STRENGTH AND FRACTURE TOUGHNESS OF BAMBOO FIBER REINFORCED LATERITE COMPOSITE

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DECLARATION

I hereby declare that the matter embodied in this thesis entitled "Strength and Fracture Toughness of Bamboo Fiber-Reinforced Laterite Composites" is the result of investigation carried out by me under the supervision Engr. F.O Kolawole, Materials and Metallurgical Engineering Department, Federal University Oye-Ekiti and that it has not been submitted elsewhere for the award of any degree or diploma. In keeping with the general practice in reporting scientific observation, due acknowledgement has been made whenever the work described is based on the findings of other investigators.

CERTIFICATION

I hereby certify that this research work was carried out by OLUGBEMI OLUWAMAYOWA MOSES with matriculation number MME/11/0426 of the department of Materials and Metallurgical Engineering under the Faculty of ENGINEERING, FEDERAL UNIVERSITY OYE EKITI, EKITI STATE on the partial fulfilment of the award of bachelor of Engineering program (B.Eng.). Therefore, the information provided in this report is honest and has been meticulously checked by me.

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SUPERVISOR SIGN&DATE

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H.O. D SIGN&DATE

DEDICATION

I dedicate this work to the Almighty God who has kept me from the beginning of my program till this moment and also to my Mother who has been there from the day I was born till this time.

ACKNOWLEDGEMENT

My utmost gratitude goes to my parents who has given me the support from childhood till this stage, may god continue to bless and reward them their labor (Amen).

Most of all, I gratefully acknowledge the encouragement, advice and assistance of my supervisor, Engr. F. O. Kolawole. Gratitude also goes to all the teaching and non-teaching staffs in materials and metallurgical engineering department for them advises and love.

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ABSTRACT

This study examined the strength and fracture toughness of bamboo fiber reinforced laterite composite materials that are relevant to the development of building materials adding economic values. The composite materials were produced by mixing laterite and cement together and varying with different percentage volume of bamboo fiber. The mechanical tests showed that the optimum performance of various samples was obtained at a fiber content of 25% by volume, with compressive strength value of about 5.0±0.25MPa, flexural strength values of about 2.25±0.113MPa and fracture toughness ranging from 0.68±0.034 -1.70±0.085 MPa√m. The results indicate that the mechanical performance of the composites being studied is in line with those in prior studies on natural fiber-reinforced laterite matrix composites.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Materials from planet earth has been used in the construction of shelters for thousands of years and approximately 30% of people living in this world's present population still live in earthen structures (Cofirman *et.al*; 1990). Earth based materials are not expensive; they are environmentally friendly and abundantly available building material. It has been used extensively for wall construction around the world, particularly in developing countries. Fibrous ingredients like straw has been used to improve the tensile strength of mud bricks by home brick-makers. However, scientific experimental investigation on the balance of ingredients and the optimization of this production has not been done (Ren and kagi, 1995).

The fibers, which are held together by mud, provide a tensile strength in mud bricks, and provide a better coherence between the mud layers. The stress–strain relation of mud bricks under compression is very important. The compressive strength of fiber reinforced mud brick has been found to be higher than that of the conventional fibreless mud brick. Because, fibers are strong against stresses. In the mud brick, there are fibers in both the longitudinal and transverse directions. These fibers prevent the deformations that may appear in the mud brick, thus, preserving the shape of the brick and preventing the regions near the surface from being crushed and falling off. Where there are fibers in the mud, the transverse expansion due to the Poisson's effect is prevented by the fibers. The existence of these fibers increases the elasticity of the mud brick. When the mud brick starts to dry, it deforms and contraction (shrinkage) takes place. The distribution of the fibers being arbitrary as their number increases, therefore tensile strength and elasticity properties of the mud brick increases. Thus, the mud brick behaves more flexible (Ren and kagi, 1995).

Most studies reported in the literature are focused on the stabilization and utilization of laterite and lateritic soils with the addition of bamboo, lime, cement, or bentonite (Kumar, 2002). Southern Turkey is rich in natural pozzolans, which are also called ***trass*** in the cement industry. Almost 155,000 km^2 of the country is covered by Tertiary and Quaternary-age volcanic rocks, among which tuffs occupy important volumes. Although there are many geological investigations on these volcanic rocks (pumice), their potential as natural pozzolans is not well established (Kaplan and Binici, 1996).

Housing is a great problem in the world today, for example in Turkey, many houses in rural areas are built with one floor (Kaplan and Binici, 1996). The most common building material for construction of houses is the burnt clay brick. Continuous removal of topsoil, in producing conventional bricks, creates environmental problems (Kaplan and Binici, 1996). In Cukurova region of Turkey, a huge quantity of straw is produced every summer. This is often a cause of major concern because farmers burn this straw and give rise to ecological problems. Instead of burning this straw, it can be used in mud brick production. Similarly, plastic fibers and polystyrene fabric of vast amounts are produced in textile and plastic industries deteriorating the environment. Those materials will also serve as auxiliary materials in the production of fiber reinforced mud bricks (Kaplan and Binici, 1996).

The recent energy crisis provoked by indiscriminate industrial growth has caused increasing concerns about managing the energy resources still available and about environmental degradation. There is an intense on-going search for non-polluting materials and manufacturing processes, which require less energy. Attention of researchers and industries has turned to materials such as vegetable fibers including bamboo, soil, wastes from industries, mining and agriculture for engineering applications. In a global effort to find a substitute for the health hazardous asbestos cement new cements using all types of wastes are being developed and used for the production of composites, reinforced with fibers (Ghavami, 2004).

In this era of industrialization, the selection of materials is based mainly on the price and the type of facility used for production or processing. Industrialized materials, such as ordinary Portland cement (OPC) and steel, find applications in all sectors. In the second half of the 20th century, advanced materials such as synthetic polymers (e.g. Rayon, Nylon, Polyester, Kevlar), new alloy metals and carbon fibers were developed. They were introduced in places where locally produced materials exist in abundance. In developing countries due to the educational system, which is mainly based on programs from industrialized nations, there are to date no formal education or research programs concerning the traditional and locally available materials and technologies. Lack of reliable technical information about the local materials makes the consumers use mainly industrialized materials for which the information is freely available (Ghavami, 2004).

Utilization of local materials is an important step to sustainable construction by reducing transportation cost, embodied energy and environmental protection (Baker, 1987). Laterite, a type of soil rich in iron and aluminum formed in hot and wet tropical conditions, is a popular building material utilized in tropical and subtropical regions of the world where it is readily available and economical compared to other natural stones (Gidigasu, 1976). Despite its long term use in building applications worldwide, only few countries have scientifically documented its engineering properties and standards (Kasthurba and Santhanam, 2005). Non-availability of standards and lack of scientific data on laterite are the main issues for its building application in various countries especially in Burkina Faso, Africa (Lawane *et.al*; 2011). Indian standards code IS 3620-1979 provides specifications and standards for laterite masonry construction. Extensive studies on laterite masonry blocks (LMB) undertaken at the Indian Institute of Technology Madras (IITM) demonstrated the deficiencies in the IS code specifications on testing procedures which was favorably considered for amendments (Ghavami and Hombeeck, 1981). However, unique material properties and regional variations have rendered laterite stone as subject of controversy. Often this material faces uncertainties and reluctance to use by engineers for its building applications due to the ambiguity of behavior, local variations and lack of standards. Standardization and optimal use of laterite is highly essential for its efficient utilization and for economic, energy and environmental benefits.

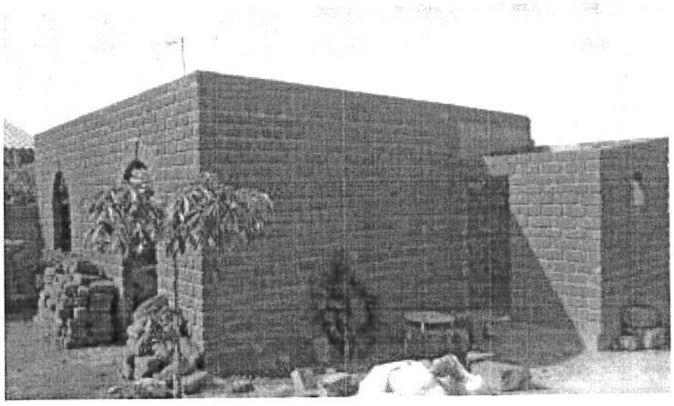


Figure. 1.1: Image of laterite building material

In consequence of the consumer choosing industrialized products, among other effects, activities are suppressed in rural areas or even in small towns, and renewable materials are wasted and causing permanent pollution. In this sense, it becomes obvious that ecological materials satisfy such fundamental requirements, making use of agricultural by-products such as rice husk, coconut fibers, sisal and bamboo and therefore minimizing energy consumption, conserving non-renewable natural resources, reducing pollution and maintaining a healthy environment (Ghavami *et.al*; 2002). Bamboo is one material, which has a tremendous economic advantage, as it reaches its full growth in just a few months and reaches its maximum mechanical resistance in just few years. Moreover, it exists in abundance in tropical and sub-tropical regions of the globe (Barbosa *et al*;1993).

The energy necessary to produce 1m^3 per unit stress projected in practice for materials commonly used in civil construction, such as steel or concrete, has been compared with that of bamboo. It was found that for steel it is necessary to spend 50 times more energy than for bamboo (Ghavami and Janssen, 1995). The tensile strength of bamboo is relatively high and can reach 370MPa (Ghavami, 1995). This makes bamboo an attractive alternative to steel in tensile loading applications. This is due to the fact that the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel (Ghavami, 2005). In South American countries the natives have used bamboo intensively for centuries (Ghavami, 1994), but the European colonizers never knew how to use bamboo until 1970s. In Brazil the use of bamboo was limited to the construction of some scaffolding and simple dwellings. Systematic studies have been carried out on bamboo since 1979 at PUC and in Brazil. The greater part has been dedicated to the development of a methodology for bamboo's application in space structures and as reinforcement in concrete (Ghavami, 1994).

1.2 Aim and Objectives of the Study

The aim of this study is to develop bamboo fiber-reinforced laterite composite as a building materials that is cheap, environmental friendly and readily available. This will be achieved through the following specific objectives:

1. To source for laterite and bamboo
2. To obtain and modify fibers from bamboo
3. To mould laterite blocks reinforced with varying volume percentage of bamboo fibers
4. To determine the compressive strength and fracture toughness of the developed bamboo fiber-reinforced laterite composite
5. To examine the microstructure of the fractured surface of the bamboo fiber-reinforced laterite composite.

1.3 Scope of the Study

This study examines the effect of processing, composition and natural fiber reinforcement on the strength and fracture toughness of bamboo fiber-reinforced laterite composites. The study includes:

1. The processing of local (laterite) materials with different compositions;

2. The material characterization of local materials and processed materials with:

i. Energy Dispersion X-ray Spectroscopy (EDS);

ii. Scanning electron microscopy (SEM);

3. The measurements of the strength of the samples produced. In this study, two (2) forms of strength will be considered. These are:

i. Compressive strength.

ii. Bend/Flexure strength.

4. The determination of the fracture toughness of the different samples produced

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Composites

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are ***reinforcement*** and a ***matrix***. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part (Tuttle, 2004).

The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness (Tuttle, 2004).

A fiber has a length that is much greater than its diameter. The length-to-diameter (*l/d*) ratio is known as the *aspect ratio* and can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios. Continuous-fiber composites normally have a preferred orientation, while discontinuous fibers generally have a random orientation. Examples of continuous reinforcements include uni-directional, woven cloth, and helical winding (Figure 2.1a), while examples of discontinuous reinforcements are chopped fibers and random mat (Figure

2.1b). Continuous-fiber composites are often made into laminates by stacking single sheets of continuous fibers in different orientations to obtain the desired strength and stiffness properties with fiber volumes as high as 60 to 70 percent. Fibers produce high-strength composites because of their small diameter; they contain far fewer defects (normally surface defects) compared to the material produced in bulk. As a general rule, the smaller the diameter of the fiber, the higher its strength, but often the cost increases as the diameter becomes smaller. In addition, smaller-diameter high-strength fibers have greater flexibility and are more amenable to fabrication processes such as weaving or forming over radii (Niu, 2000). Typical fibers include glass, aramid, and carbon, which may be continuous or discontinuous. The continuous phase is the matrix, which is a polymer, metal, or ceramic (Niu, 2000). Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibers in the proper orientation and spacing and protecting them from abrasion and the environment. In polymer and metal matrix composites that form a strong bond between the fiber and the matrix, the matrix transmits loads from the matrix to the fibers through shear loading at the interface. In ceramic matrix composites, the objective is often to increase the toughness rather than the strength and stiffness; therefore, a low interfacial strength bond is desirable. (Niu, 2000).

The type and quantity of the reinforcement determine the final properties. Figure 2.2 shows that the highest strength and modulus are obtained with continuous-fiber composites. There is a practical limit of about 70 volume percent reinforcement that can be added to form a composite (Niu, 2000).

