and can be divided into two classes: micro indentation and macro indentation tests.

Micro indentation tests typically have forces less than 2 N. The term "macro indentation" is applied to tests with a larger test load, such as 1 kgf or more force is applied. There are various macro indentation tests, including:

Vickers hardness test (HV), which has one of the widest scales. Widely used to test hardness of as well as Knoop hardness test (HK), Rockwell hardness test (HR) and others,

4.3.1 Vickers' hardness tester

The Vickers' hardness tester uses the square based pyramid indenter with an angle of 136^0 between the opposite face at the vertex, which is pressed in to the surface of the test piece using prescribed force; (F)

$$HV = \frac{\text{constant} * \text{test force}}{\text{surface indentation}^2} \quad [4.1]$$

$$HV = \frac{0.102 * 2f(\frac{\sin 136}{2})}{d^2} \quad [4.2]$$

where:

Hv is Vickers hardness value

F is applied force for indentation

d^2 is indentation surface

d^2 = (d1+d2)/2 d1, d2 value of diagonal 1 and 2

Table4. 1 Vickers hardness test result in 5kgf

Type of orientation	Vickers hardness value with 5kgf					Average Vickers hardness value
Natural lowland bamboo	73.9	72.5	79.5	65.2	73.9	73
Steam treated bamboo	71.8	83.1	87.3	89.5	92.1	84.76
Uni directional bamboo fiber reinforced epoxy	83.7	56.9	99.1	91.4	116.9	89.6
Bi directional bamboo fiber reinforced by epoxy	63.3	82.5	94.5	93.1	57.1	78.1
Multi directional bamboo fiber reinforced by epoxy	69.8	80.6	75.2	69.1	99.1	78.76

Table4. 2 Table Vickers hardness test result using 10kgf

Type of orientation	Vickers hardness value with $10_{kg\ f}$					Average Vickers hardness value
Natural lowland bamboo	147.8	145	159	130.4	147.8	146
Steam treated bamboo	143.7	166.2	174.6	179	184.2	169.54
Uni directional bamboo fiber reinforced by epoxy	167.4	113.8	198.2	182.8	233.8	179.2
Bi directional bamboo fiber reinforced by epoxy	126.6	165	189	186.2	114.2	156.2
Multi directional bamboo fiber reinforced by epoxy	139.6	161.2	150.4	138.2	198.2	157.52

The hardness test was conducted using the standard Vickers hardness tester 10kgf and other option of using minimum force of 5kgf. Depending on this force the hardness test was conducted, comparison between the natural bamboos, steamed bamboo as well as the uni-directional bamboo fiber reinforced by epoxy was conducted. Also comparison of the synthesized composite material (uni directional, bi directional and multi directional bamboo fiber reinforced by epoxy) was performed.

4.4 Flexural strength result

Flexural strength is the ability of the material to withstand the bending forces applied perpendicular to its longitudinal axis. The flexural strength test was performed using three point bending machine using universal testing machine (UTM).Flexural strength was calculated as follow

$$\delta = f * s = \frac{3FL}{2bd^2} \qquad [4.3]$$

The data recorded during the three point bending test also used to describe the inter laminar shear strength (ILSS). Inter laminar shear strength is the parameter which characterizes the binding strength of fiber and matrix in the composite structure. The inter laminar shear strength can be obtained as follow:

$$\mathrm{ILSS} = \frac{3F}{4bt} \qquad [4.4]$$

Table4. 3 Flexural strength and inter laminar shear strength value

Type of bamboo sample	Peak load in (KN)	Flexural strength in (MPa)	Inter laminar shear strength in (MPa)	Displacement in (mm)
Natural bamboo	0.55	33	6.6	54.69
Steamed bamboo	1.01	60.5	12.12	32.51
Uni directional with epoxy	1.42	85.2	17.07	28.13
Bi directional with epoxy	2.12	127.2	25.44	51.18
Multi directional with epoxy	3.17	190.2	38.04	48.43

For the flexural strength also five different samples was prepared and used. Using the load applied to bend the specimens, width of the specimens and thickness of the specimens the flexural strength and the inter laminar shear strength were determined.

4.6 Water absorption test

Water absorption is an important characteristic which can be used to predict durability of bamboo fiber reinforced epoxy composites. Water absorption of composites was performed as per ASTM D570.

Specimens were immersed in normal (pH=7), distilled (pH=6.5) water at room temperature, the water absorption test was conducted using normal water and distilled water with different time frames. After specific time intervals specimens were removed from the container, their surface moisture was removed.

The content of water absorption by the specimen was measured using a precise digital balance machine. The normal and distilled water absorption was carried out for 24, 48, 72, 96, 120 and 144 hours. Specimens were prepared from natural lowland bamboo, synthesized with epoxy and steamed bamboo types. The formula used to calculate the water absorption percentage was as follow:

$$W\% = \frac{w2 - w1}{w1} * 100\% \qquad [4.5]$$

where

W% is percentage of water absorption

W1 is initial weight of sample before immersed

W2 is final weight of sample after immersed

The test was carried out by measuring the initial weight of the sample using precise weight balancer having accuracy of measuring weight 0.0001g.

Table4. 4 Initial sample weight of water absorption test

Sample name	Natural bamboo	Steamed bamboo	Uni directional bamboo fiber with epoxy	bi directional bamboo fiber with epoxy	multi directional bamboo fiber with epoxy
Initial weight (g)	14.785	14.346	29.84	26.21	35.11

Table4. 5 Water absorption result normal water condition (pH= 7)

Type of bamboo sample	Immersion time in (hr.) and water absorption in (%)						Average water absorption result
	24	48	72	96	120	144	
Natural bamboo	8	14.98	22.15	28.5	28.6	28.6	21.2
Steamed bamboo	4.21	11.53	19.16	24.4	25.5	25.5	18.4
Uni directional	2.21	6.09	7.24	10.6	10.6	10.6	7.89
Bi directional	2.81	5.6	6.83	9.88	10.6	10.6	7.72
Multi directional	2.39	3.96	5.4	5.5	5.5	5.5	4.7

Table4. 6 Water absorption result in distilled water condition (pH =6.5)

Type of bamboo sample	Immersion time in (hr) and water absorption in (%)						Average water absorption result
	24	48	72	96	120	144	
Natural bamboo	11.2	14.98	18.29	23.9	25.13	25.13	19.77
Steamed bamboo	11.5	15	18.74	24.3	25.7	25.7	20.15
Uni directional	3.88	6.4	7.24	9.4	9.4	9.4	7.62
Bi directional	4.9	8.13	10.6	13.3	13.3	13.3	10.6
Multi directional	2.67	5.24	6.15	6.8	6.8	6.8	5.7

CHAPTER FIVE

RESULT AND DISCUSSION

5.1 Density measurement

The density can be measured according the Archimedes principle of the weight of material in air is equal with the weight of material in liquid using the following formula

The density calculated above is dimension less in order to get the dimensioned density of the fiber ,the technique of immersing the fiber in fluid for 1 minute and taking the volume difference before immersion and after immersion the density can be calculated

Density measurement using lowland bamboo fiber taking aluminum foil weight 0.095g

$$\rho = \frac{\mathrm{mf}}{\mathrm{vf} - \mathrm{vi}} = \frac{0.6014 - 0.095}{250 - 200} = \quad 1.013\mathrm{g/cc}$$

Specific density of the fiber is

$$s = \frac{\rho f}{\rho w} = \frac{1.013}{1000} = \quad 0.001013$$

5.2 Hardness test analysis

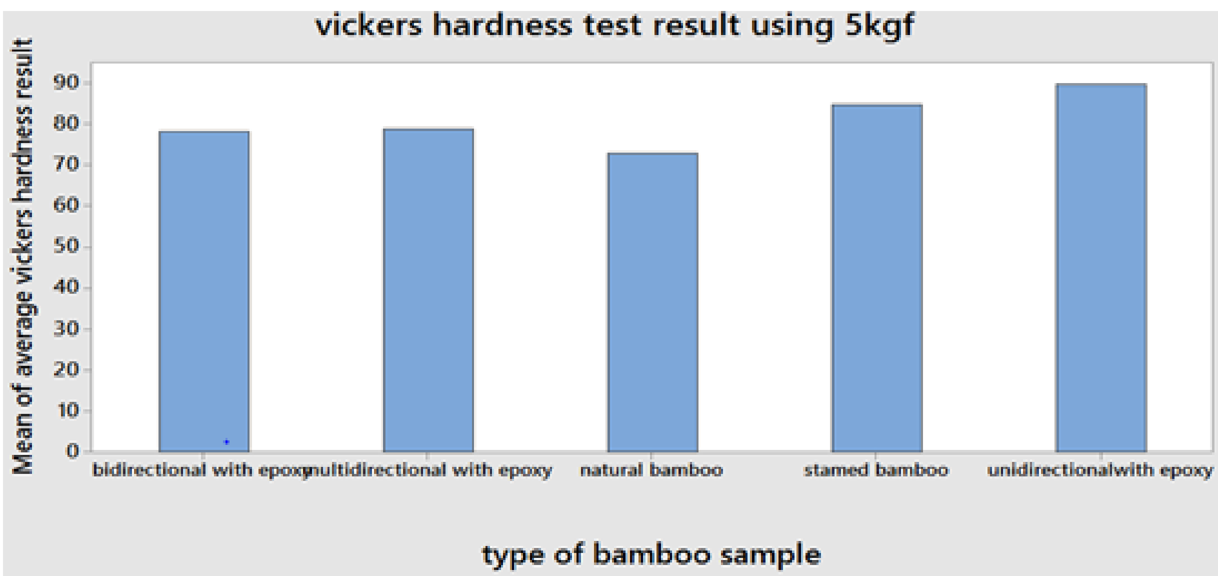
The Vickers hardness test shows that the uni-directional bamboo fiber reinforced by epoxy composite have highest Vickers hardness number in both 5 and 10 kgf average values of 89.6 HV and 179.2HV.The peak hardness value was obtained in unidirectional 116.9 HV using 5kgf and 233.8 HV using 10kgf. From the synthesized composite material the bi directional bamboo fiber reinforced epoxy composite show the least value. This is a rise from the fiber properties has less hardness in the transverse direction.

(a)

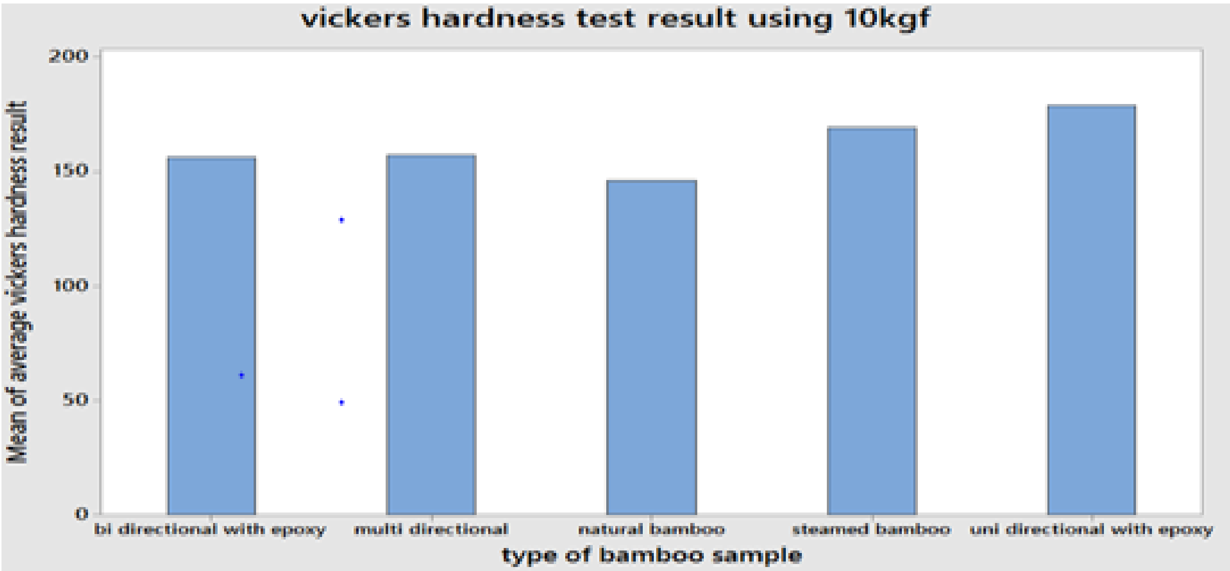
(b)

Figure5. 1 Vickers hardness test sample preparation (a) prepared sample (b) tested samples

From all taken samples the natural bamboo fiber shows least hardness value. This shows that the matrix of the natural bamboo has great effect on the hardness of the bamboo fiber. The uni-directional fiber reinforced epoxy composite has higher hardness. This is due to the natural matrix is substituted by epoxy matrix and fiber has high hardness in the longitudinal direction.