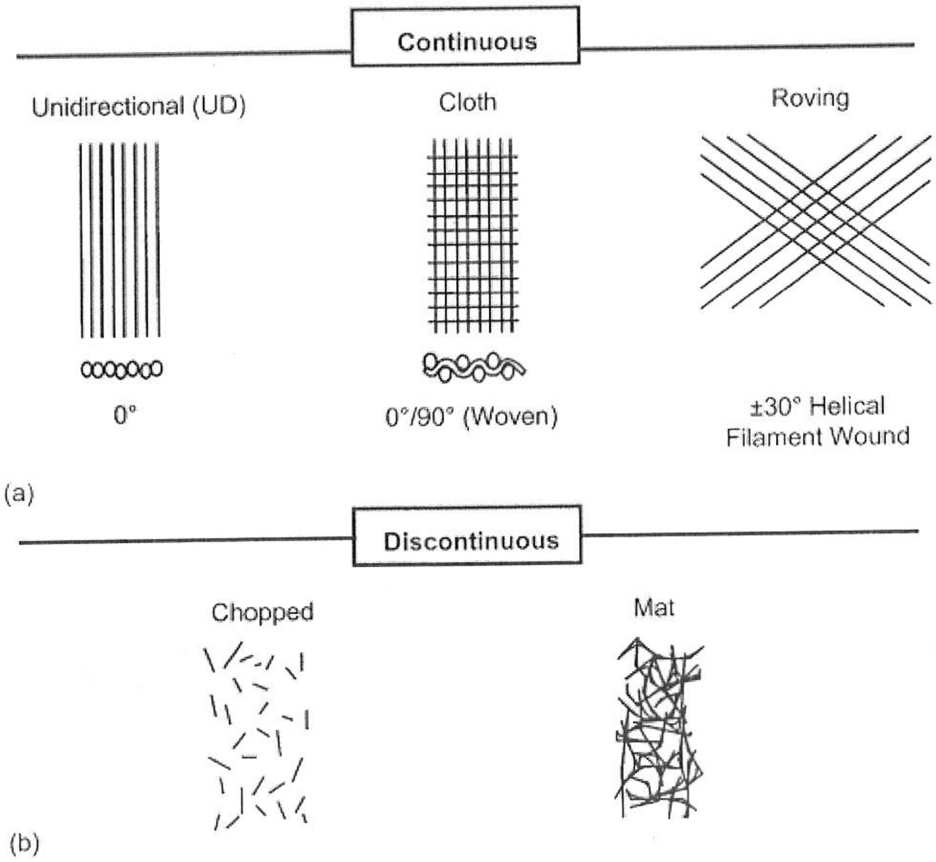


Figure 2.1: Typical reinforcement types (a) continuous (b) discontinuous (Horton and McCarty, 1987)

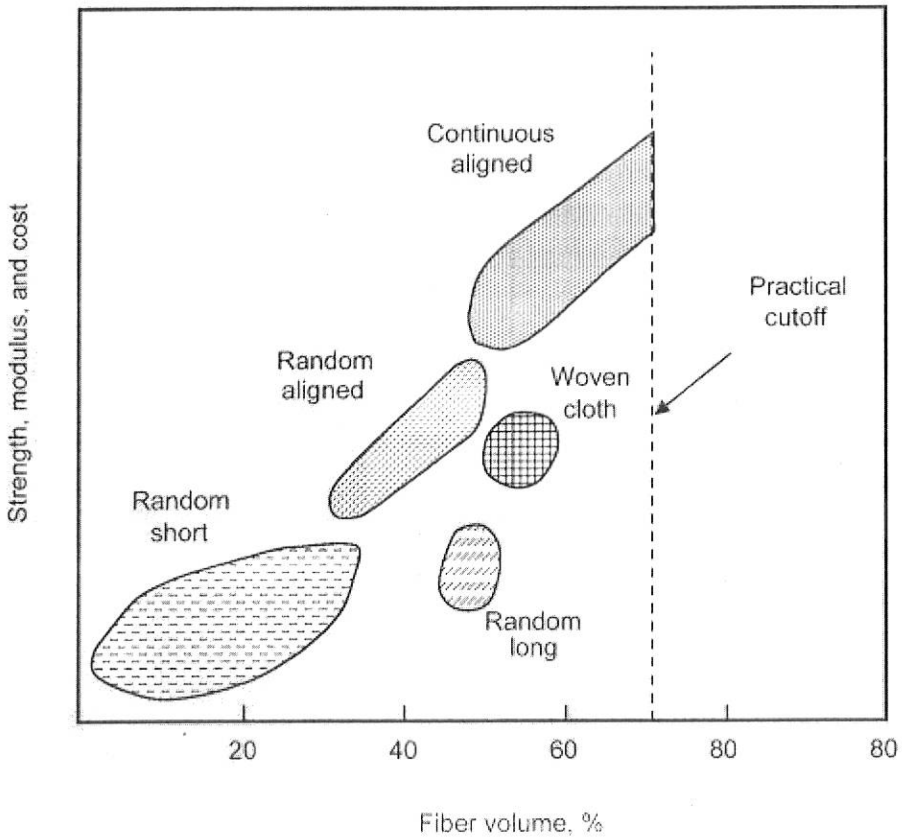


Figure.2.2: Influence of reinforcement type and quantity on composite performance (Horton and McCarty, 1987)

The major processing routes for polymer matrix composites are shown in Figure 2.3. two types of polymer matrices are shown: thermosets and thermoplastics. A thermoset start as a low-viscosity resin that reacts and cures during processing, forming an intractable solid. A thermoplastic is a high-viscosity resin that is processed by heating it above its melting temperature. Because a thermoset resin sets up and cures during processing, it cannot be reprocessed by reheating. By comparison, a thermoplastic can be reheated above its melting temperature for additional processing. there are processes for both classes of resins that are more amenable to dis- continuous fibers and others that are more amenable to continuous fibers. In general, because metal and ceramic matrix composites require very high temperatures and sometimes high pressures for processing, they are normally much more expensive than polymer matrix composites. However, they have much better thermal stability, a requirement in applications where the composite is exposed to high temperatures.

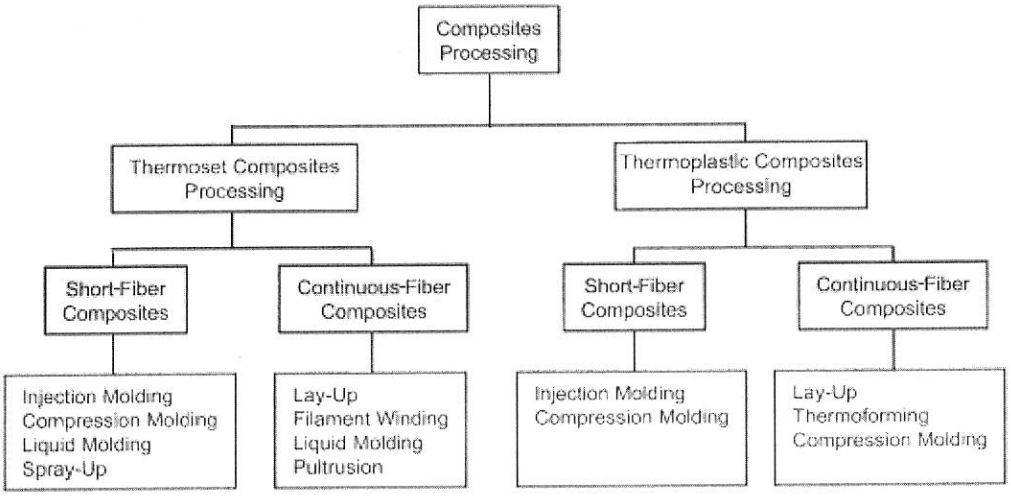


Figure 2.3: Major polymer matrix composite fabrication processes. (Horton and McCarty, 1987)

2.2 Laminates

When there is a single ply or a lay-up in which all of the layers or plies are stacked in the same orientation, the lay-up is called a lamina. When the plies are stacked at various angles, the lay-up is called a laminate. Continuous-fiber composites are normally laminated materials as shown in Figure 2.4 in which the individual layers, plies, or laminae are oriented in directions that will enhance the strength in the primary load direction. Unidirectional (0°) laminae are extremely strong and stiff in the 0° direction. However, they are very weak in the 90° direction because the load must be carried by the much weaker polymeric matrix. While a high-strength fiber can have a tensile strength of 500 ksi (3500 Mpa) or more, a typical polymeric matrix as shown in Figure

2.5 normally has a tensile strength of only 5 to 10 ksi (35 to 70 Mpa). The longitudinal tension and compression loads are carried by the fibers, while the matrix distributes the loads between the fibers in tension and stabilizes the fibers and prevents them from buckling in compression. The matrix is also the primary load carrier for interlaminar shear (i.e; shear between the layers) and transverse (90°) tension (Horton and McCarty, 1987).

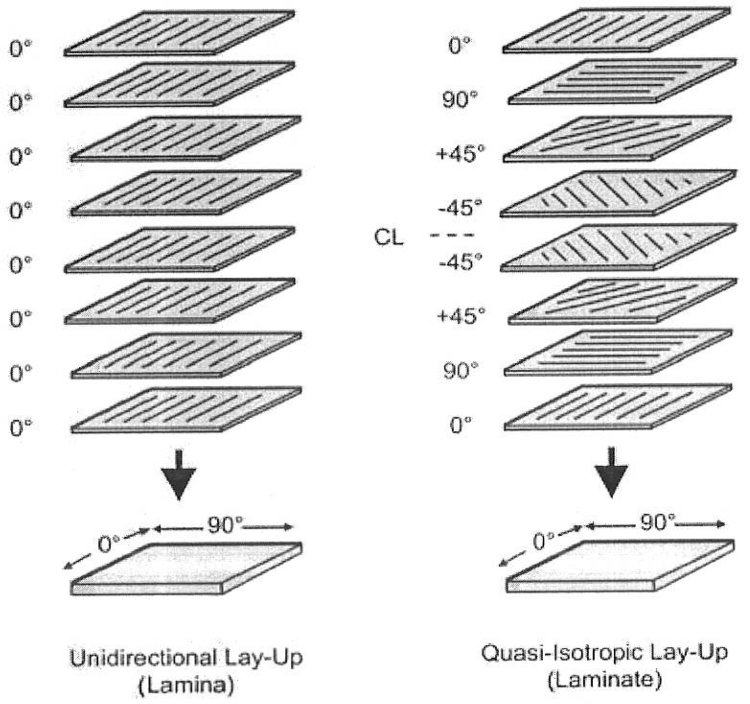


Figure 2.4: Lamina and laminate lay-ups (Horton and McCarty, 1987)

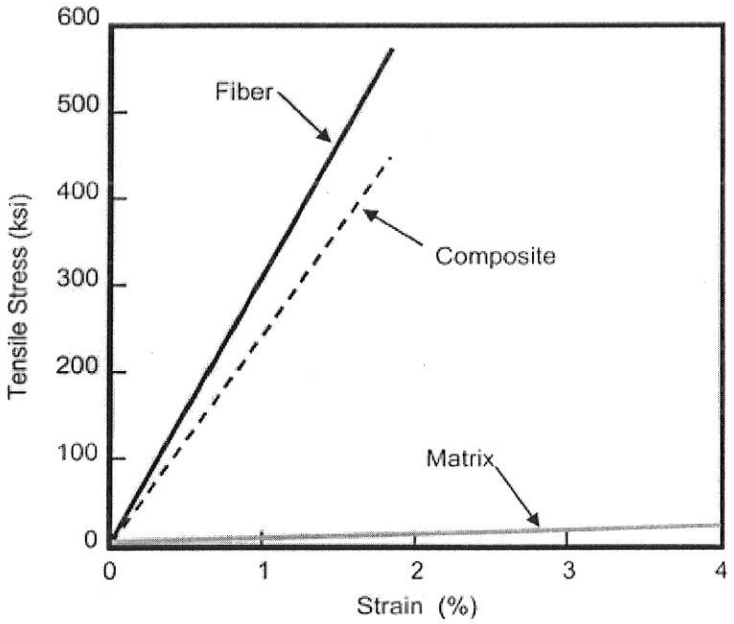


Figure2.5: Comparison of tensile properties of fiber, matrix, and composite (Horton and McCarty, 1987)

2.3 Fundamental Property Relationships

When a uni-directional continuous-fiber lamina or laminate (Figure 2.6) is loaded in a direction parallel to its fibers (0° or 11-direction), the longitudinal modulus E_{11} can be estimated from its constituent properties by using what is known as the rule of mixtures:

$$E_{11} = E_f V_f + E_m V_m \qquad (2.1)$$

where E_f is the fiber modulus, V_f is the fiber volume percentage, E_m is the matrix modulus, and V_m is the matrix volume percentage.

The longitudinal tensile strength σ_{11} also can be estimated by the rule of mixtures:

$$\sigma_{11}= \sigma V_f + \sigma_m V_m \qquad (2.2)$$

where σ_f and σ_m are the ultimate fiber and matrix strengths, respectively. Because the properties of the fiber dominate for all practical volume percentages, the values of the matrix can often be ignored; therefore:

$$E_{11} \approx E_f V_f \qquad (2.3)$$

$$\sigma_{11} \approx \sigma_f V_f \qquad (2.4)$$

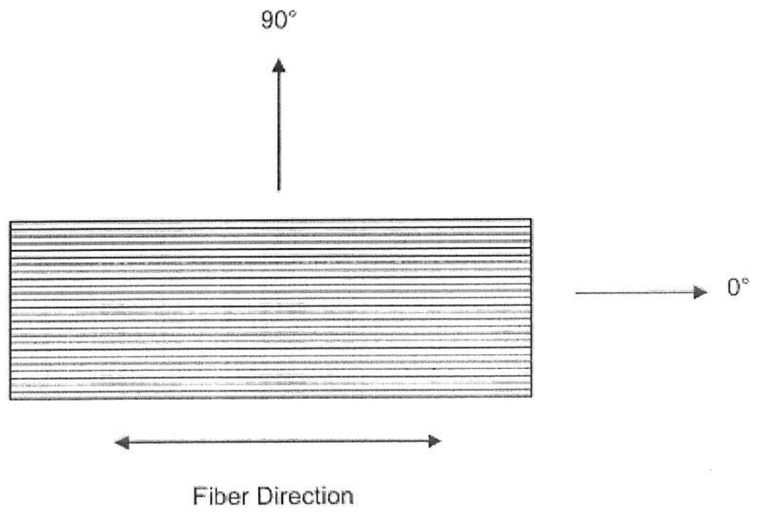


Figure 2.6: Uni-directional continuous-fiber lamina or laminate

2.4 Fiber-Based Composites

One popular form of composites is fiber-reinforced polymer (FRP) composites which combine a polymer matrix with fiber reinforcement such as glass, carbon or other reinforcing fiber material. The advantage of using a composite material lies in the fact that their constituent materials retain their identities/properties because they do not dissolve or merge completely into each other, while acting together to provide a range of new benefits that would not be possible as an individual material. These characteristics can include, but are not limited to having high strength, corrosion resistance, high strength-to-weight ratio and directional strength (Horton and McCarty, 1987).

2.5 Bamboo Fiber

Increasing prices of raw materials in engineering applications, along with a continuous threat to our environment from processing, has led to the use of natural renewable materials for development and fabrication of polymer composites (Puglia *et al*; 2005). There has been extensive research on making composites with synthetic fibers in the past, however utilizing natural fiber reinforcements as a substitution has garnered increasing attention in various applications (Chand and Farim, 2008). Specifically, researchers have extracted fibers from both softwood and hardwood materials for reinforcement in composites (Chand and Farim, 2008). Bamboo fiber composites have served as an area of research as a renewable alternative to petroleum-chemical based materials (Jawaid *et al*; 2010). Investigation has been done in several areas of research that were related to fabrication of various bamboo fiber composites and bamboo's mechanical properties. There is previous research involving bamboo treatment methods, bamboo fiber extraction techniques, and carbon fiber weaving patterns that simulate the models that were incorporated (Jawaid *et al*; 2010).

2.5 Fiber Extraction Techniques

Previous research has shown that bamboo fibers have been extracted from culms by a number of innovative techniques. Some of these techniques include steam explosion, roller mill techniques, compression and a sifter machine. While all of these techniques can result in successful fiber extraction, the difference lies in the fiber diameter and length achieved. According to research done by Okubo *et al.* (2004), voids around the fibers seen in SEM imaging result in a higher risk of surface fracture and poor adhesion between bamboo fibers and the epoxy matrix (Okubo *et al*; 2004). Additionally, they concluded that when bamboo fibers are stacked on top of each other, these spaces are more likely to occur. In order to reduce the number of voids in the composite, optimal designs will decrease the diameter of the fibers as much as possible. The smallest diameter that was discovered involved using a steam explosion method. This is an extraction technique that uses a vessel to violently boil water into steam and thereby breaking up the wood into small pieces and fibers (Okubo *et al*; 2004). This method resulted in fibers ranging from 10-30 micrometer in diameter and lignin almost completely removed from the surface of the fibers (Okubo *et al*; 2004). While this method may produce desirable fibers, access to this type of equipment is not always readily available or found. Other fiber extraction techniques involve using compression techniques. These techniques are outlined in the work done by Deshpande *et al.* (2000). Their research employed both a rolling mill technique (RMT) and compression technique. The RMT resulted in an average fiber diameter of 90 micrometers, and the compression technique resulted in an average fiber diameter of 149 micrometers. The two parameters that need to be optimized in order to obtain quality fibers are compression time and the starting bed thickness. After a series of trials, Deshpande *et al.* (2000) determined that a constant load of 10 tons with a compression time of 10 seconds and bed thickness between 1.25-2 cm resulted in an optimal fiber generation (Deshpande *et al;* 2000).

2.6.1 **Bamboo Treatment**

Bamboo fibers are highly hydrophilic due to their chemical constituents such as lignin which can decrease adhesion with hydrophobic matrix materials (Yang *et al*; 2006). Many researchers have taken chemical-treatment based approaches such as alkalization, graft co-polymerization and coupling agents in order to delignify the bamboo (Yang and Das, 2009). However, other designs are based around finding a natural, eco-friendly solution. Kushwaha, Varadarjulu, and Kumar employed a method that modified the bamboo fiber surface through the use of distilled water (Kushwaha *et al*; 2012). This was a clean, environmental-friendly process because no chemicals were involved. The work done by this group involved setting bamboo in distilled water for varying time intervals including 1 month, 3 months, 6 months and boiling for 6 hours. The results found that the bamboo soaked for 3 months provided the best balance between mechanical and water resistance properties.

However, even the 1-month water modified bamboo improved the tensile strength of their composite by 36% when compared to un-treated surfaces (Kushwaha *et al*; 2012). Results from chemical and nonchemical based treatments provided a flexural strength of about 120-145 MPa (Das and Kushwaha, 2012). Both treatments have the potential to successfully remove the lignin from fibers. Subsequent to the soaking, the bamboo is put through a drying process in order to reduce the water absorption of the fibers. The interfacial adhesion between the polymer matrix and bamboo fibers can be heavily degraded if levels of water absorption are too high (Buehler and Seferis, 2000). One group exposed the bamboo to 120°C of heat for three hours in a drying machine before processing the fibers (Okubo *et al*; 2004).

2.7 Basic Characteristics of Bamboo

Bamboo's are giant grasses and not trees as commonly believed. They belong to the family of the Bambusoideae. The bamboo culm, in general, is a cylindrical shell, which is divided by transversal diaphragms at the nodes. Bamboo shells are orthotropic materials with high strength in the direction parallel to the fibers and low strength perpendicular to the fibers respectively (Wegst *et al;* 1993).

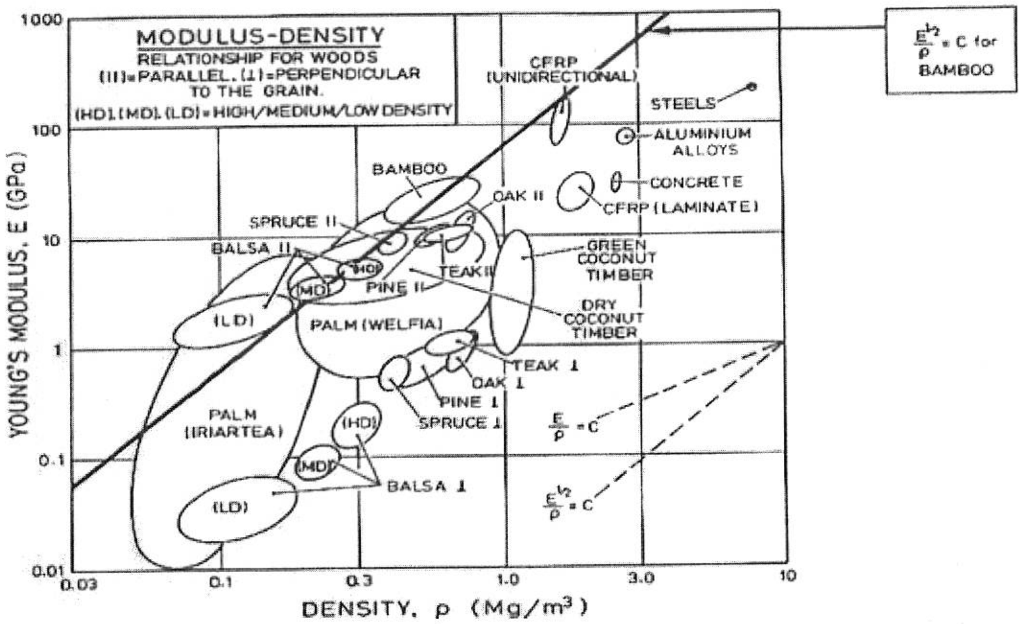


Figure 2.7: Performance of bamboo and other materials, in relation to their E and q. (Ashby, 1992)

Bamboo is a composite material, consisting of long and parallel cellulose fibers embedded in a lignocellulose matrix. The density of the fibers in the cross- section of a bamboo shell varies along its thickness. This presents a functionally gradient material, evolved according to the state of stress distribution in its natural environment. As seen in Figure 2.7 bamboo has a high young's modulus and a low weight ratio (Ashby, 1992).

From figure 2.8, the fibers are connected in regions closer to the outer skin. This is consistent with the state of stress distribution when the culm is subjected to wind forces (Culzoni, 1986).

In establishing the mechanical properties of bamboo, in the elastic range, the rule of mix for the composite materials is used. The properties of the fibers and matrix with their volumetric fractions are taken into account. Equation (2.5) presents the calculation of the elasticity modulus, E_c, of the bamboo as a composite. In this equation E_f and E_m are elasticity moduli and V_f and $V_m = (1-V_f)$

are the volumetric fractions of the fibers and matrix respectively. In the development of Equation (2.5) long uniformly spaced and aligned fibers are assumed in addition to a perfect bonding between fibers and matrix (Culzoni, 1986).

$$Ec= E_f V_f + E_m (1-V_f) \quad (2.5)$$

In the application of Equation (2.5) to the analysis of bamboo, the variation of the volumetric fraction of fibers, Vf(x), with thickness should be taken into account. Considering that the Vf(x) distribution follows an axis, x, with the origin at the internal wall and the maximum limit at the outer wall of the bamboo culm, Equation (2.6) can be written. The variation of Vf(x), was determined using the digital image processing, (DIP) (Culzoni, 1986).

$$E_c= f(x)= E_f V_f + E_m=(1-V_f(x)) \quad (2.6)$$

Using the DIP method, the variation of the fiber volume fraction of the bamboo shell was determined for 10 culms of different species. For each culm, three samples were taken from the bottom, middle and the top part of the culm, as shown in Figure 2.9(a) for bamboo *Dendrocalamus giganteus* (Culzoni, 1986) (DG).

The variation, $V_f(x)$, at the three loci of culms, is presented in Figure 2.9(b). It is observed that the fiber distribution is more uniform at the base than at the top or the middle part. This phenomenon could be explained knowing that the bamboo is subjected to maximum bending stress due to wind and its own weigh t in the base. However, the difference s between the distributions are not very significant. Therefore, all the data presented in Figure 2.9(b) were used to establish Equation (2.7) where the mean volume fraction variation of fibers across the thickness of bamboo DG is presented:

$$V_f(x)= 49 :83x^2-0.49x + 12 :01 \qquad (2.7)$$

The variation of the shell thickness, t, and intermodal distance, L, with the height of bamboo expressed in internode for the species *Dendrocalamus giganteus* (DG), Moso, Matake, Guadua and Phyllostachys pubescens is presented in Figure 2.10. The internodal length is larger in the middle of the culm. The thickness, however, decreases from the base to the top of the bamboo shell. Based on the obtained data, a mathematical formula, which relates the thickness, t, to the position of the internode, n, is established for all species of bamboo studied. Equation (2.8) gives the relation between t and n for bamboo DG. With the help of this equation the designer can choose the required thickness from the range of bamboo species DG (Culzoni, 1986).

$$t = -0.0003n^3 + 0.025n^2 \ 0.809n + 16.791 \qquad (2.8)$$

Similar mathematical formulas have been developed for diameter and internodal length of the bamboo. The international norm for the evaluation of the mechanical behavior of bamboo proposed by the international Bamboo Committee of INBAR (Swamy, 1984) is being adopted by ISO and should be available to the general public soon.

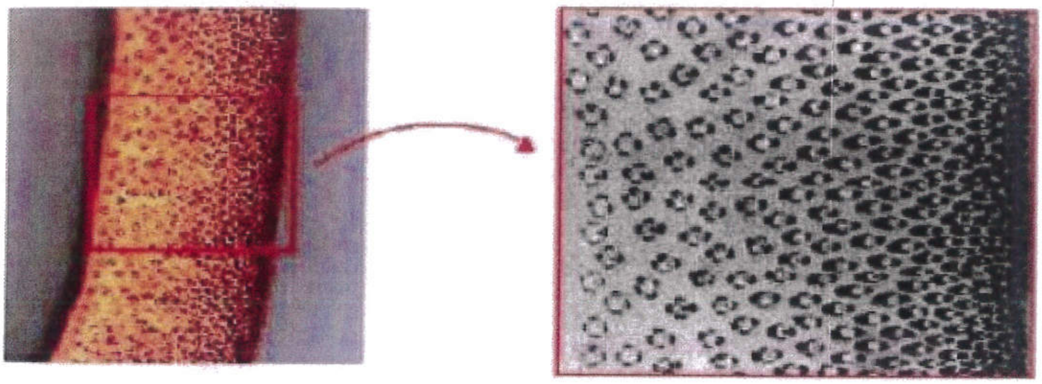
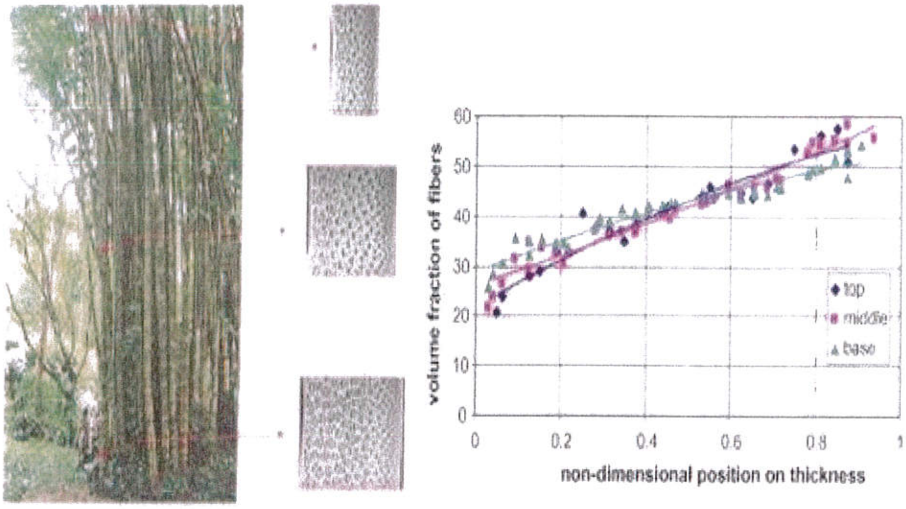


Figure 2.8: Non-uniform fibre distribution on cross-section of bamboo (Culzoni, 1986)



(a) (b)

Figure 2.9: Fiber distribution across the thickness using DIP method along bamboo. (a) Location of samples for DIP along the bamboo shell length DG. (b) Fiber distribution across bamboo thickness at base, middle and top part of DG. (Culzoni, 1986)

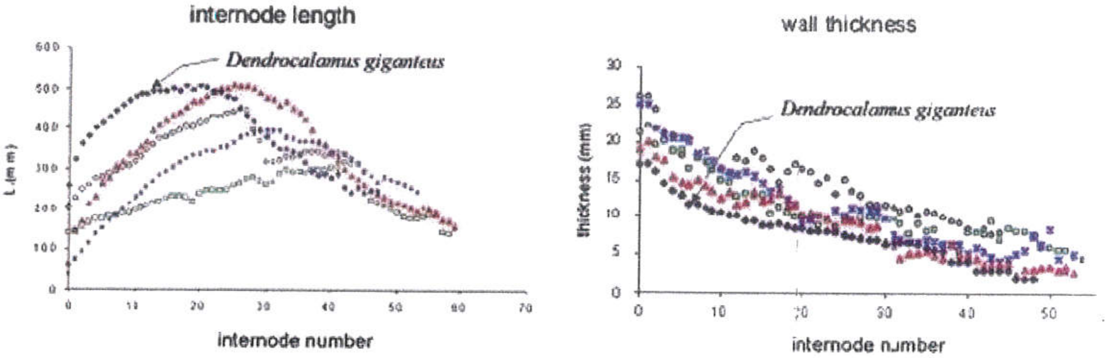


Figure 2.10: Variation of thickness and internodal length along the whole bamboo culm (Culzoni, 1986)

2.7.1 Effect of Water Absorption

One of the main shortcomings of bamboo is water absorption when it is used as a reinforcement and/or permanent shutter form with concrete. The capacity of bamboo to absorb water was studied on several species. A summary of the results is presented in figure 2.11. As seen from figure 2.11, DG, and Bambusa vulgaris schard, VS, absorbed the least amount of water among all compared species. The dimensional variations of the transversal section of bamboos DG and VS reached up to 6% after 7days immersion in water (Gidisau and Culzoni, 1986). The dimensional variation of un-treated bamboo due to water absorption can cause micro or even macro cracks in cured concrete as shown in figure 2.12.