(a)



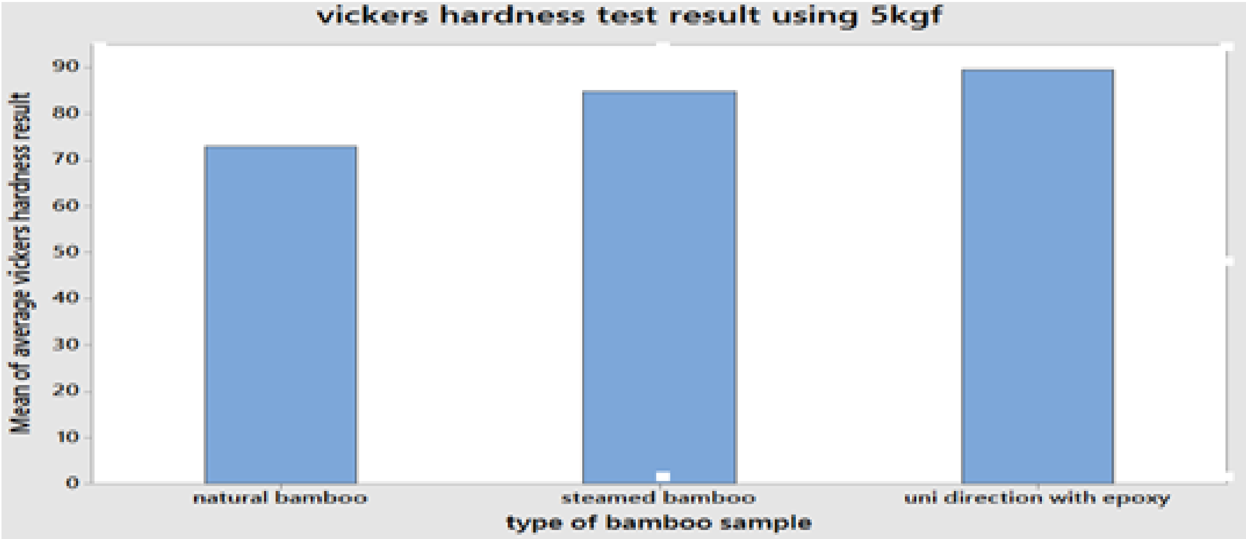
(b)

Figure5. 2 Average Vickers hardness test results using (a) 5kgf (b) 10kgf

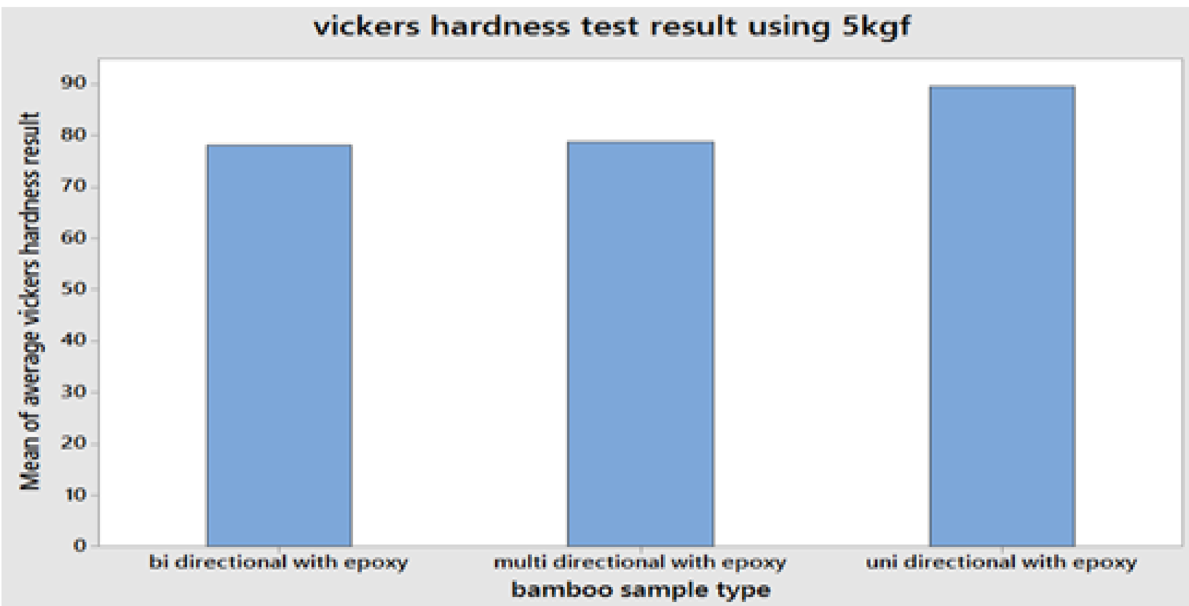
While comparing the hardness of each sample individually the natural bamboo shows the minimum hardness value. The steamed bamboo show comparable hardness with the uni, bi and multi directions orientations.

The lowland bamboo fiber reinforced with epoxy composite results in a higher value of hardness for all selected samples.

The comparison of natural, steamed and the uni-directional as well as the comparison of uni, bi, multi directional bamboo fiber reinforced with epoxy composite was shown in figure 5.3 (a) and (b).



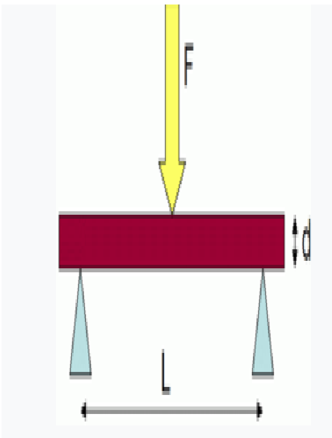
(a)



(b)

Figure5. 3 Comparison of the (a) natural, steamed and uni-directional (b) three synthesized epoxy composite

5.3 Flexural strength result

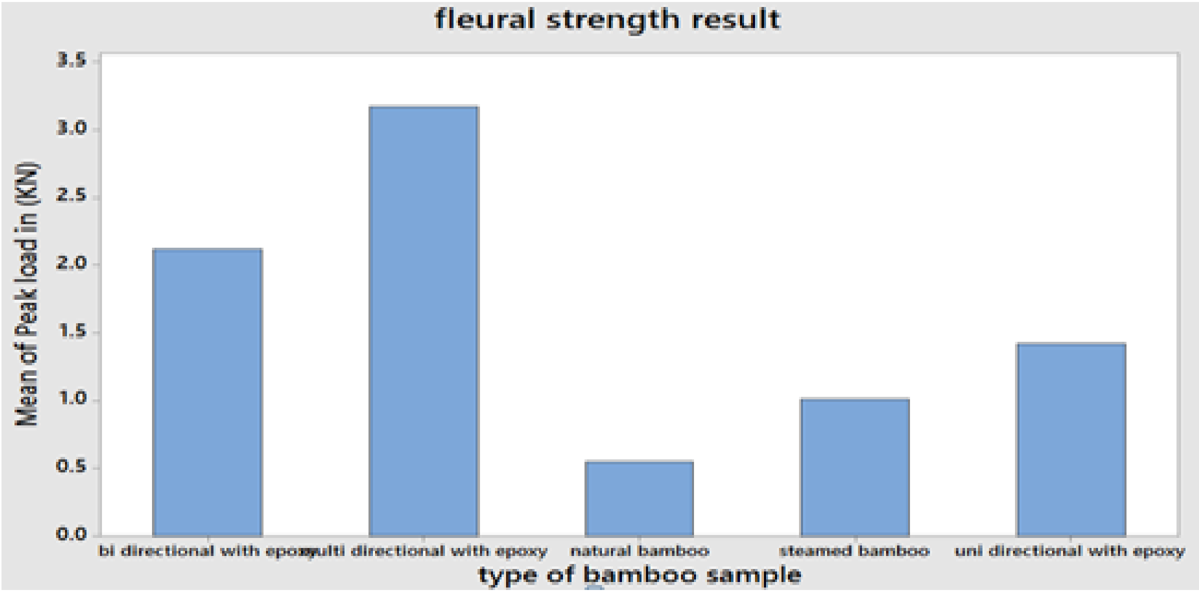


(a)

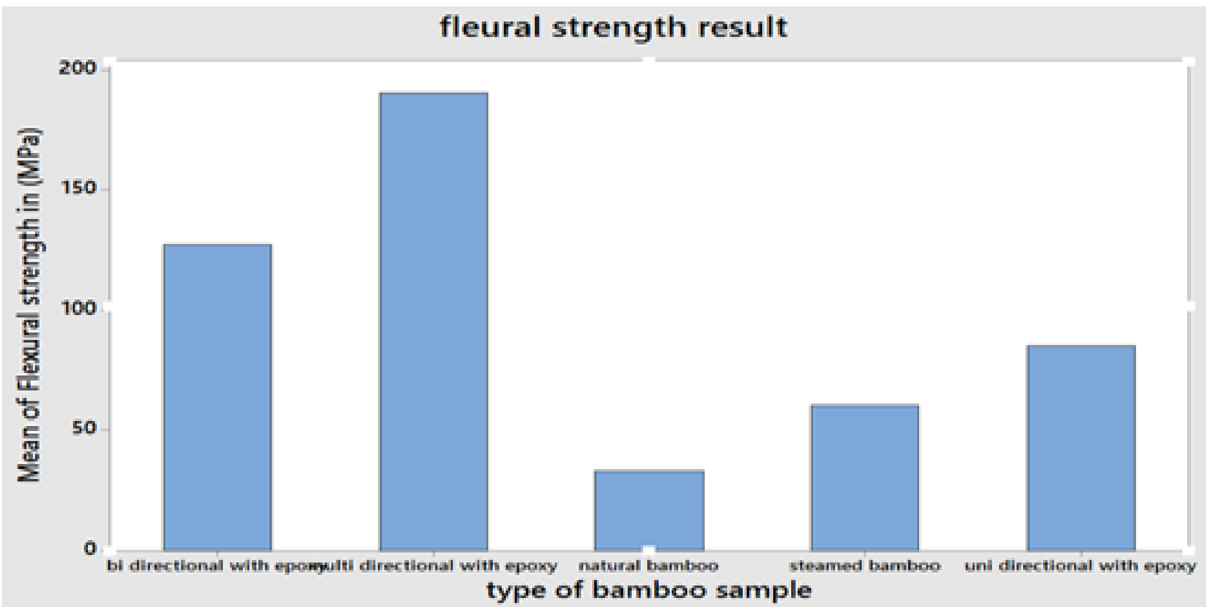
(b)

Figure5. 4 Flexural strength test (a) principle of three point bending (b) prepared sample for flexural test.

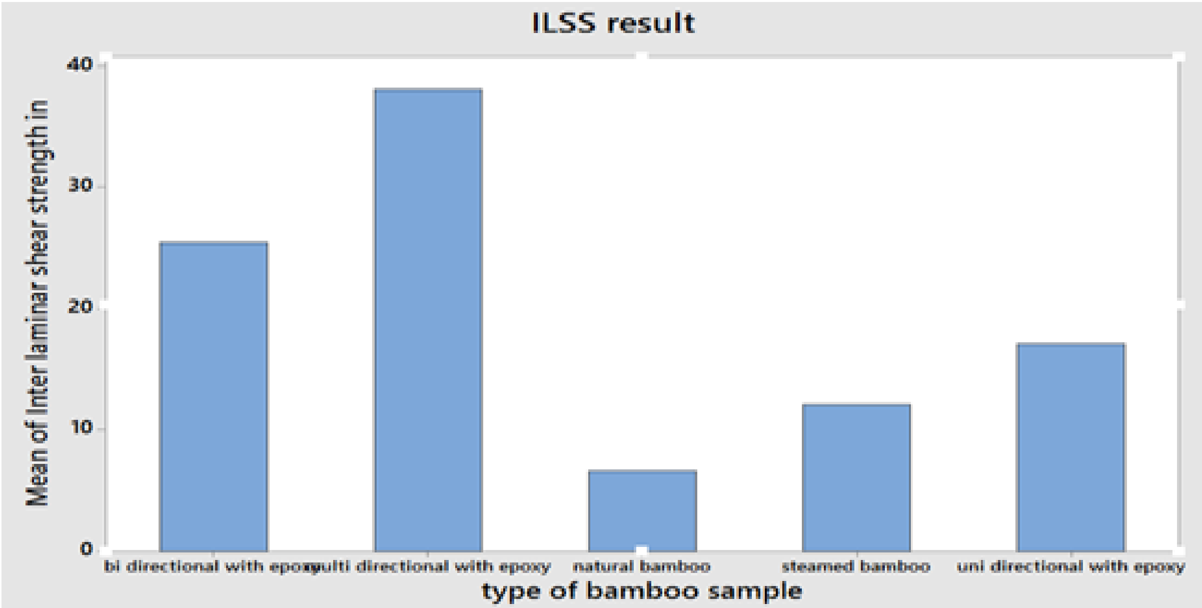
The flexural strength test results reveal that the multi directional bamboo fiber reinforced epoxy composite show the highest value 190.2MPa and also it resists 3.17 KN load at fracture and the natural bamboo shows the smallest flexural strength value of 33MPa and resists only 0.55KN load. This shows that the synthesized bamboo fiber reinforced epoxy composite has better flexural strength than the natural as well as the steamed bamboo. Figure 5.5 (a) - (c) shows the flexural test results of the samples for peak loading, flexural strength and inter laminar shear strength categories respectively.


fleural strength result
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mean of Peak load in (KN)
bi directional with epoxy
multi directional with epoxy
natural bamboo
steamed bamboo
uni directional with epoxy
type of bamboo sample

(a)


fleural strength result
200
150
100
50
0
Mean of Flexural strength in (MPa)
bi directional with epoxy
multi directional with epoxy
natural bamboo
steamed bamboo
uni directional with epoxy
type of bamboo sample

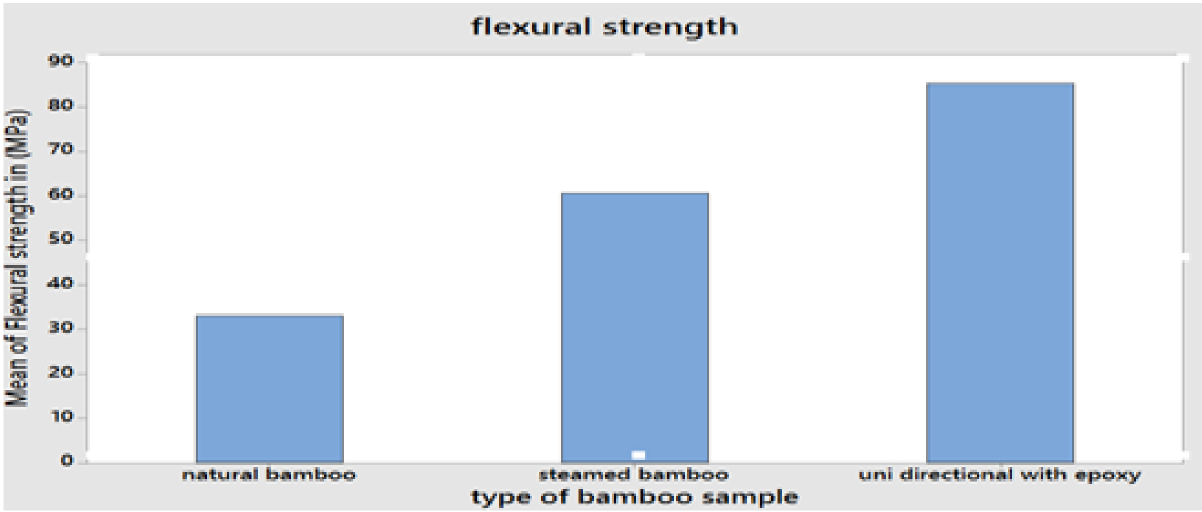
(b)



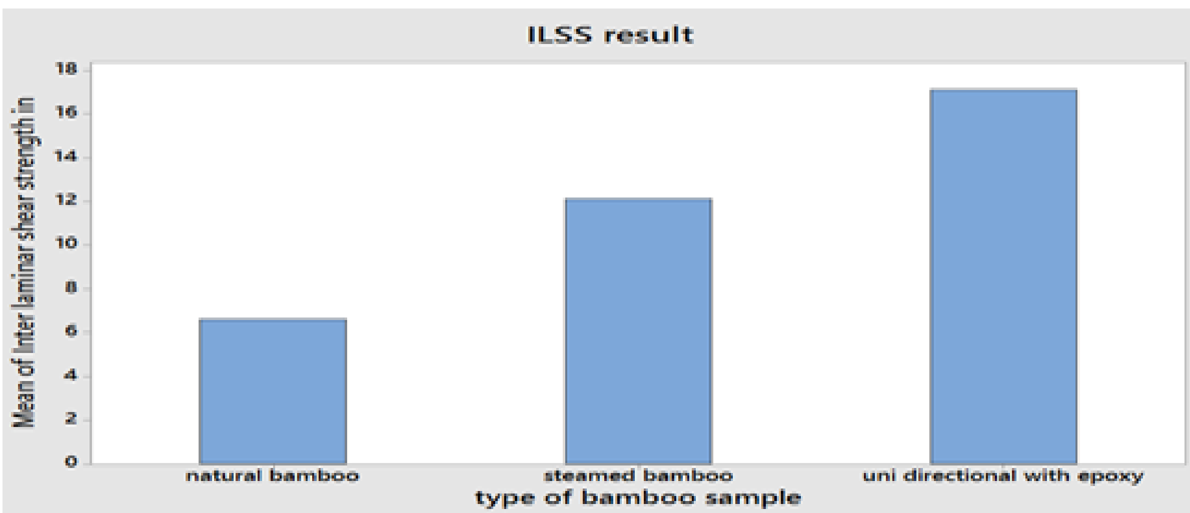
(c)

Figure5. 5 Flexural strength test result (a) peak load (b) flexural strength (c) inter laminar shear strength.

While comparing the natural bamboo, steamed bamboo and the uni directional bamboo fiber reinforced with epoxy, the uni directional bamboo fiber reinforced epoxy composite shows highest flexural as well as inter laminar shear strength 85.2MPa and 17.07MPa respectively. While the natural bamboo shows the smallest value of flexural strength and inter laminar shear strength of 33MPa and 6.6MPa, respectively. Figure 5.6 (a) and (b) compare the flexural strength and ILSS values, for natural bamboo, steamed bamboo and uni-directional bamboo.



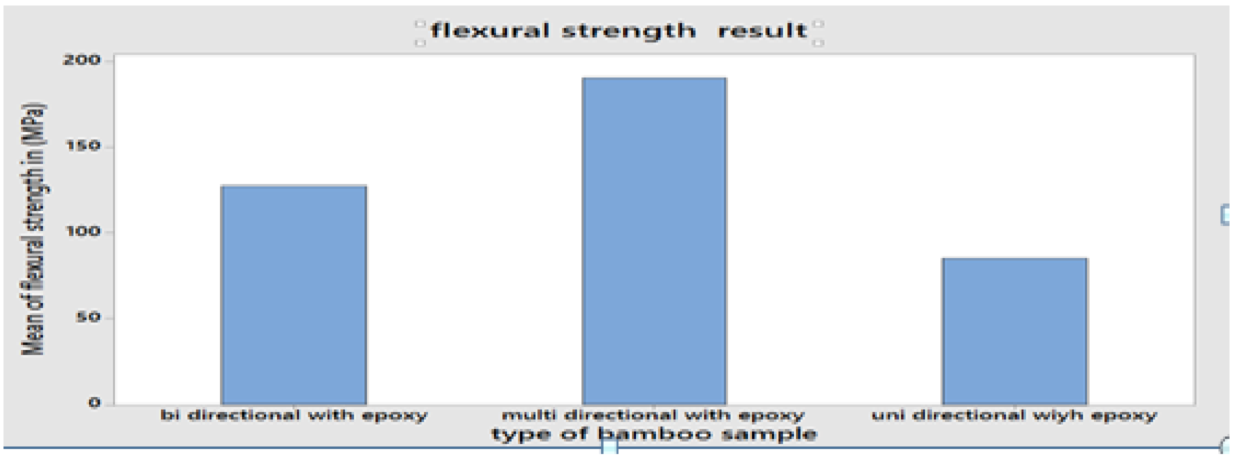
(a)



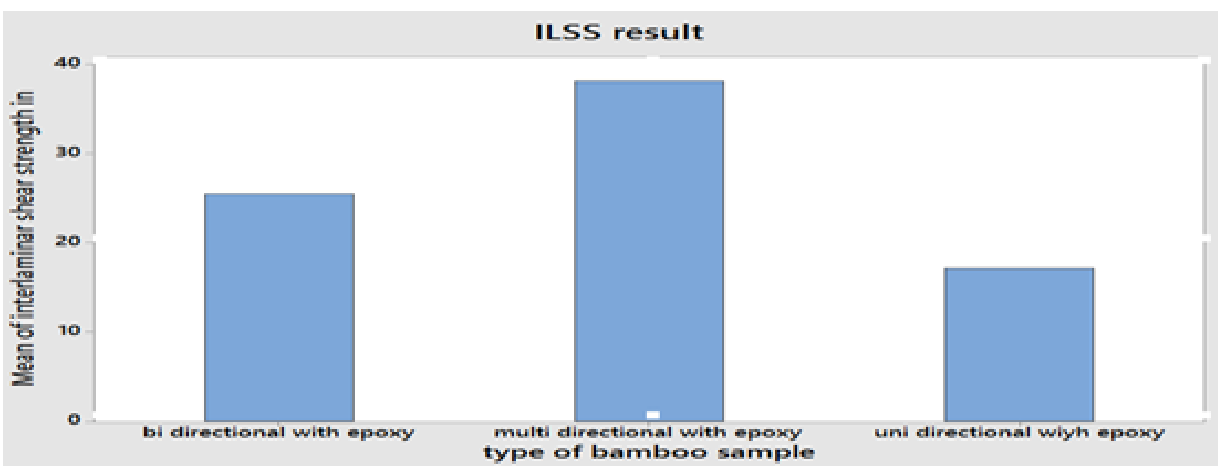
(b)

Figure5. 6 Comparison of flexural strength and inter laminar shear strength between natural, steamed and uni directional bamboo samples (a) flexural strength (b) inter laminar shear strength.

Also when the uni directional, bi directional and multi directional bamboo fiber reinforced with epoxy composite samples are compared with each other the multi directional bamboo fiber reinforced composite sample shows superiority over the other sample. Figure 5.7 (a), (b) present the comparison made on the values of flexural strength and ILSS for different orientation of fibers.



(a)



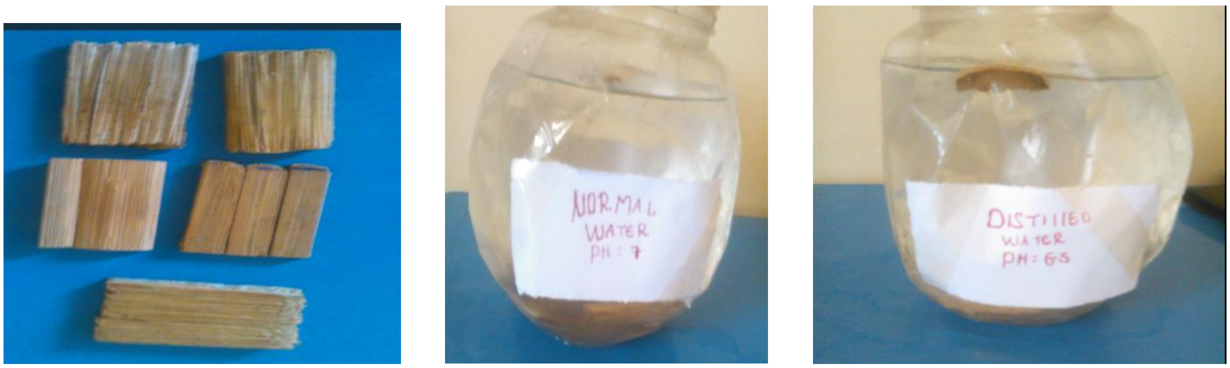
(b)

Figure5. 7 Comparison of flexural strength result between unidirectional, bi directional and multi directional reinforced bamboo with epoxy matrix (a) flexural strength (b) inter laminar shear strength.

The result show that the flexural and inter laminar shear strength of the bamboo fiber reinforced epoxy composite material is superior up on the steamed bamboo as well as natural bamboo.

5.5 Water absorption test

The samples prepared for water absorption testing are depicted in figure 5.8.