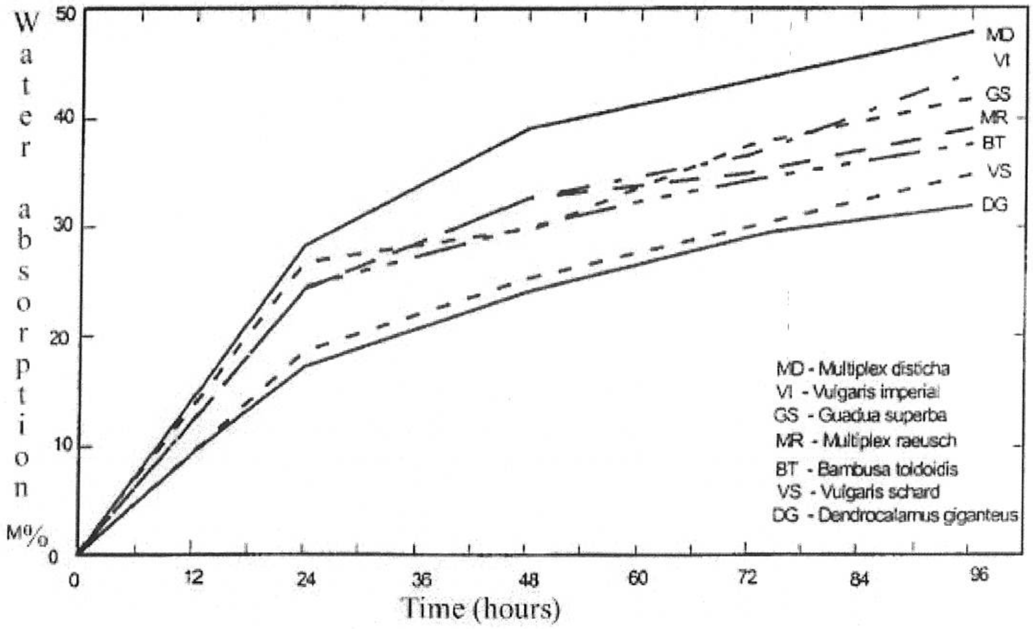


Figure 2.11: Water absorption of different species of bamboo.

2.7.2 **Bonding Strength**

A reinforcing bar in concrete is prevented from slipping by adhesion or bond between them. The main factors which affect the bond between the reinforcing bar and concrete are: adhesive properties of the cement matrix, the compression friction forces appearing on the surface of the reinforcing bar due to shrinkage of the concrete and the shear resistance of concrete due to surface form and roughness of the reinforcing bar. The dimensional changes of bamboo due to moisture and temperature variations influence all the three bond characteristics (Culzoni, 1986). During the casting and curing of concrete, reinforcing bamboo absorbs water and expands as shown in Figure 2.12(a).

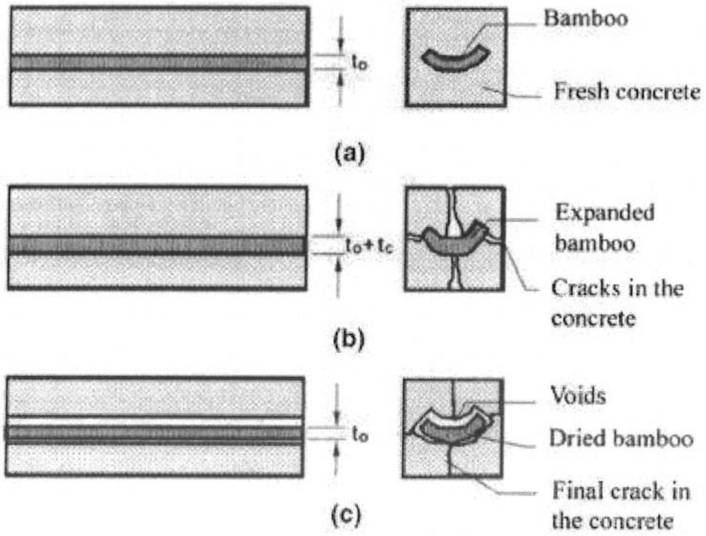


Figure 2.12: Behavior of untreated segment bamboo as reinforcement in concrete: (a) bamboo in fresh concrete, (b) bamboo during curing of concrete and (c) bamboo after cured concrete.

The swelling of bamboo pushes the concrete away, shown in figure 2.12(b). Then at the end of the curing period, the bamboo loses the moisture and shrinks back almost to its original dimensions leaving voids around itself, as shown in figure 2.12(c). The differential thermal expansion of bamboo with respect to concrete may also lead to cracking of the concrete during service life. The swelling and shrinkage of bamboo in concrete create a serious limitation in the use of bamboo as a substitute for steel in concrete. To improve the bond between bamboo segments and concrete, an effective water-repellent treatment is necessary. Various types of treatment have been studied with different degrees of success. (Culzoni, 1986)

The impermeability treatment of bamboo is affected by three factors: The adhesion properties of the substance applied to bamboo and concrete, water repellent property of the chosen substance and the topography of bamboo/concrete interface. One effective treatment is the application of a thin layer of epoxy to the bamboo surface followed by a coating of fine sand. However, this is an expensive treatment in many countries including Brazil. Materials such as asphalt paints, tar based paints and specific bituminous materials satisfy all the impermeability requirements. (Culzoni, 1986).

2.8 Fracture Toughness

Fracture toughness is an inherent characteristic of a material that describes its ability to resist crack propagation (Fujishima and Ferracane, 1996). The "plane strain fracture toughness", (K_{IC}), is a measure for the crack resistance of a material (Drummond, 2008). It is defined as the critical value of the stress intensity factor at a crack tip which produces catastrophic fast fracture (Watanabe *et al;* 2008). K_{IC} is an important measure of a material's properties, as it indicates the largest amount of stress that a material can withstand prior to failure and represents the ability of a material to resist crack propagation from an existing flaw. Therefore, characterization of this property can help prevent devastating failures of resin composite restorations (Watanabe *et al*; 2008). The main concern with restorative composites is to increase the fracture toughness, and consequently prolong their service life in the oral cavity while maintaining their aesthetic value. Although longevity and survival studies in posterior teeth continue to show that amalgam has a better track record than composite (Bernardo and Soncini, 2007), a new formulation of resin composite is continually appearing on the market with improved mechanical properties (Ferracane, 2001).

Understanding the failure mechanisms and the correlation between the laboratory strength tests and clinical behavior of resin composites still need to be established to enhance their survival. The values of strength or failure load have been associated with the failure mode. Hence, the efforts are being made to find an appropriate method to reproduce the damage process occurring in service. Due to the complexity of the forces that direct restorations to resist in the oral cavity, it is not easy to select a suitable method for testing fracture toughness of resin composites (Fischer and Marx, 2002). In the oral environment, dental restorations are subjected to continuous mechanical loads which lead to progressive degradation and crack propagation, resulting in catastrophic failure of the restorations (Lien and Vandewalle, 2010). Moreover, pre-existing voids introduced during material processing, imperfect interfaces, and residual stresses will further increase the failure of the restorations in a period of time (Drummond, 2008). Most of the published work is concerned with mode I straight-line crack growth, and toughness characterization of various composites, which have been exposed to air, water, ethanol, and other environments (Fani *et al*; 2015)

2.8.1 Fracture Mechanics

Fracture mechanics is an important tool in supporting and expecting the durability of materials. Fracture mechanics can be used to expect the rate at which a crack can reach a critical size in fatigue or by environmental influences, and can be used to determine the conditions under which a rapidly propagating crack can be arrested (Kanninen and Popelar). Fracture toughness testing is standardized by the American Society for Testing and Materials (ASTM PS070–97. 1997). A test method that has been used extensively in the study of fracture properties of brittle materials is the

Mode I, also referred to as the Brazilian disk test or diametral tensile test (Awaji *et al*; 1996). The procedure of fracture toughness measurement involves creating a sharp crack tip. The crack tip condition is difficult to satisfy in brittle materials due to problems associated with growing a sharp crack normal to the applied load. Researchers have implemented various techniques to introduce sharp notches in brittle specimens including single edge-notched beam, chevron notch, compact tension, and indentation hardness method (Sanchez *et al*; 1986). The study of fracture surface markings on brittle materials has been well documented. During failure, the crack front propagates through the material, creating fracture features known as the mirror, mist, and hackle (Figure 2.13).

The crack front initially produces a smooth mirror region. However, as the crack accelerates, it becomes more unstable, creating a dimpled surface known as mist. This instability eventually causes the crack to branch out, producing the rough hackle region. The hackle region is characterized by elongated markings that proceed in the direction of crack propagation (Frechette, 1990).

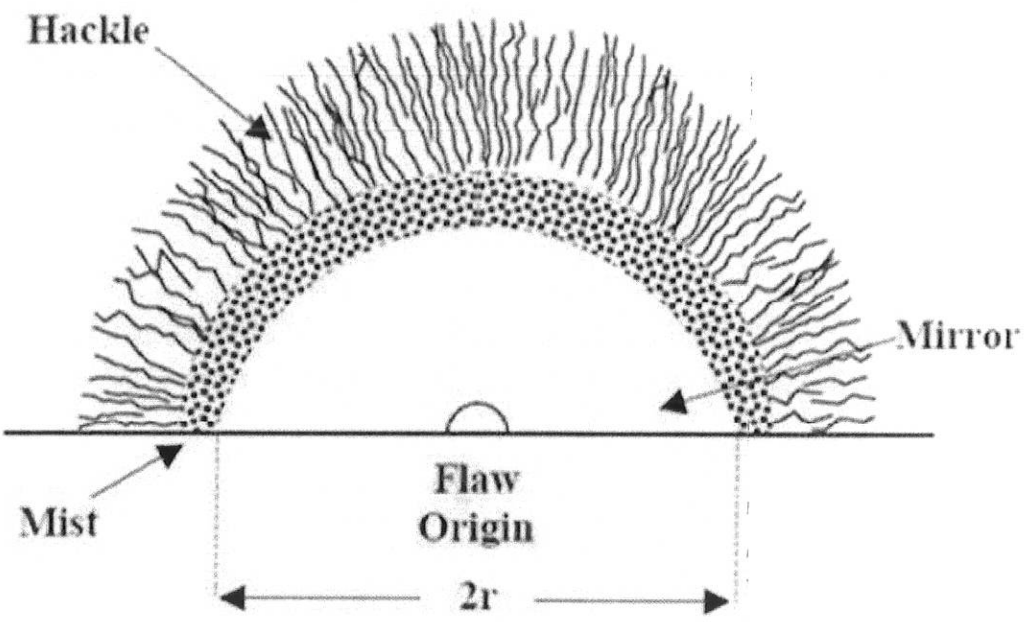


Figure 2.13: Schematic view showing brittle material surface features formed during failure (Frechette, 1990)

2.8.2 Different Types of Fracture Toughness

There are actually four different types of fracture toughness, K_C, K_{IC}, K_{IIC}, and K_{IIIC}. K_C is used to measure a material's fracture toughness in a sample that has a thickness that is less than some critical value, B. When the material's thickness is less than B, and stress is applied, the material is in a state called plane stress. The value of B is given in Equation (2.9). A material's thickness is related to its fracture toughness graphically in Figure 2.14. Equation (2.10) shows a material's K_C value in relation to the material's width (Shyamu, 2015).

$$B \geq 2.5\left(\frac{K_{IC}}{\sigma_y}\right)^2 \tag{2.9}$$

The minimum thickness of material before plane strain behavior occurs.