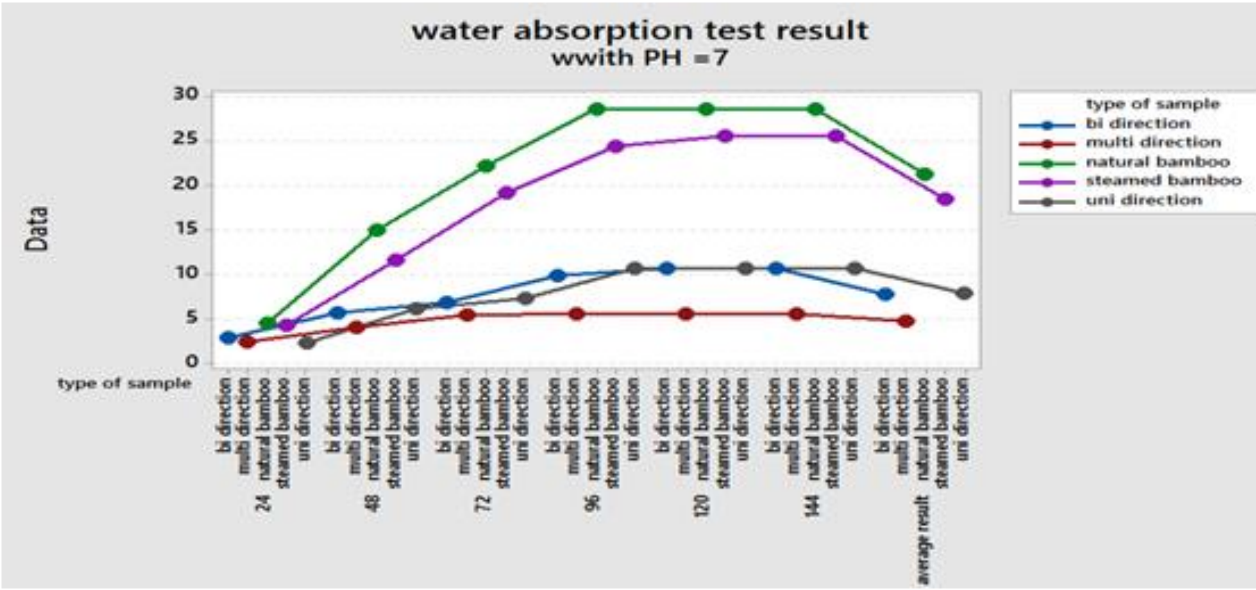


(a) (b) (c)

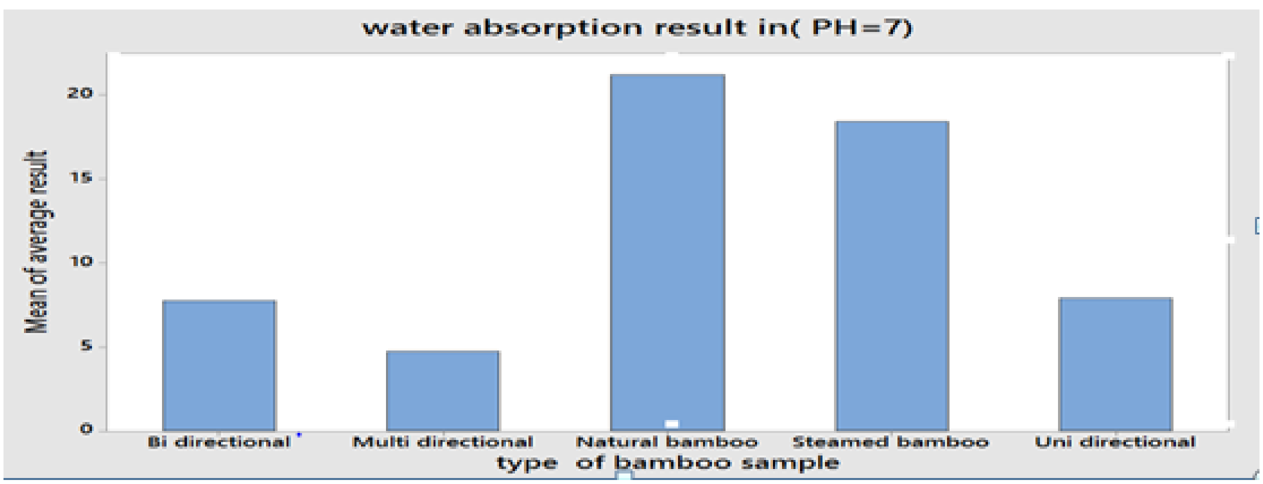
Figure5. 8 Water absorption test (a) prepared specimen (b) immersion in normal water (c) immersion in distilled water.

Based on the result shown in figure5.9 the natural bamboo shows high water absorption percentage this is due to the nature of natural fiber which has high tendency to absorb water (hydrophilic properties of natural fiber) 21% in average. The synthesized bamboo fiber shows less water absorption capability. This is due to the properties of the matrix material (hydrophobic) properties of the matrix material which bind the fibers. The multi directional bamboo fiber reinforced absorbs minimum percentage of water and the value is 4.7%.

Figure 5.9 shows the water absorption test result in normal water both in graphical method and bar charts, respectively.



(a)



(b)

Figure5. 9 Average water absorption in normal water.

Based on the results comparison is made. From the natural, steamed and uni directional bamboo fiber, the uni directional bamboo fiber show minimum water absorption 7.72% and natural bamboo show maximum 21.2% and steamed bamboo shows 18.4%. Figure 5.10 shows the comparison made on the results of water absorption testing capability of natural bamboo, steamed bamboo uni-directional bamboo based composite.

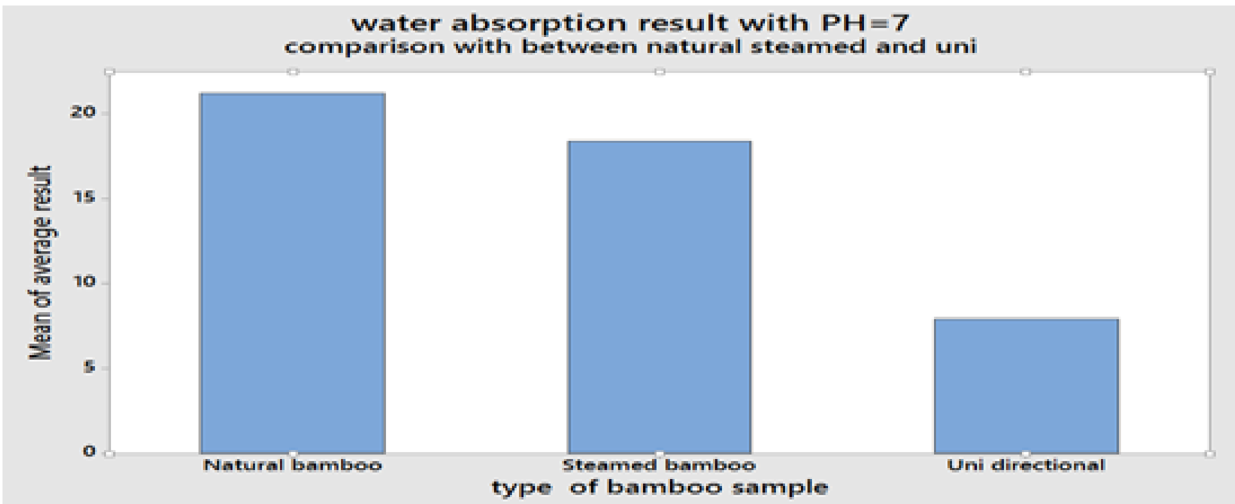


Figure5. 10 Comparison of water absorption between natural, steamed and unidirectional bamboo fiber with epoxy.

Also when the uni directional, bi directional as well as multi directional compared the uni directional bamboo fiber show maximum water absorption of 7.89% and multi directional show minimum of 4.7%. Figure 5.11 depicts the comparison made on the results of water absorption capability of the three synthesized composite materials (uni, bi and multi directional).

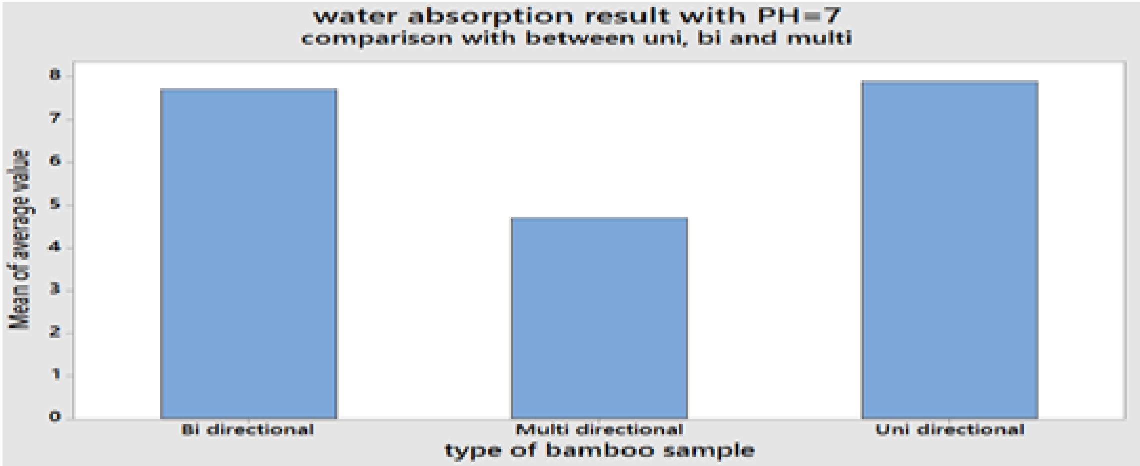
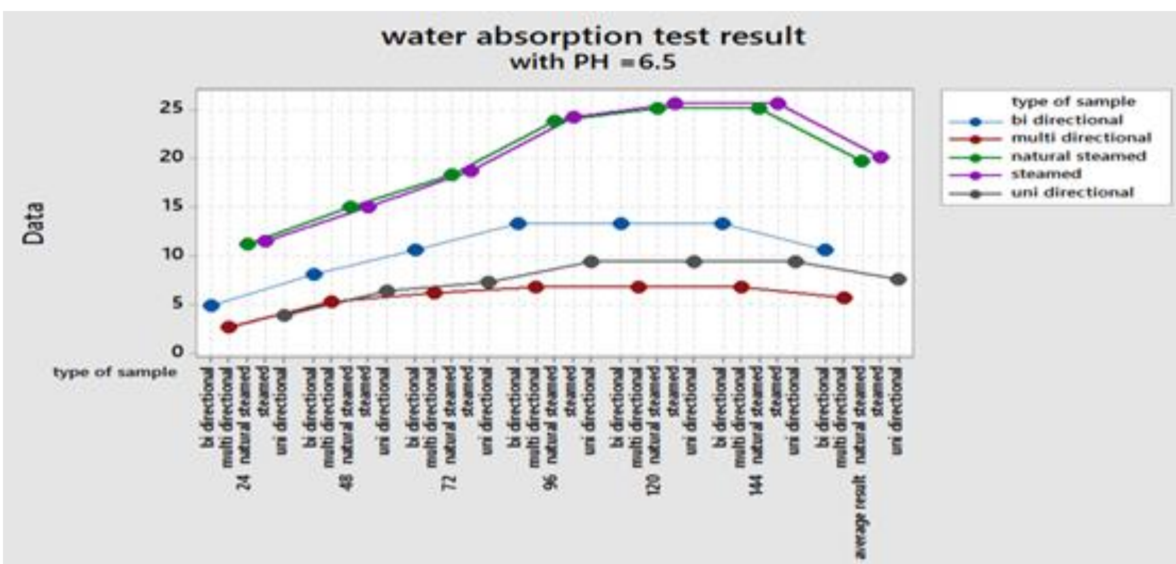


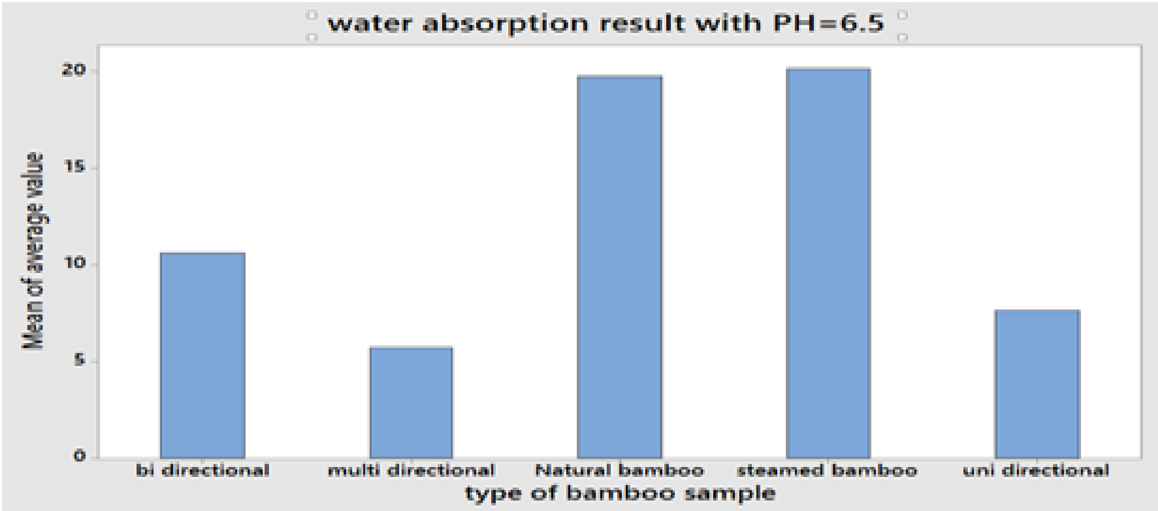
Figure5. 11 Comparison of water absorption between uni, bi and multi directional fiber reinforced epoxy composite.

The other condition to conduct the water absorption test was the distilled water having PH value of 6.5.The prepared specimens were immersed in water and the results were conducted and the percentage of water absorption was found.

Figure5.12 shows the water absorption test result in distilled water both in graphical method and bar charts, respectively.



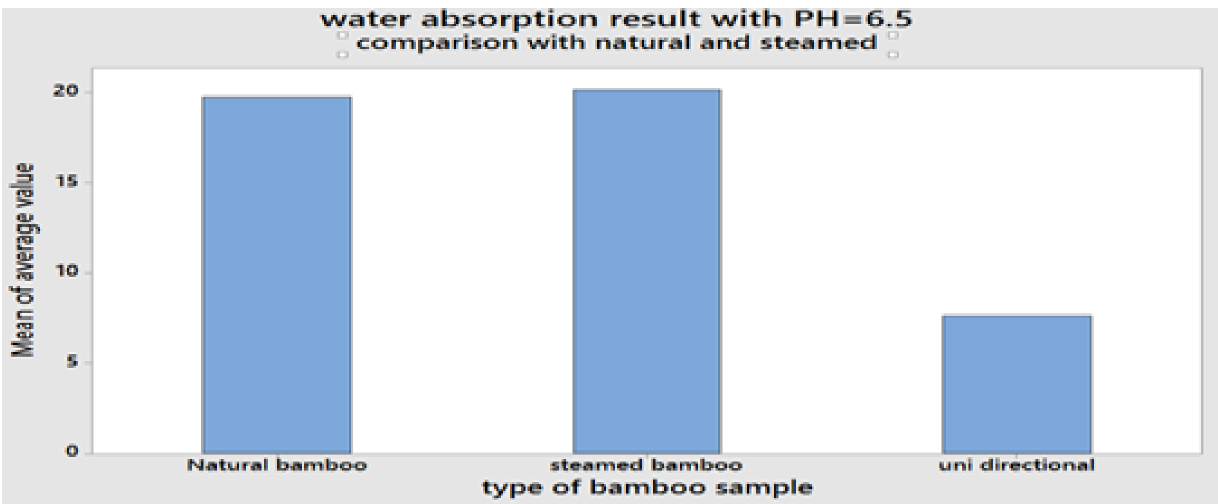
(a)



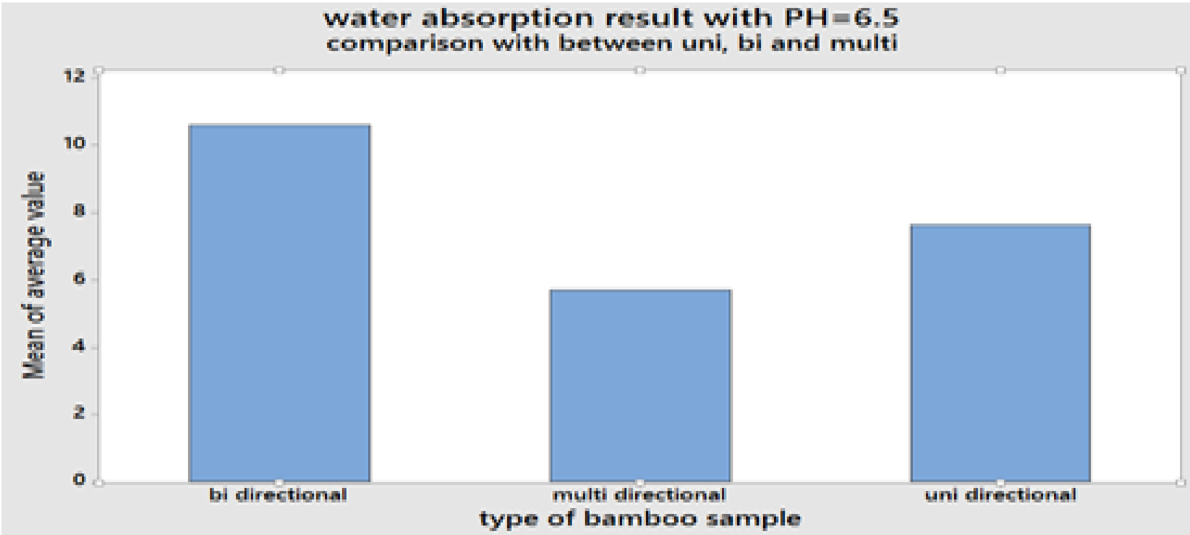
(b)

Figure5. 12 Water absorption test with distilled water (a) graphical (b) bar chart

In the distilled water case also natural bamboo shows high water absorption capability



(a)



(b)

Figure5. 13 Comparison of water absorption test between (a) natural, steamed and uni-direction (b) synthesized bamboo

The result presented in figure5.13 (a), (b) shows that the water absorption of the specimens almost increases with the immersion time at the starting stage and later keeps less water absorption after that water absorption does not change significantly. In other way, water absorption of the specimen immersed in distilled water is larger than that in normal water. This is due to the hydrolysis mechanism of the cellulose within natural fiber. The hydrolysis of cellulose is expected to be more noticeable in normal water. Generally, the natural fibre composites exhibit large water absorption due to the presence of micro voids at the reinforcement/matrix interface in nature. As a conclusion the natural fiber have tendency to absorb more water than plastic materials. This can be overcome by synthesizing the natural fiber with plastic matrix and reduce the water absorption rate as well as improve other mechanical properties.

5.6 Comparison of LBFREC with other plastic as well as synthetic fibers

Table5. 1 Comparison of bamboo fiber reinforced epoxy composite with other plastic materials

	Bamboo fiber	Glass fiber	Boron fiber	Carbon fiber
Cost	Lower	Higher	Higher	Higher
Density	0.6-1.1	2.5-2.55	2.34-2.6	1.4-1.75
Processing techniques	Simple	Difficult	Difficult	Difficult
Bio degradability	YES	NO	NO	NO
CO_2 absorption	YES	NO	NO	NO
Renewability	YES	NO	NO	NO
Source	Natural	Synthetic	Synthetic	Synthetic
Tensile strength (MPa)	130-230	2000-3500	3000-4000	4000
Flexural strength (MPa)	201-251	-	-	-
Availability	Easy	Difficult	Difficult	Difficult

Table5.1 presents comparison made on the properties of LBFREC with other equivalent materials available.

5.7 Verification

Verification describes the validity of the performed task by comparing with other related work as well as tasks performed before. The fiber selected was found in lowland part of our country. So the verification can be done by referring literatures .The verification to be done on

- Tensile strength
- Flexural strength
- Water absorption

The lowland bamboo fiber as well as lowland bamboo fiber reinforced epoxy composite material prepared in this work has density, tensile strength, flexural strength and water absorption result similar with other works. This can be discussed as below

Table5. 2 Tensile strength, density, flexural strength and water absorption test verification with different literatures**.**

Type of test	Lowland bamboo fiber with epoxy	Bamboo fiber with epoxy	References
Density	1.013g/cc	0.6-1.1g/cc	[37]
Tensile strength In MPa	109.9,133.4,119.5,103.6,108	130-230, 26.417 at 2.4 kN. 43.47,138.88	[16],[36], [25],[37],[38]
Flexural strength in MPa	190.2,127.2,MPa	211.1,201-251,58.11	[16], [24],[36],[40],
Water absorption	7.89,7.78,4.7, normal 7.62,10.6,5.7 distilled	11%	[39]

As presented in table 5.2 above the lowland bamboo fiber with epoxy has showed better water absorption capability, comparable nearly equal density, as well as tensile and flexural strength results of the previous scholars provided in tables.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Bamboo fiber is the least cost fiber compared to the synthetic fibers. This arises from the source and also the renewability of the plant in a few years. It also reaches in few years for production within low initial investment cost. So utilizing this eco friend fiber for advancement in substitution of synthetic fiber in future work can aid the environment as well as the country by reducing the expense needed for synthetic fibers. The bamboo fiber reinforced epoxy composite materials carried out in this study also shows, good mechanical properties and the tendency to replace other pollutant materials. Depending on this the following conclusions are drawn.

1. The uni directional bamboo fiber reinforced epoxy composite material shows better hardness value as compared to other this is because of the strength of the fiber in the longitudinal direction as well as from the strength of the matrix material (epoxy resin).
2. The multi directional bamboo fiber reinforced epoxy composite material shows higher flexural strength that arise from the fiber orientation with the properties of the fiber to carry applied load on them. So these bamboo fibers reinforced epoxy composite material has the ability to substitute different products ranging from house hold to different luxuries products such as frame for door and windows, kitchen cabinets, partition walls, PVC tiles (flooring), sealing, chairs, tables, honey comb, automobile body to advanced level of application such as for luxury boat, house, turbine blade shells, etc.

3. In other way, the multi directional bamboo fiber reinforced epoxy composite shows lower water absorption capability, which a rise from the reinforcement of the fiber in different orientation as well as the matrix materials. So, these bamboo fiber reinforced epoxy composite has the ability to substitute indoor as well as outdoor applications.
4. Depending up on the above conclusion these bamboo fiber reinforced epoxy composite has the capacity to substitute different construction as well as house hold products like selling, flooring, partition walls and also different type of chairs and table, kitchen cabinets and office equipment exported from other countries.

6.2 Recommendation

Bamboo fiber reinforced composite materials are eco-friendly materials that do not contribute to environmental pollution. They have high carbon dioxide absorption in contrast to the synthesized one.

In the same way many researchers conducted many works around the world on the bamboo fiber depending on the species available around them, supposed that most of the time, materials used for the purpose construction the costs are increase tremendously, the production cost is also difficult and they are not eco-friend. These materials are almost 90% synthetic materials. From this regard, it is possible to conclude that result output of this LBFREC material can be hopefully has a potential to substitute synthetic fibers such as fiber glass alone composite.

6.3 Future works

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

1. To the future for researchers' those have willing to do on related work, delaminating test, thickness swelling, impact test, compression test, life cycle assessment the current research work can be extended for determination of the mentioned tests determine.
2. To show the interfacial properties between fiber and matrix it is recommended to further conduct the fiber pull out and fiber push out test.
3. The joining mechanism should have to be investigated to the future in order to assemble these bamboo fiber reinforced composite materials in the needed size and shape.
4. Substitute the bamboo fiber in the form of powder, chopped and by orienting the fiber randomly, conduct the tensile, flexural, compression as well as the impact test, is essential to explore the overall properties and performance of the materials.
5. Develop the lowland bamboo fiber to the hybrid type of composite by adding other natural as well as synthetic fibers and other filler materials in order to improve different mechanical properties.
6. Conduct the tensile test by preparing the specimen in the dog bone structure as well as by preparing tapper attachments.

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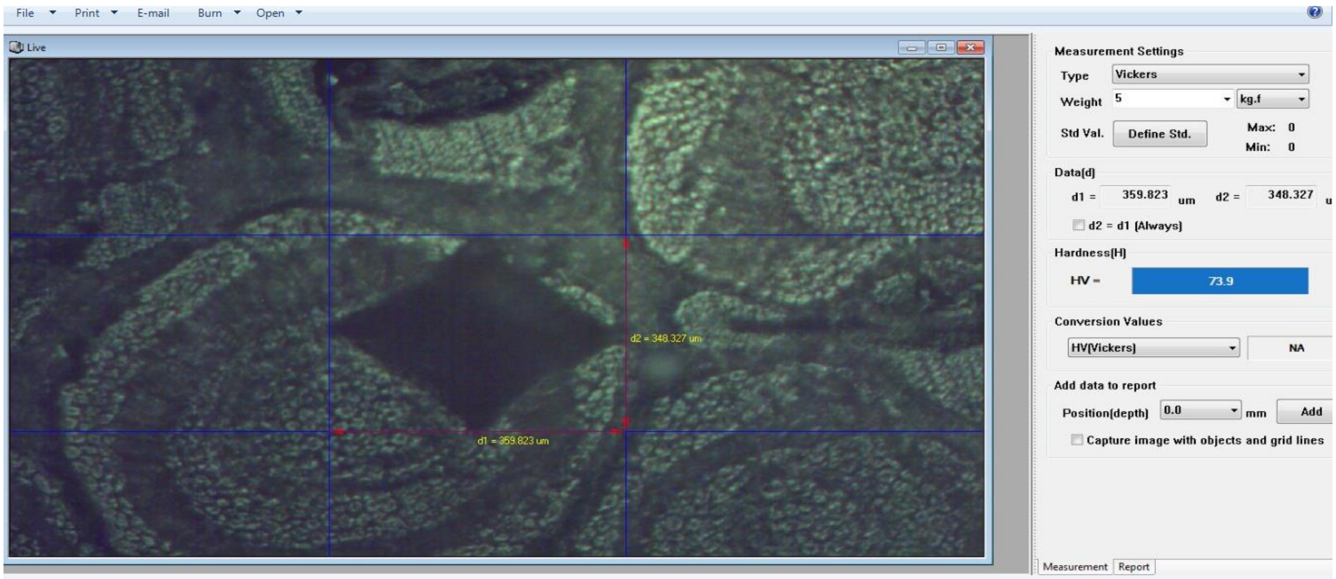
APPENDIX