B = minimum thickness to distinguish between K_C and K_{IC}

K_c = fracture toughness, when the sample has a thickness less than B

S_y = yield stress of material

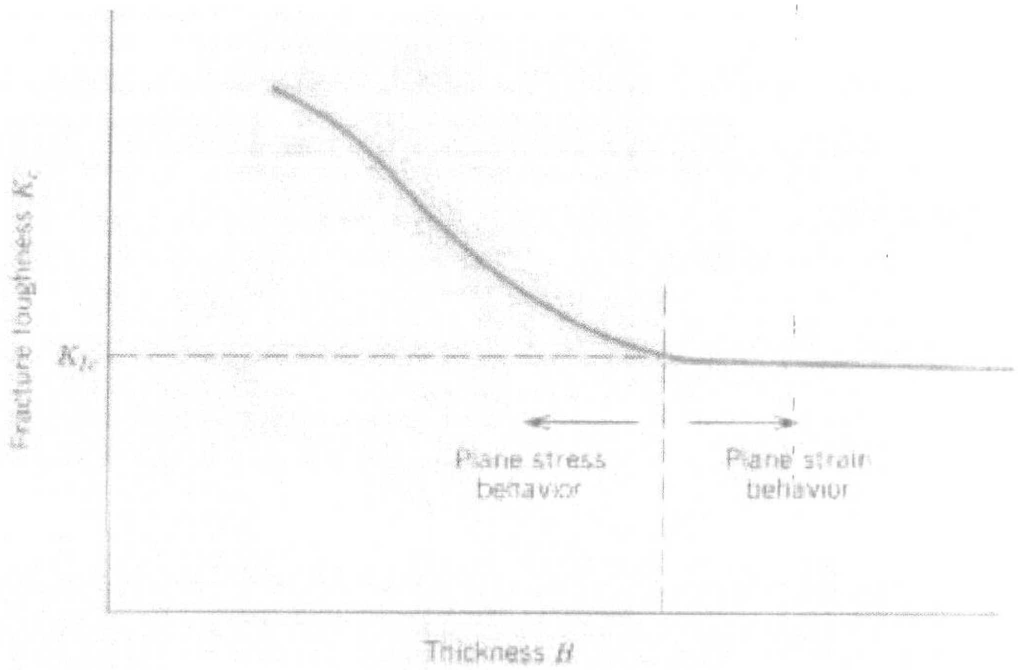


Figure 2.14: Fracture Toughness as a function of material thickness(Shyamu, 2015)

$$K_C = Y\sigma\sqrt{\pi a} \tag{2.10}$$

The fracture toughness of a material with a thickness less than B

K_c = fracture toughness, when the sample has a thickness less than B

Y = constant related to the sample's geometry

a = crack length (surface crack), one half crack length (internal crack)

s = stress applied to the material

K_{IC}, K_{IIC}, and K_{IIIC} all represent a material's fracture toughness when a sample of material has a thickness greater than B. If a stress is applied to a sample with a thickness greater than B, it is in a state called plane strain. The differences between K_{IC}, K_{IIC}, and K_{IIIC}, however, do not depend on the thickness of the material. Instead, K_{IC}, K_{IIC}, and K_{IIIC} are the fracture toughness of a material under the three different modes of fracture, mode I, mode II, and mode III, respectively. The different modes of fracture I, II, and III are all graphically expressed in figures 2.15, 2.16, and 2.17. Equation, 2.11 shows how K_{IC} can be calculated knowing the material's parameters.

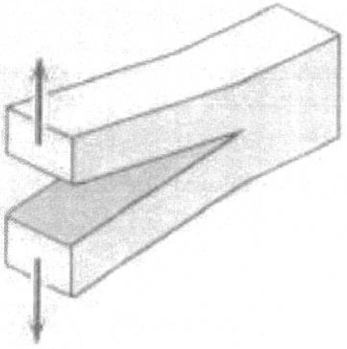


Figure 2.15: Mode I Fracture (Shyamu, 2015)

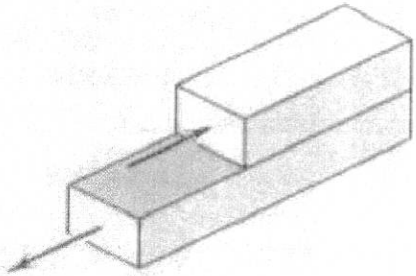


Figure 2.16: Mode II Fracture (Shyamu, 2015)

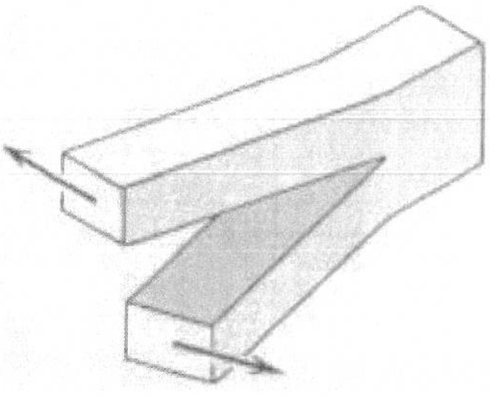


Figure 2.17: Mode III Fracture (Shyamu, 2015)

$$K_C = Y\sigma\sqrt{\pi a} \tag{2.11}$$

The fracture toughness of a material with a thickness equal to or greater than B; when it fractures in mode I. (Shyamu, 2015)

K_{ic} = fracture toughness, when the sample has a thickness greater than B

Y = constant related to the sample's geometry

a = crack length (surface crack), one half crack length (internal crack)

s = stress applied to the material

KIC values can be used to help determine critical lengths given an applied stress; or a critical stress values can be calculated given a crack length already in the material with equations 2.12 and 2.13

$$\sigma_C \geq 2.5\frac{K_{IC}}{Y\sqrt{\pi a}} \tag{2.12}$$

Critical applied stress required to cause failure in a material. (Shyamu, 2015)

S_c = critical applied stress that causes the material to fail

K_{IC} = fracture toughness, when the sample has a thickness less than B

Y = constant related to the sample's geometry

a = crack length (surface crack), one half crack length (internal crack)

$$a_c = \frac{1}{\pi}\left(\frac{K_{Ic}}{\sigma Y}\right)^2$$

Critical crack length required to cause failure in a material (Shyamu, 2015)

a = critical crack length (surface crack), one half crack length (internal crack)

s = stress applied to the material

KIC = fracture toughness, when the sample has a thickness less than B

Y = constant related to the sample's geometry

2.9 Laterite Composite

The recognition of laterite as an earth material, with unique properties, dates back to 1807 when Buchanan first encountered a material in India which he called laterite and defined as soft enough to be readily cut into blocks by an iron instrument, but which upon exposure to air quickly becomes as hard as brick, and is reasonably resistant to the action of air and water (Vallerga and Rananandana, 1969).

Since Buchanan's time; the word laterite has been used to describe a wide variety of tropical soils without reaching an agreement on the exact origin, composition and properties of laterites. If one attempts to find the definition of laterite by searching the literature, he will encounter several different definitions. Among them, the one of Alexander and Cady is widely accepted; "Laterite is a highly weathered material rich in secondary oxides of iron, aluminum, or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying." Among those characteristics listed in the above definition, hardness is the only one which makes laterite unique (Alexander and Cady, 1962).

Figure 2.17: Image of laterite

2.9.1 Genesis and Evolution of Laterites/ Lateritic Soils

The weathering of laterites essentially involves the chemical and physico-chemical alteration and/or transformation of primary rock-forming materials into material rich mainly in 1:1 latice clay minerals and the lateritic constituents (iron, aluminium, manganese and titanium). There are three main identified stages of the formation of laterites and they include:

a) The first stage involves the physical and chemical breakdown of primary minerals and release of the basic constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O and other metallic ions) which appear in ionic forms.

b) The second stage involves the leaching under appropriate drainage conditions of the combined silica and bases and relative accumulation or enrichment from outside sources of oxides and hydroxides of sesquioxides (mainly, Al_2O_3 , Fe_2O_3 and TiO_2).

c) The third stage involves partial or complete dehydration of the sesquioxide rich minerals and secondary minerals (Lohnes *et al*; 1971).

The level to which each of these stages are carried depends upon the nature and the extent of the physico-chemical weathering, the primary rock forming mineral and the nature of the weathering system determined by the soil forming factors (i.e. parent material, climatic-vegetation conditions, topography and drainage conditions and time during which the weathering process have operated) (Lohnes *et al*; 1971).

2.9.2 **Engineering Properties of Laterites and Lateritic Soils**

Many studies have shown that plasticity and grain size distribution data for lateritic soils are extremely varied and erratic (Lohnes *et al*; 1971). The reasons for this are discussed in detail by several investigators (Townsend *et al*; 1969). When soils are manipulated their characteristics vary a lot. Pre-testing drying causes variations in some properties of lateritic soils and this behavior is commonly attributed to the dehydration of the colloidal hydrated oxides occurring in these soils. In most of the cases the variation, resulting from drying, is irreversible and results in a soil with more granular characteristics. To disperse such a system for plasticity and grain size determination is almost impossible (Vallerga and Rananandana, 1969). Because of such difficulties it is extremely difficult to derive an acceptable generalization for lateritic soils with regard to plasticity and gradation. Lohnes and Demirel. are the first investigators who have put emphasis on using specific gravity as an indicator for engineering behavior of lateritic soils. By definition specific gravity is the weighted average of the specific gravities of the minerals which comprise the soil (Lohnes and Demirel, 1971).

In the weathering process of lateritic soils, it is always stated that the contents of high specific gravity minerals increase with age of formation. This fact, of course, should be reflected in the value of specific gravity, that is, specific gravity of lateritic soils should increase with increasing degree of weathering. Lohnes and Demirel made an attempt to verify this thought by plotting extractable iron content versus specific gravity for several selected Puerto Rican soils and ended up with a good correlation between increasing specific gravity and increasing iron content. They also used the data presented by Trow and Morton on Dominican Republic soils to show increasing specific gravity with increasing amount of goethite (Trow and Morton, 1969)

Thus it appears that specific gravity of lateritic soils can be regarded as a parameter which can be used for a better understanding of the engineering behavior of tropical soils in relation to degree of weathering. Other engineering properties of lateritic soils, such as wet and dry densities, moisture content, and void ratio (or porosity), have not been taken into account in the majority of studies. There are very limited data on such properties of lateritic soils in the literature. This is an unfortunate situation, because these properties have an advantage over plasticity and gradation, in that, the majority of them are determined by bulk measurements and as such are not influenced by degree of manipulation. Specific gravity, which is used in determining the void ratio, is also a parameter not affected much by the manipulation of soils prior to testing. In addition, the bulk properties reflect the behavior of un-disturbed soils; so, from the engineering point of view, they provide better information on laterites and lateritic soils. In their study on Puerto Rican soils, Lohnes and Demirel observed a relationship between void ratio and specific gravity, indicating a decrease in void ratio as specific gravity increases. Besides that, they observed increasing cohesion with decreasing void ratio. By making use of these relationships, they suggested the possibility of an engineering classification system for lateritic soils which relates void ratio, strength and degree of weathering to each other (Lohnes and Demirel, 1971).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Materials

The experimental materials which were used are:

Bamboo stick and laterite soil were obtained from Oke-Ayedu Ekiti, Ekiti state, Nigeria. Half bag of cement (25kg) was obtained from a Dangote cement outlet in Ikole-Ekiti, ekiti state, Nigeria.

Then sodium hydroxide (500g) used for the treatment of bamboo fiber was obtained from Finlab in Lagos, Nigeria.

3.2 Equipment

- Digital weighing balance
- Wooden Casting mold
- Phenom pro X Scanning electron microscope (SEM) with energy dispersion x-ray spectroscopy (EDS)
- Compressive test machine
- Flexural/bending test machine
- Gwydion software
- Optical lenses (proscope HR & microscope)
- 350-micron meter sieve

3.3 Methods

3.3.1 Sample Preparation

3.3.1.1 Production of Bamboo Fiber

The bamboo was mechanically milled to small pieces using a local mortar, after which the bamboo fibers were soaked in sodium hydroxide for 9 hours, this was to allow for removal of lignin content, so as to provide proper interfacial bonding between the matrix and the fibers. Thereafter, the bamboo fibers were dried in the sun for a period of 14 days to allow complete removal of water.

3.3.1.2 Collection of Laterite Sand

Laterite sand was dug from the Oke-Ayedun local town in Ekiti state and was dried for 3 days, after drying, the lumps were broken into small pieces and sieved using a sieve size of 150-micron meter.

Figure 3.1: laterite clay

3.3.1.3 Fabrication of Mould for Casting

The samples were obtained with the aid of a locally made mould. The mould was constructed to correspond to the shape and size of the samples for compressive (figure 3.2a) and (figure 3.2b)

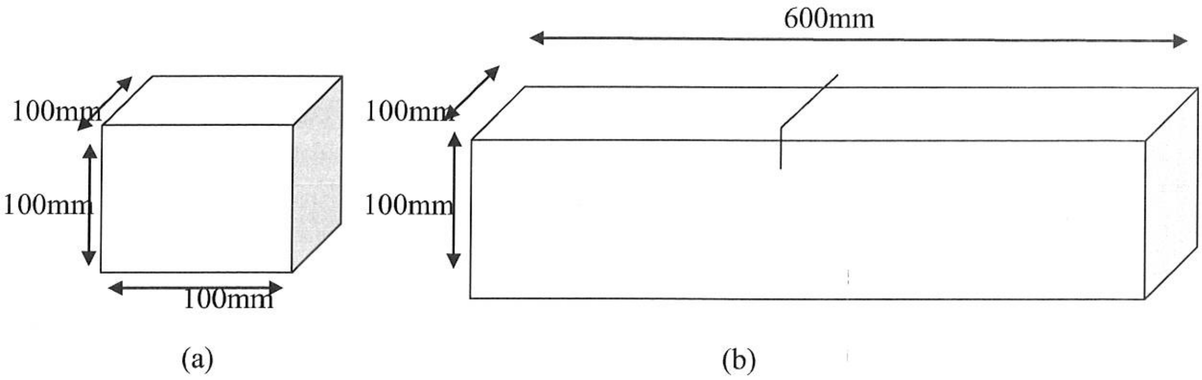


Figure 3.2: Compressive and Flexural samples

A wooden sand mould was made with dimension of 100mm x 100mm x 100mm for the compression test samples, and dimension of 600mm x 100mm x 100mm was made for the bending test samples.