Appendix 1 **Vickers hardness test using 5and 10 kgf**



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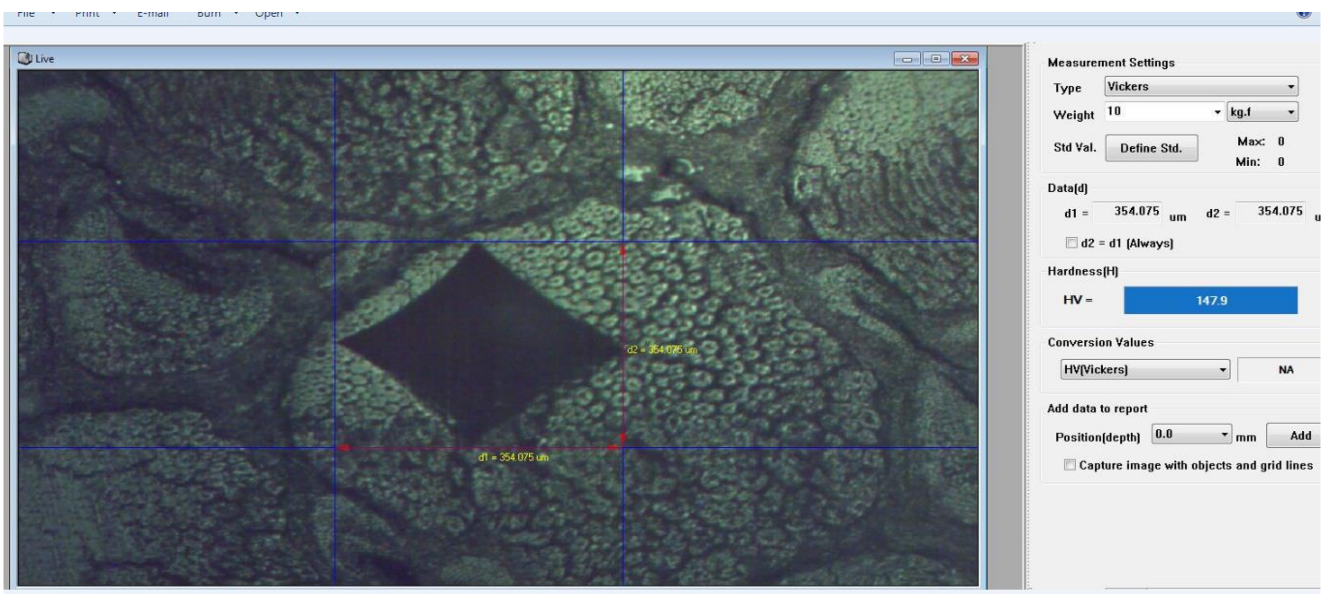
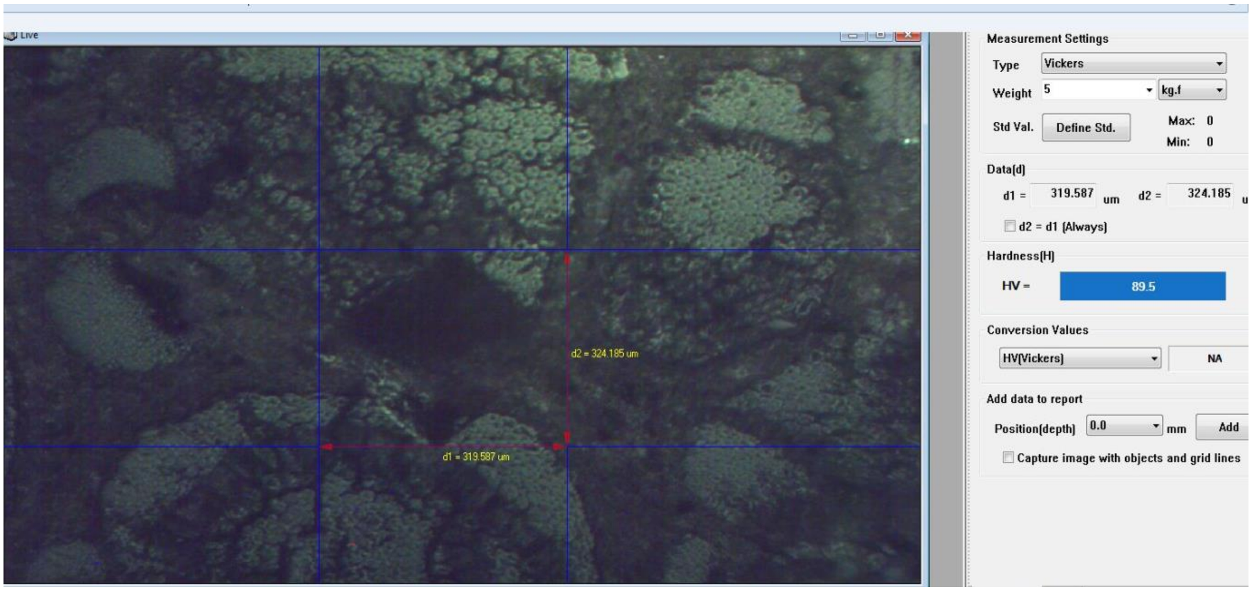


(b)

Vickers hardness test result for natural bamboo (a) using 5kgf (b) using 10kgf



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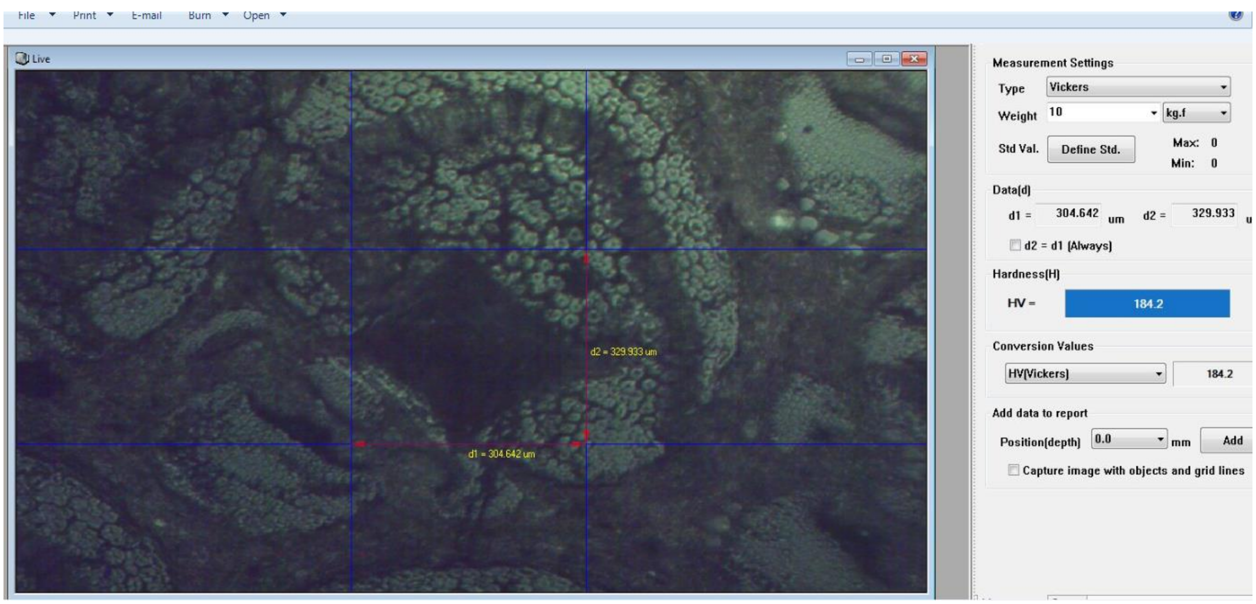
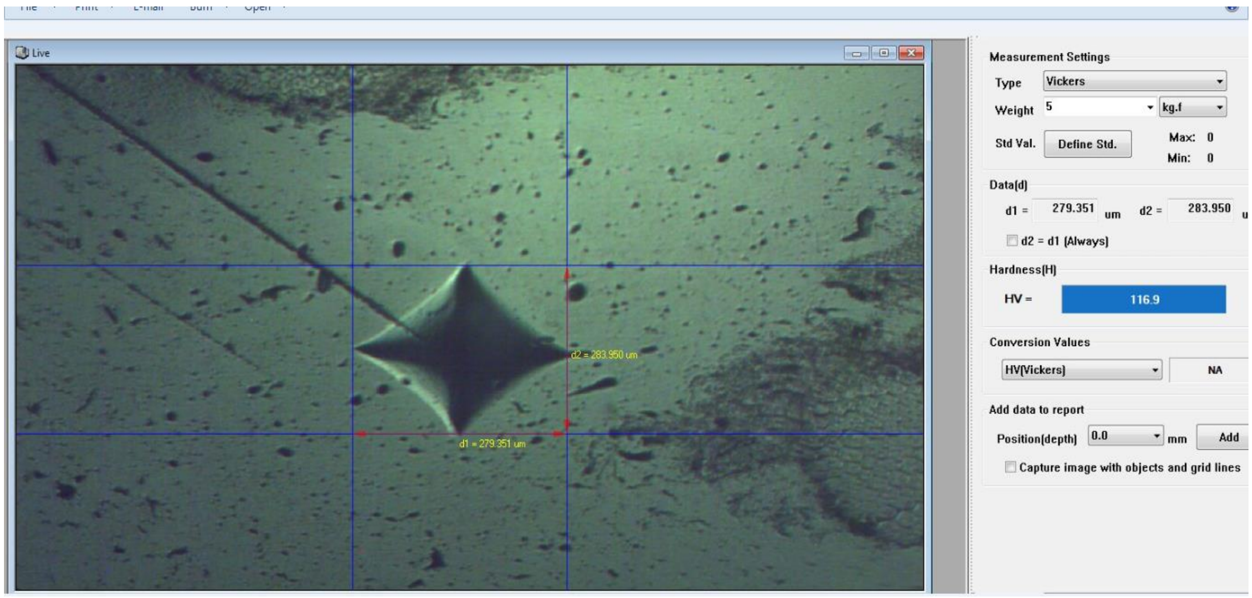


(b)