3.4 Matrix Preparation

In this work, the matrix compositions were produced differently to serve as the control samples to the reinforced ones. The matrices were prepared by the direct mixing of desired material(s) with appropriate amount of water. The mixtures were then moulded to the required sample shapes. The material composition in the matrix preparation was based on percentage composition by weight of laterite, and cement. The matrix composition which was used was 80% laterite and 20% cement.

Table 3.1 Percentage composition of laterite and cement

Sample	Laterite (% weight fraction)	Cement (%weight fraction)
I	80	20

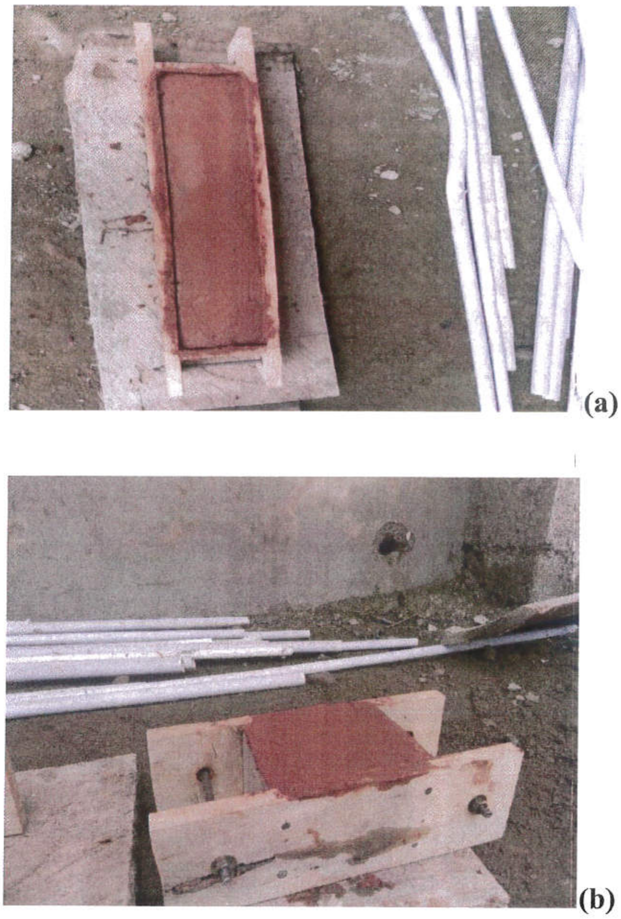


Figure 3.3: (a) cast for flexural test (b) cast for compressive test

3.5 Composite Preparation

Bamboo fiber reinforced matrix composites with fiber weight fractions ranging from 0% to 25% were produced. During the process, the matrix materials were added to the appropriate amount of fiber. The fibers had been treated to obtain shorter fiber composites. In order to study the effect of the reinforcement, the percentage composition by weight of the fiber was varied. The laterite-cement matrix was varied and 412.5mL of water was added for the compressive samples and 2200mL for the flexural samples. The compositions are shown in the table below:

Table 3.2 Percentage composition of fiber and matrix composite

Samples	Weight of laterite + cement (%)	Weight of fiber (%)
I	100	0
II	95	5
III	90	10
IV	85	15
V	80	20
VI	75	25

Figure 3.4: Weighing of Fiber for Composite Preparation

All the compositions were left to dry in the sun for 14 days before carrying out the compressive and flexural test.

3.6 Mechanical Testing

The mechanical properties tested in this study were compressive strength, flexural strength. A digital compression/bending testing machine electromechanical (MI-100-2P (ECMO-FTM)) was used to test the samples. This was used to measure the compressive and flexural strengths. The compressive and flexural strength were carried out in Federal University of Technology, Akure (FUTA), Ondo state, Nigeria.

$$compressive\ strength = \frac{max.load\ applied\ (N)}{area\ (mm)^2} = \frac{F}{A} \tag{3.1}$$

$$\delta_f = \frac{3FL}{2BD^2} \tag{3.2}$$

δ_f=flexural strength

F= Applied Load (kN)

L= Length of Sample

B= Breadth of Sample

D= Thickness/Height of Sample

A= X-Sectional Area of Sample

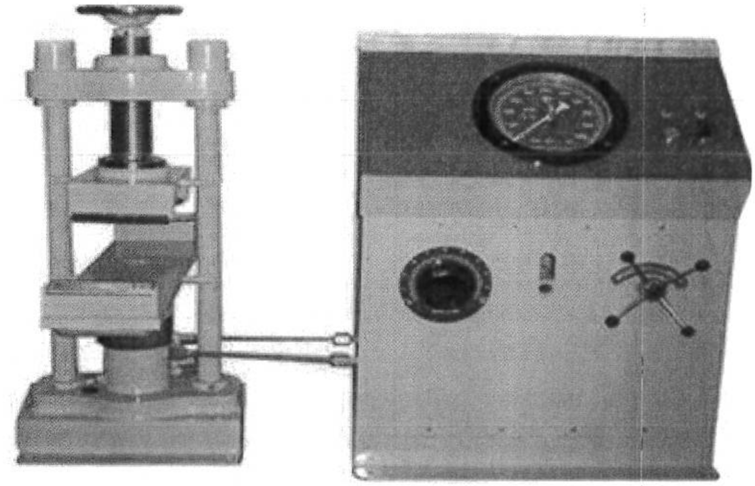


Figure 3.5: Digital Compressive/Bending Test

Figure 3.6: Samples Ready for Test

Figure 3.7: Testing of Flexural Strength

3.7 Optical Microscopy

This was done using Proscope HR microscope (Bodeline Technologies, 6077A Lakeview Blvd. lake Oswego, OR 97035) to study the fracture surface of the laterite composite.

3.8 Characterization of Bamboo Fiber Reinforced Laterite Composite

Samples of laterite composites were made available for characterization. The fractured surface of the samples was viewed. The combination of scanning electron microscopy (SEM), energy dispersion spectroscopy (EDS) was used respectively to study the morphology, composition and structure of the materials.

SEM and EDS were carried out at Covenant University, Otta, Ogun state, Nigeria. The analysis was carried out with Phenom ProX SEM with EDS (Nanoscience instruments, Washington D.C USA). Gwyddion software was also used to translate the SEM images.

Figure 3.8 Phenom pro X SEM/EDS

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Compressive Strength

The table below shows the results of the compressive strength of the laterite based composite which were tested after 14 days. The trend in the data are shown in the figure 4.1 below.

Table 4.1: Compressive Strength with Different Weight fraction of bamboo fiber.

Samples	Weight Fraction Bamboo Fiber (%)	Max. Load (KN)	Compressive Strength (MPa)
I	0	20	2.0±0.100
II	5	21	2.1±0.105
III	10	24	2.4±0.120
IV	15	25	2.5±0.125
V	20	31	3.1±0.155
VI	25	50	5.0±0.25

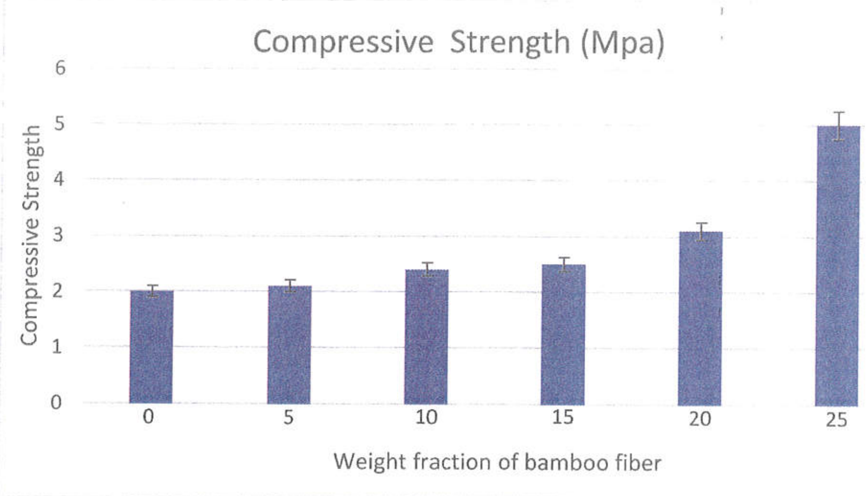


Figure 4.1: Compressive Strength with Different Weight fraction of bamboo fiber.

The result in figure 4.1 above shows that, with increase in the fiber percentage the compressive strength tends to increase as the weight fraction of fiber increases from 0% fiber to 25% fiber. The strength at 15% fiber is two times that of the 25% fiber, the presence of fibers helps to increase the resistance to breaking under compressive loading.

4.2 Flexural Strength

The table below shows the flexural test result of the composite samples with weight fraction of fiber variation

Table 4.2: Flexural Stress with Different Weight fraction of bamboo fiber

Samples	Weight Fraction Bamboo Fiber (%)	Flexural Stress (MPa)	Fracture Toughness (Mpa$\sqrt{m}$)
I	0	0.9±0.045	0.68±0.034
II	5	1.17±0.056	0.89±0.045
III	10	1.35±0.068	1.02±0.051
IV	15	1.62±0.081	1.23±0.062
V	20	1.80±0.0900	1.36±0.068
VI	25	2.25±0.113	1.70±0.085

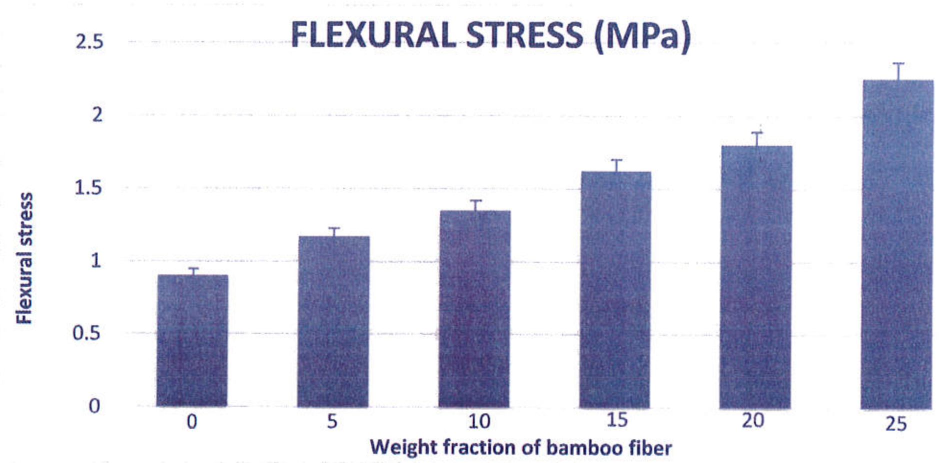


Figure 4.2: Flexural Stress with Different Weight fraction of bamboo fiber

The bar chart shows the flexural strength of the different composition of the bamboo fiber reinforced laterite composite (figure 4.2). The results obtained shows an increasing flexural strength as the weight fraction of bamboo fiber increases from 0% to 25%. This is as a result of an increase in bamboo fibers which resist fracture in the laterite based composite. From the bar chart a maximum flexural strength of 2.25±0.113 MPa was obtained at 25% bamboo fiber, while a minimum of 0.9±0.045 MPa was obtained at 0% bamboo fiber. The minimum flexural strength obtained was as a result of the absence of bamboo fiber and which fractured easily as shown in the SEM result in plate 4.2a.

4.3 Fracture Toughness

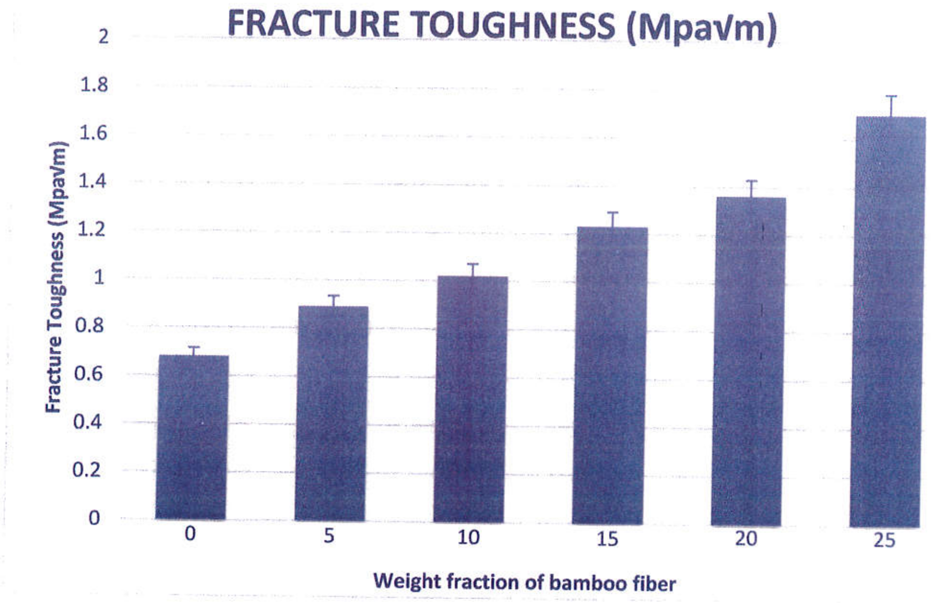


Figure 4.3: Fracture Toughness with Different Weight fraction of bamboo fiber

Figure 4.3 shows the fracture toughness results of bamboo fiber reinforced laterite composite. A minimum fracture toughness of 0.68±0.034 MPa√m was obtained at 0% weight fraction of bamboo fiber, because of the absence of fibers to arrest crack. While for 5% to 25% fiber, an increase in fracture toughness was observed which was due to the ability of the bamboo fibers to arrest cracks, which also gives the composite toughness. A maximum fracture toughness of 1.70±0.085 MPa√m was observed at 25% weight fraction of fibers.

4.4 Elemental Composition

The EDS analysis obtained from the laterite based composite are shown in Figures 4.4 to 4.9. The EDS results revealed trace elements present in the bamboo fiber-reinforced laterite composite. Trace elements such as Al, Si, Fe, Br were revealed, which are commonly found in laterite sand. Ca, C and O are commonly found in cement, while C and O can be attributed to the presence of bamboo fibers which contain cellulose in them. All these elements present form compounds which are stable and provide a strong interfacial bonding between the laterite-cement matrix and the bamboo fiber, giving the composite the necessary strength and toughness required to resist crack propagation.

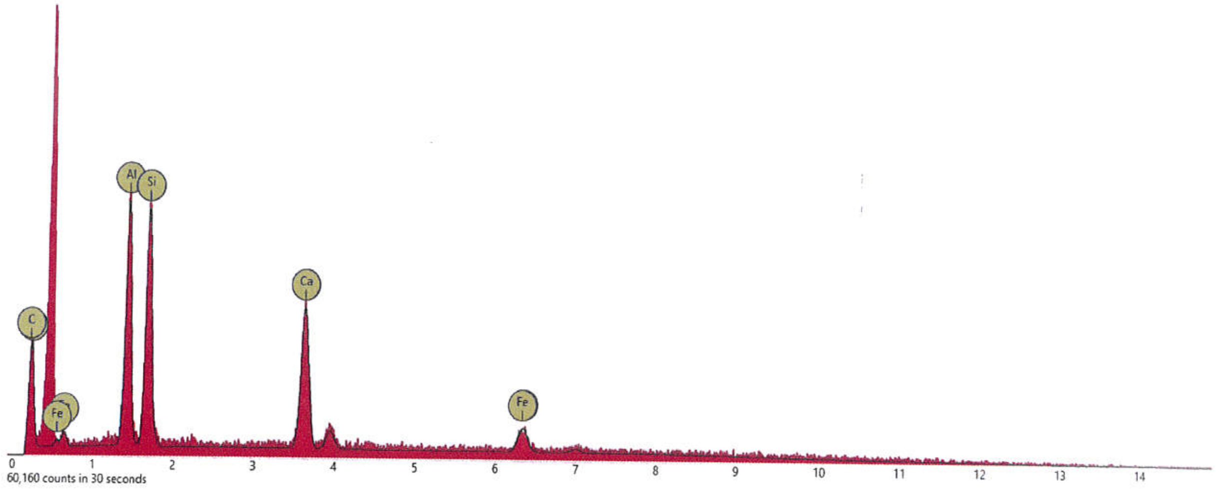


Figure 4.4: EDS analysis of Laterite-Cement Matrix

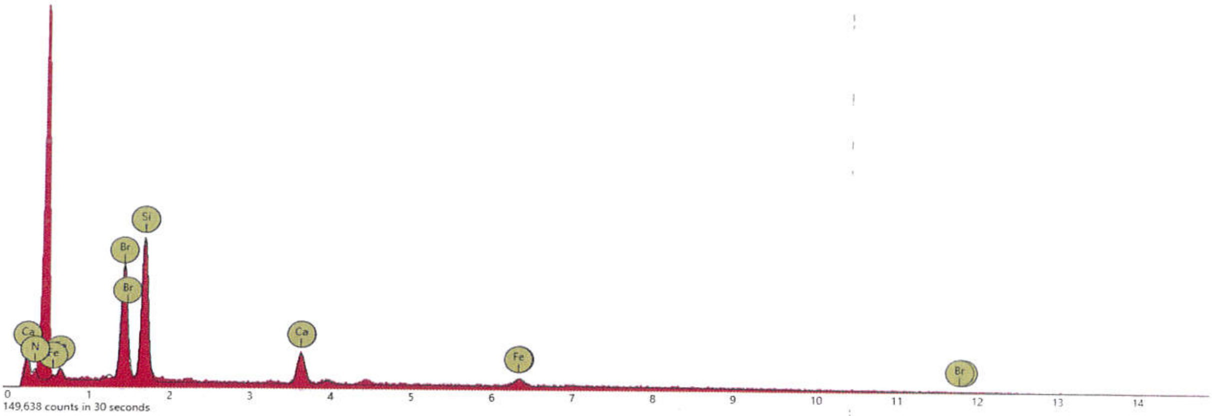


Figure 4.5: EDS analysis of Laterite, Cement with 5% Bamboo Fiber

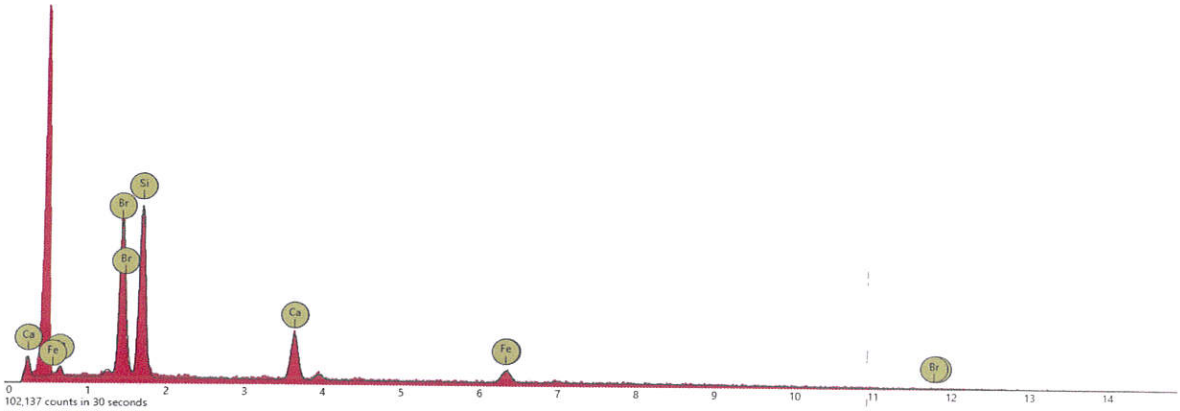


Figure 4.6: EDS analysis of Laterite, Cement with 10% Bamboo Fiber

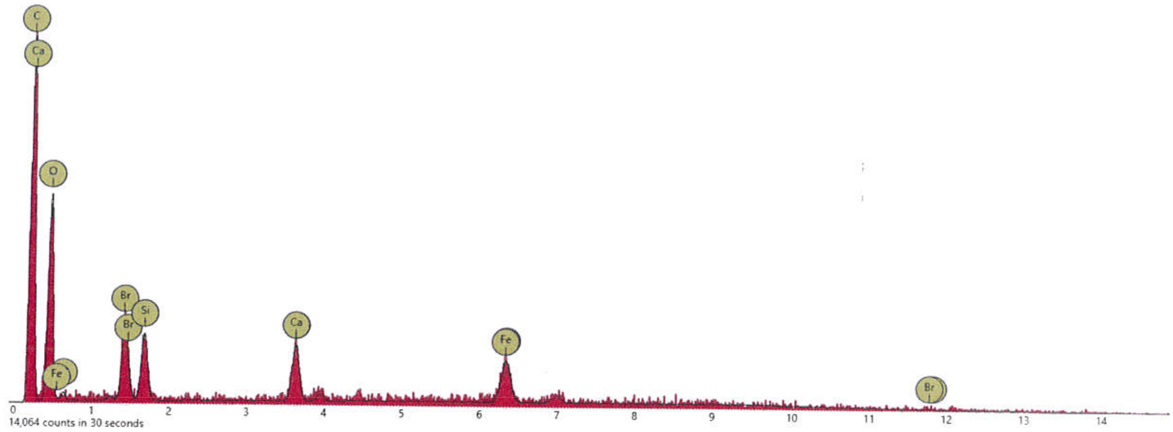


Figure 4.7: EDS analysis of Laterite, Cement with 15% Bamboo Fiber

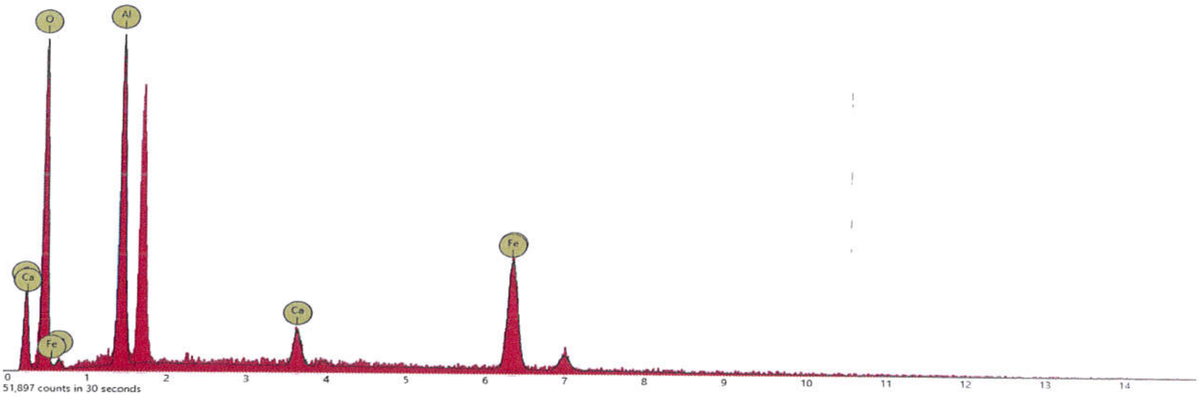


Figure 4.8: EDS analysis of Laterite, Cement with 20% Bamboo Fiber

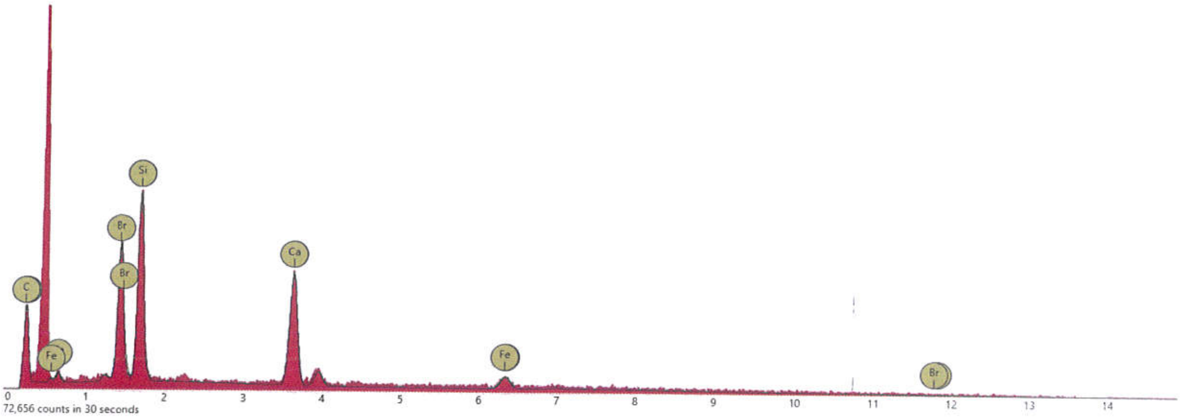


Figure 4.9: EDS analysis of Laterite, Cement with 25% Bamboo Fiber

4.5 Optical Microscopy

The optical microscope images of the structure and morphology of the laterite based composite are presented in Plate 4.1 (a - c). Plate 4.1a reveals bamboo fiber in the laterite based composite being fractured and plate 4.1b shows rough surface of the laterite based composite after being facture, while plate 4.1c reveals holes present in the laterite based composite after fracture due to fiber pull-out from the surface of the laterite based composite.

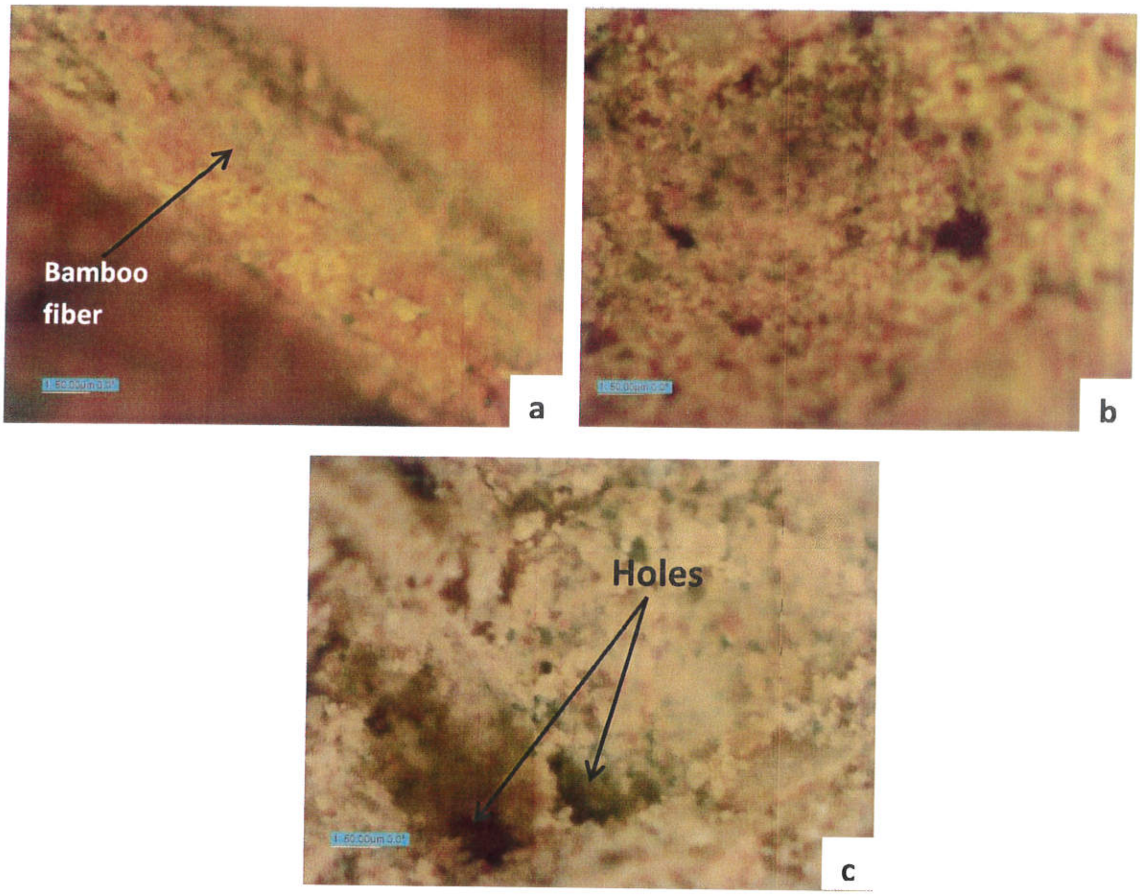
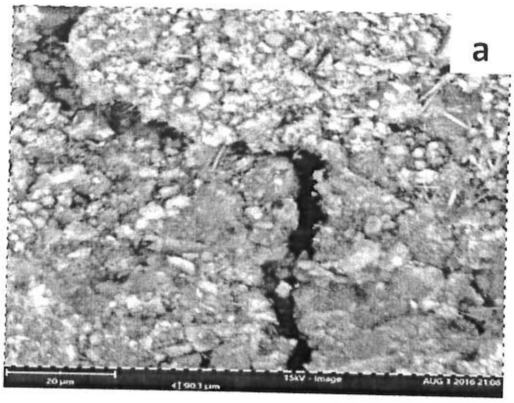
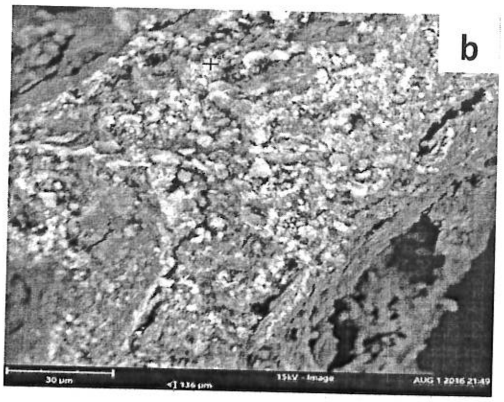