Vickers hardness result for steamed bamboo (a) using 5kgf and (b) using 10 kgf



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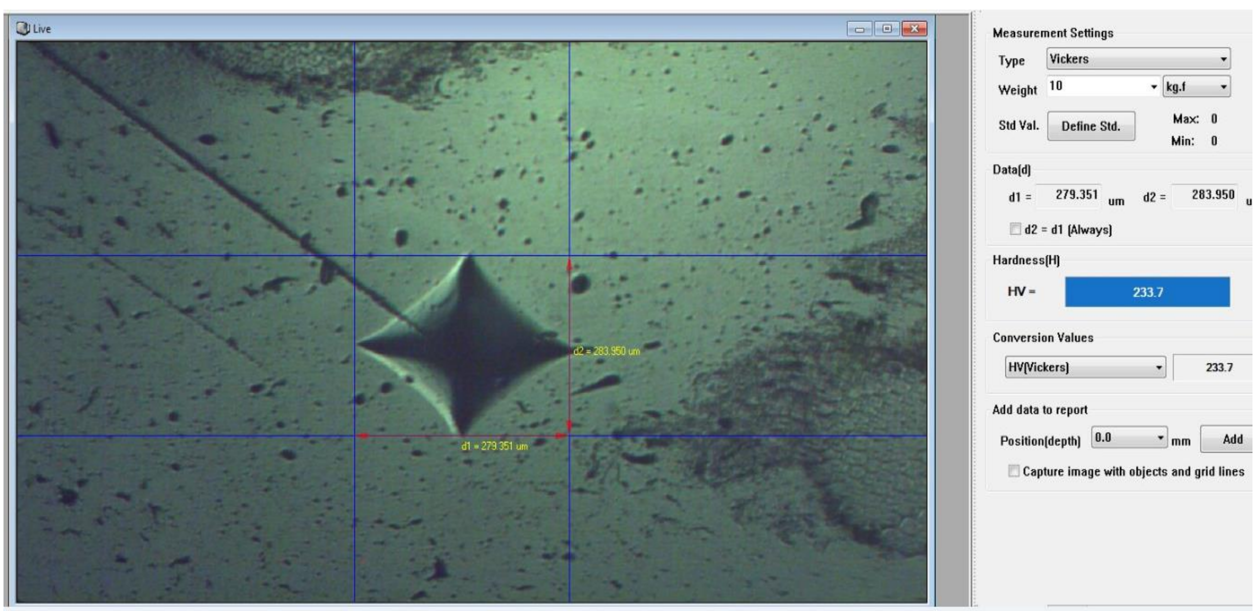
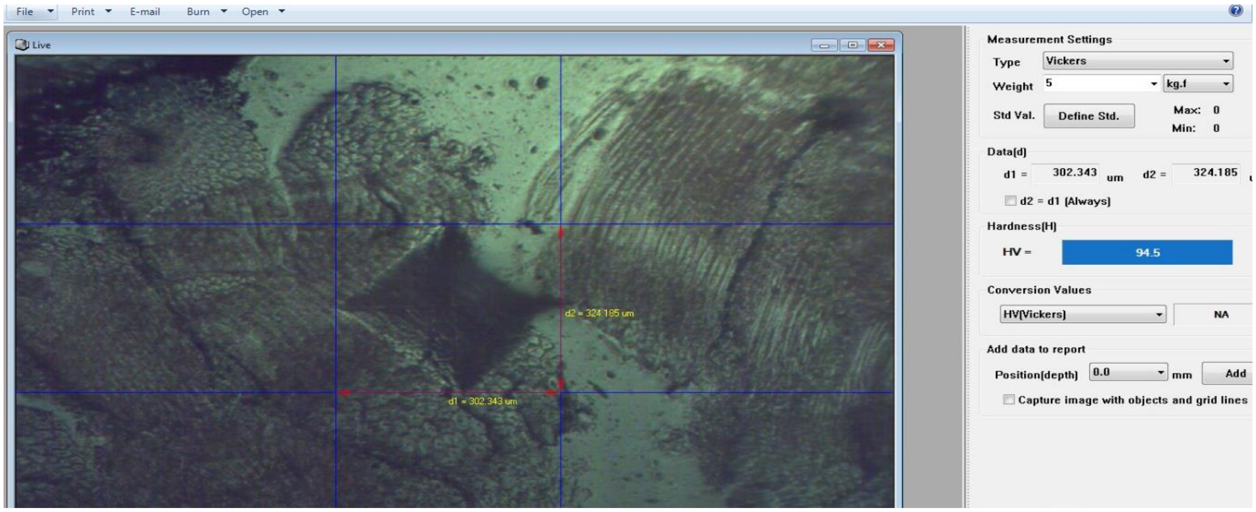
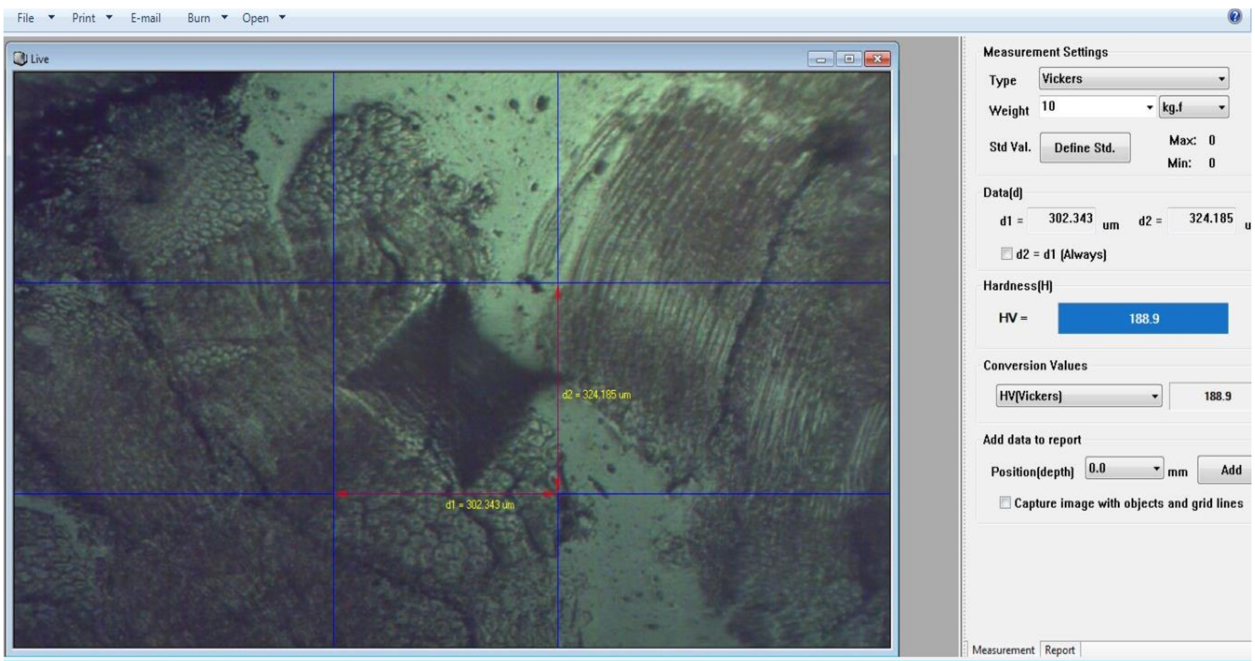


(b)

Vickers hardness test for Uni directional bamboo fiber reinforced epoxy (a)using 5kgf and (b) using 10kgf

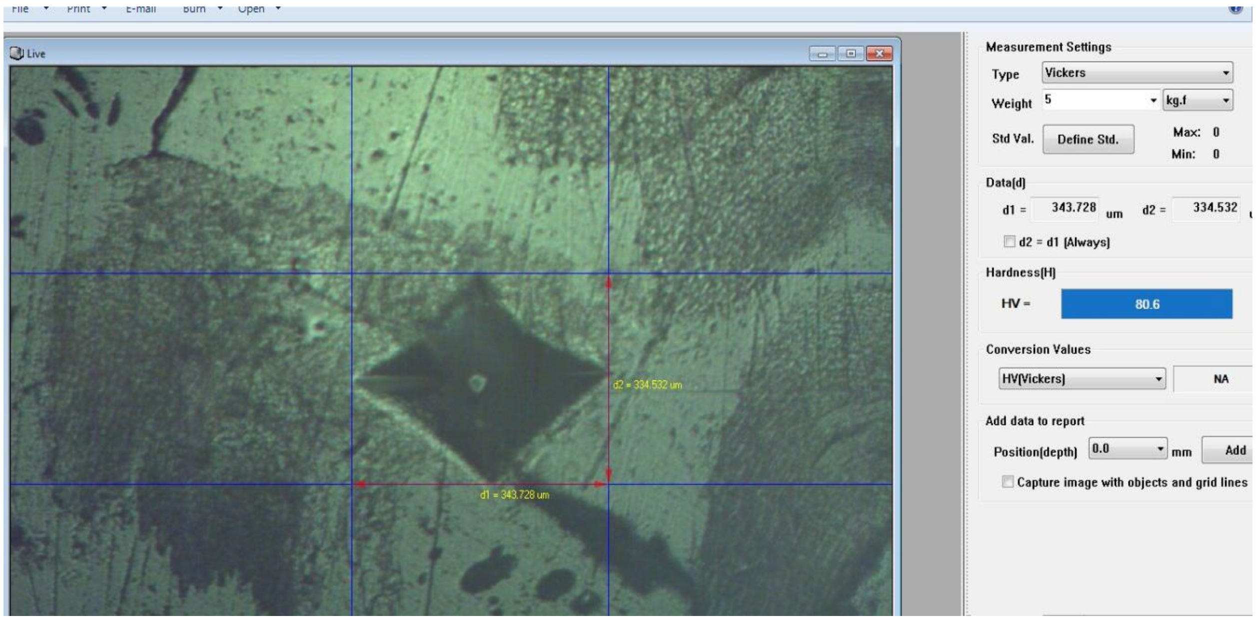


(a)



(b)

Vickers hardness test result for Bi directional bamboo fiber reinforced with epoxy (a) using 5kgf and (b) using 10kgf



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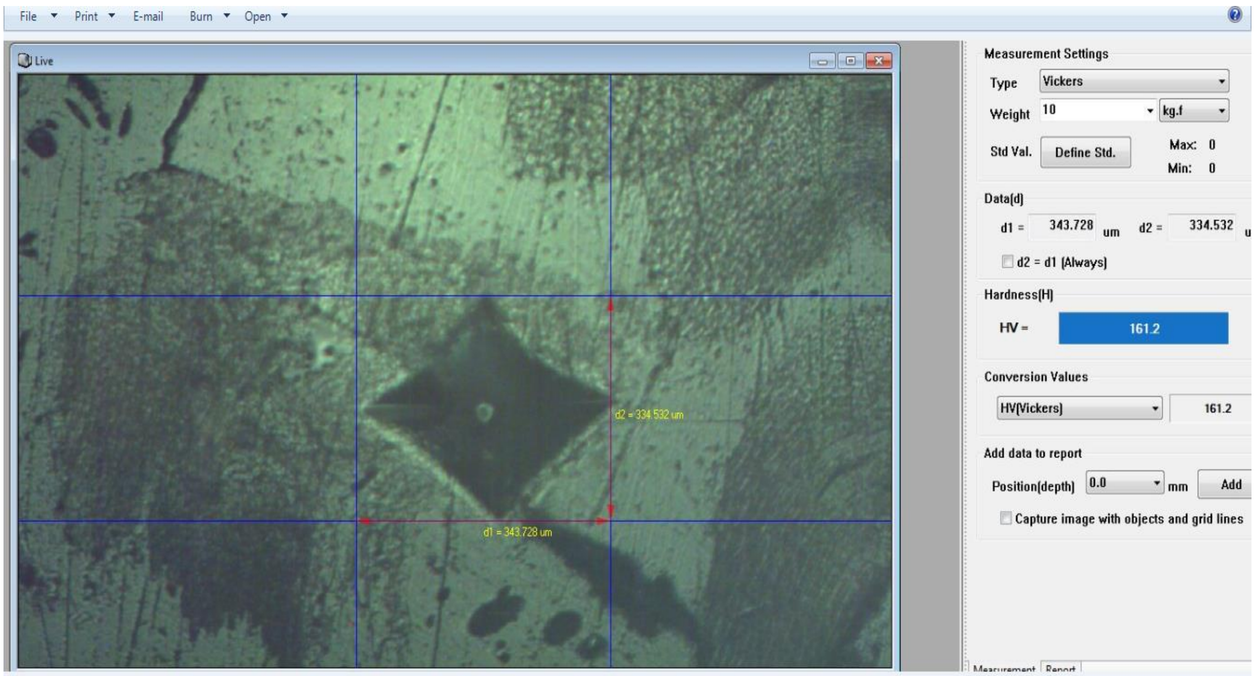
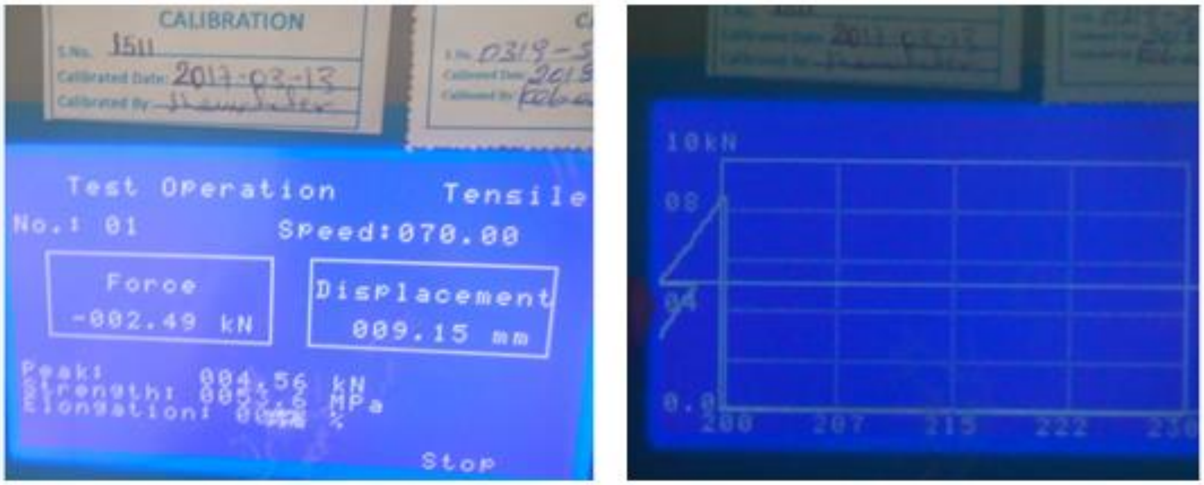