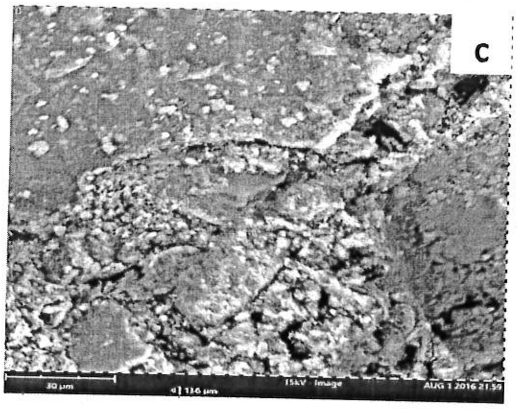
Plate 4.1: Optical Microscope Images of Laterite Based Composite (a) bamboo fiber after fracture (b) Surface of laterite based composite after fracture (c) holes generated as a result of fiber pull-out after fracture.

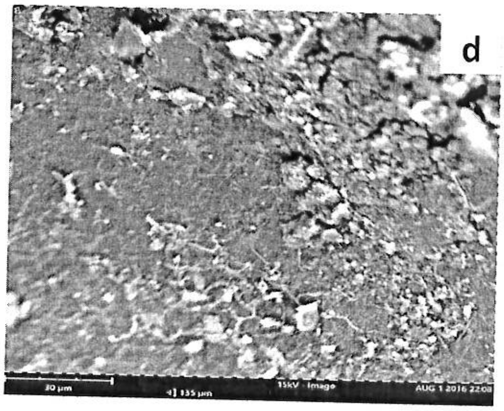
4.6 Scanning Electron Microscopy

The Scanning Electron Microscope images of the structure and morphology of the different samples are presented in plate 4.2 (a - f). Plate 4.2a shows SEM image of laterite and cement without bamboo fibers, the SEM image reveals a crack within the laterite based composite, this was due to absence of fibers to resist propagation of crack growth as compared to plate 4.2 (b-f), which had no cracks propagating throughout the laterite based composite, although cracks may be present and may not be able to propagate itself throughout the laterite based composite because of the bamboo fibers which are distributed in the composite. These bamboo fibers help in arresting cracks present and hinder the propagation of such cracks. Hence, the fracture toughness improves as the volume percentage of bamboo fibers increases.









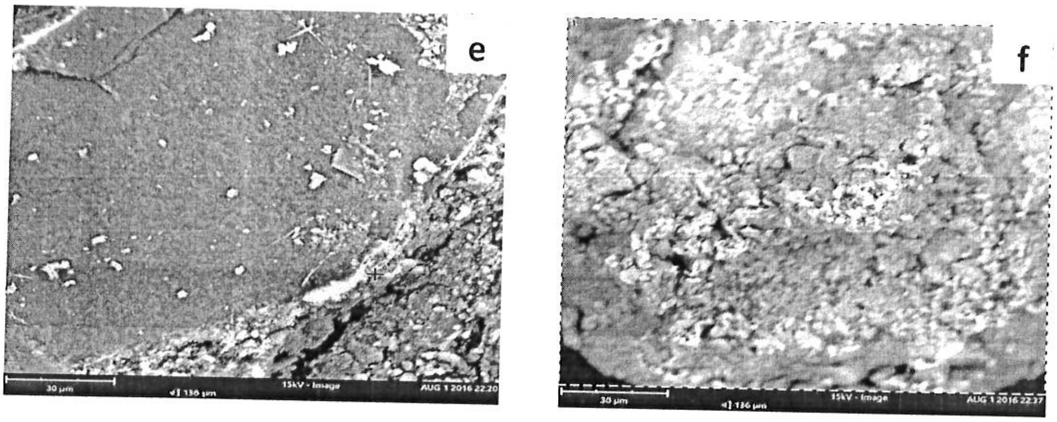
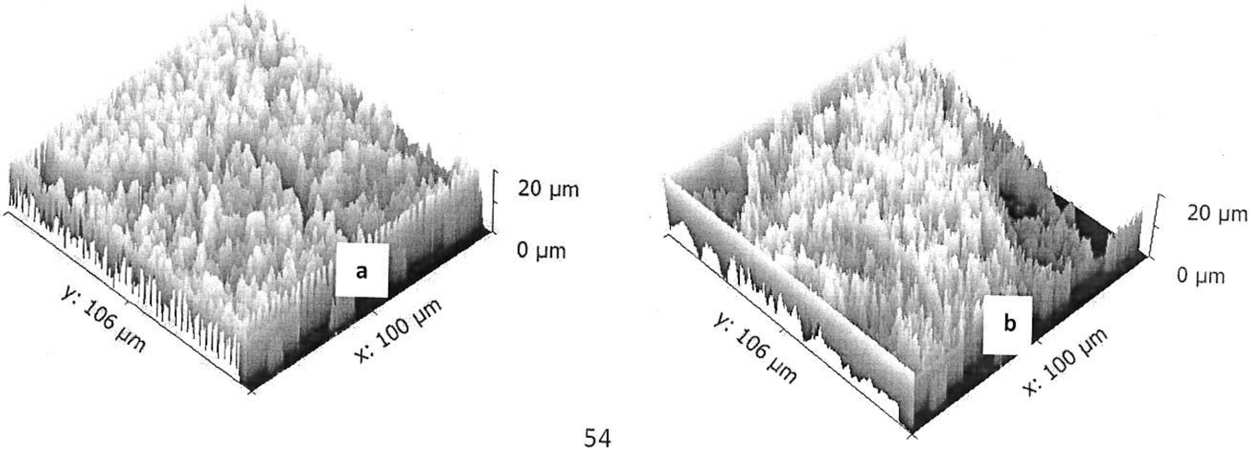


Plate 4.2: SEM Images of Laterite Based Composite (a) 0% bamboo fiber (b) 5% bamboo fiber (c) 10% bamboo fiber (d) 15% bamboo fiber (e) 20% bamboo fiber (f) 25% bamboo fiber.

4.7 Fractured Surface

Gwyddion Software was used to analyze SEM images of the laterite based composite to study the pattern of the fractured surfaces. Figure 4.10 (a-f) shows the different pattern of fractured surfaces. Figure 4.10a shows a brittle fractured surface with a crack cutting across the entire sample; this is attributed to the absence of bamboo fibers which are responsible for arresting cracks. For the other samples in figure 4.10b to 4.10f, a ductile fracture pattern was observed, for a laterite based composite, the pattern of ductile fracture will be rough, and while for a brittle fracture it will be smooth (Figure 4.10a). It is expected that there will be an increase in ductility as the volume percentage of bamboo fibers increases this is as a result of the increase in the resistance to crack propagation by the bamboo fibers.



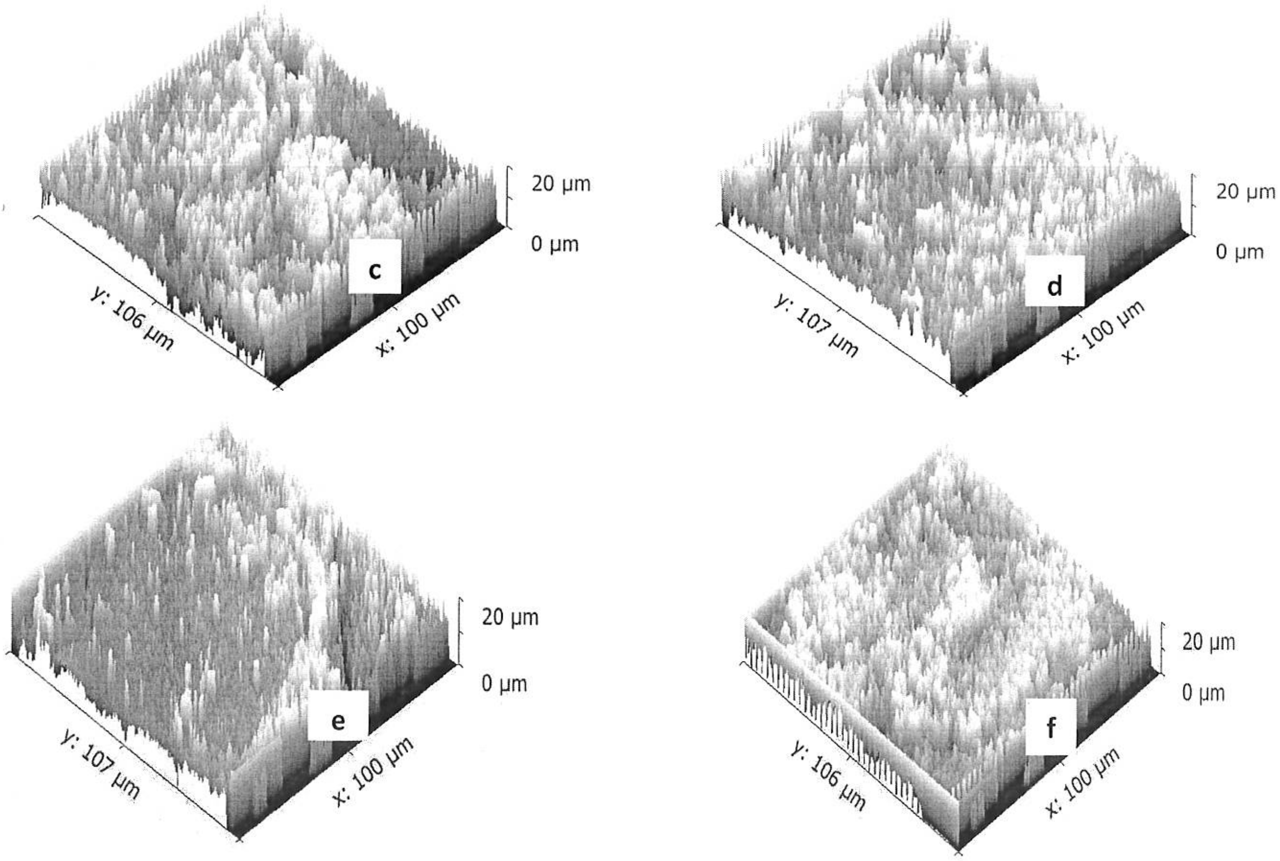


Figure 4.10: SEM Images of Laterite Based Composite analyzed using Gwyddion Software (a) 0% bamboo fiber (b) 5% bamboo fiber (c) 10% bamboo fiber (d) 15% bamboo fiber (e) 20% bamboo fiber (f) 25% bamboo fiber.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The compressive strength of the fiber reinforced laterite composite increased from 2.0±0.100 MPa to 5.0±0.250 MPa at maximum compressive strength. The sample with fiber volume of 25% has fracture toughness and flexural strength of 1.70±0.085MPa$\sqrt{m}$ and 2.25±0.113 MPa respectively.

The comparison between the control sample and other samples with fiber compositions show that the fiber present in the matrix act as crack arrester to the fractured part.

Optical and SEM images of the bamboo fiber reinforced laterite composite was then analyzed, also Gwyddion software was used to analyze the fracture surface of the laterite based composite, which showed brittle fracture surface for sample without fibers and ductile occurring in samples with fibers in them. EDS analysis showed trace element such as Al, Si, Fe and Br commonly found in laterite sand, while Ca, C, O which are also commonly found in cement. Furthermore, C, O were revealed as a result of the presence of cellulose in bamboo fibers.

The results obtained from this studies show that the bamboo fiber reinforced laterite composite at volume percentage of 25% can be used as building material. Although more work needs to be carried out to ascertain its stability when exposed to different environmental conditions.

5.2 RECOMMENDATION

1. There is need to optimize the process by increasing the bamboo fiber to 70% and study the compressive and flexural behavior at such addition.

2. There is need to study the compressive and flexural behavior of other clays reinforced with bamboo fibers and determining the toughening mechanism. Other natural fibers could also be studied to provide a range of composite materials for potential applications in affordable buildings.

3. There is the need to study the potential degradation in the chemical properties as a function of environmental exposure.

4. apart from cement which was regarded as binder for this work, other kinds of binders can be used in other to determine the mechanical behavior and chemical behavior of the composite material for potential application in affordable building materials.

5. There is a need to study the water absorption properties of the bamboo fiber reinforced laterite.

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