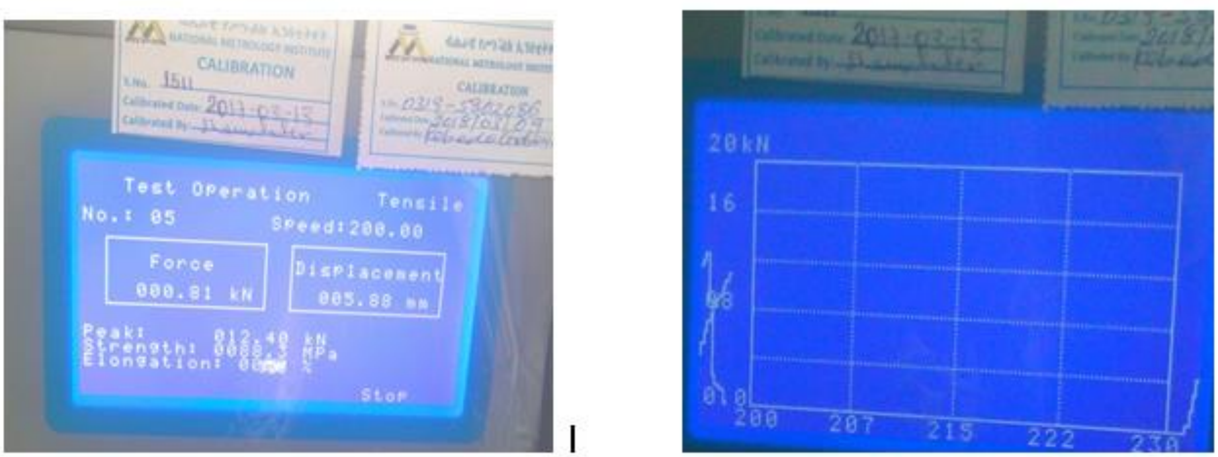
(b)

Vickers hardness test result for multi directional bamboo fiber reinforced with epoxy (a) using 5kgf and (b) using 10kgf

Appendix 2 Tensile test result

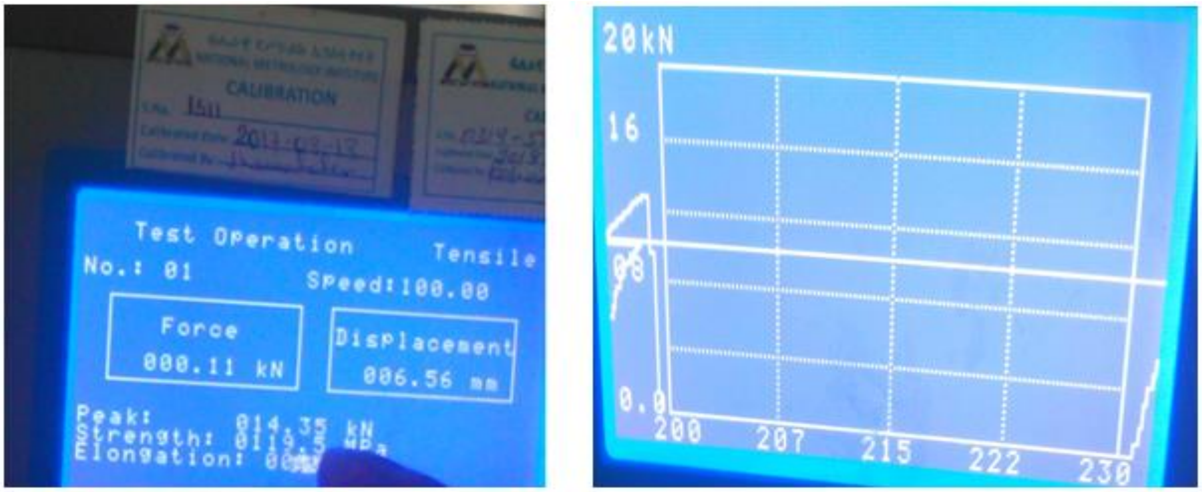


Tensile test result for natural bamboo (a) tensile strength (b) stress and strain curve



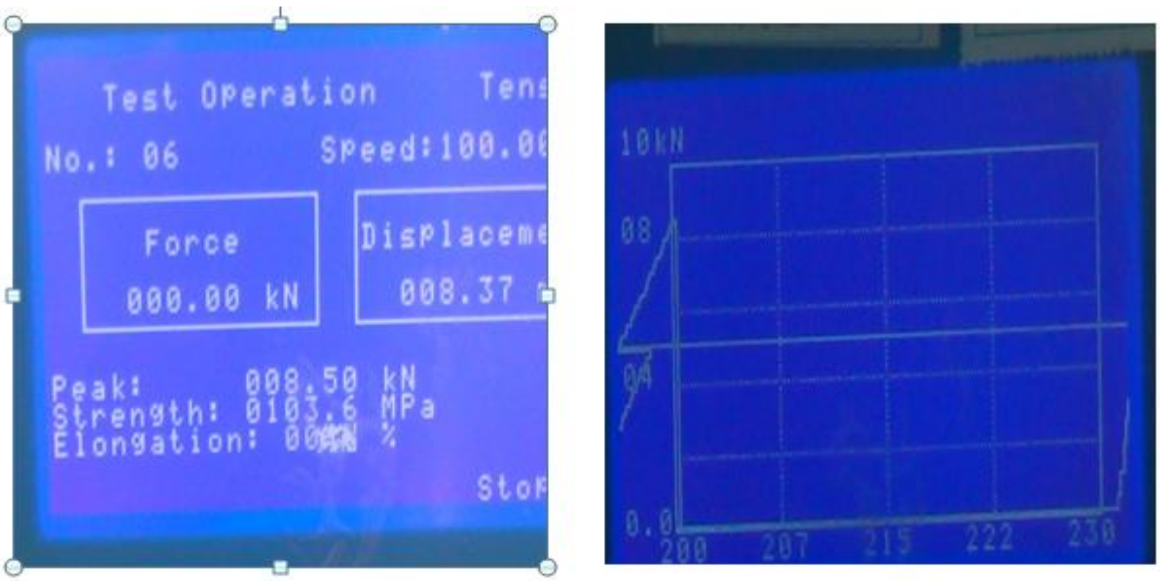
(a) (b)

Tensile test result for steamed bamboo (a) tensile strength (b) stress strain curve



(a) (b)

Tensile test result for unidirectional fiber reinforced epoxy composite. (a) Tensile strength and (b) Stress strain curve.



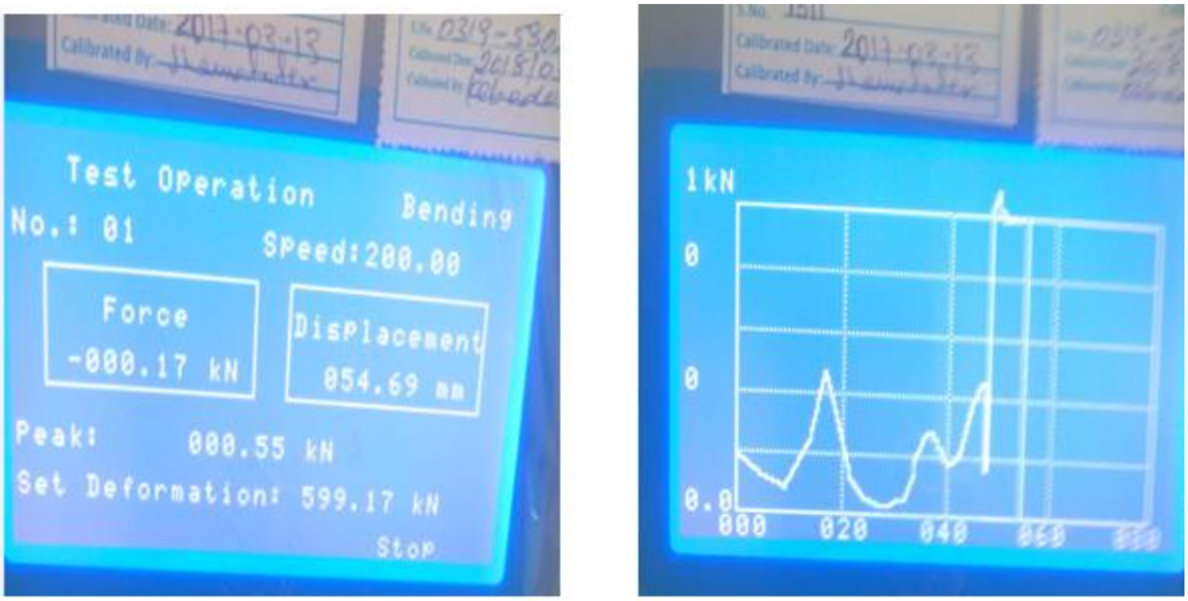
(a) (b)

Tensile test result for bi directional bamboo fiber reinforced with epoxy matrix. (a)Tensile strength and (b) stress strain curve

(a) (b)

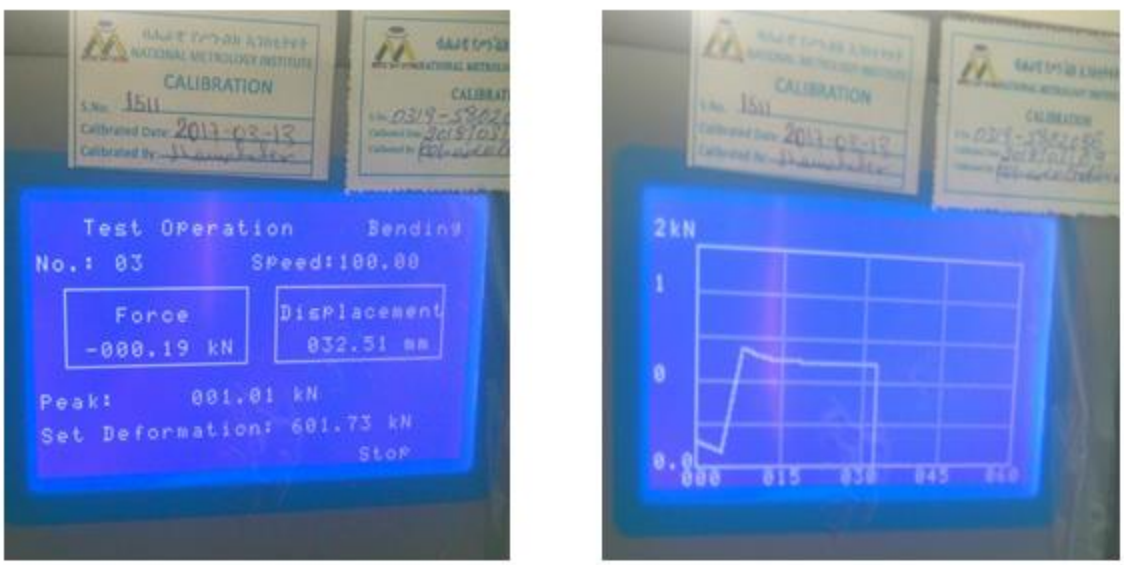
Tensile test result for multi directional bamboo fiber reinforced epoxy (a) tensile strength (b) stress strain curve

Appendix 3 flexural strength test



(a) (b)

Flexural strength test result for natural bamboo (a) applied force (b) force versus displacement diagram

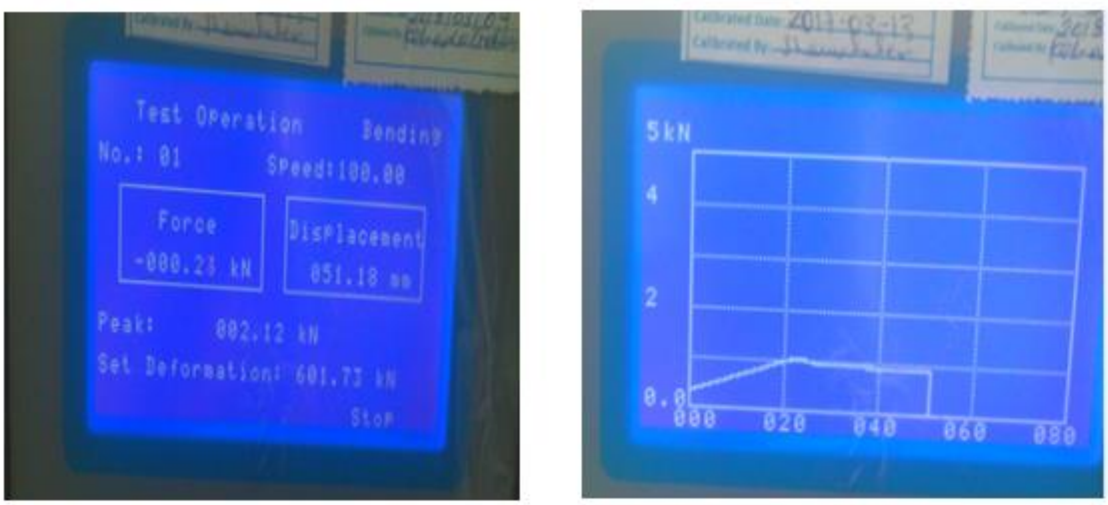


(a) (b)

Steamed bamboo flexural strength test result (a) applied force and (b) force versus displacement diagram

(a) (b)

Uni directional bamboo fiber reinforced epoxy flexural strength test result (a) applied force and (b) force versus displacement diagram



(a) (b)

Bi directional bamboo fiber reinforced epoxy flexural strength test result (a) applied force and (b) force versus displacement diagram