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Mechanical Optimisation of Earth-Based Composites Materials Reinforced with Treated Bamboo Fibres for Affordable Housing

Capstone Project

B.Sc. Mechanical Engineering

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APPLIED

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in fulfilment of the requirements for the award of Bachelor of Science Degree in Mechanical Engineering.

Benjamin Jnr Asare

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Name: ………………………………………………

Candidate's Signature: ……………………………………………

Date: ………………………………………………………………

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Name: ……………………………………………….

Supervisor's Signature: …………………………………………..

Date: …………………………………………………………………

DEDICATION

I dedicate this work to the progress and development of my beloved country, Ghana.

ACKNOWLEDGEMENTS

I am grateful to God Almighty for keeping me through this phase of my life. I will forever be grateful to Him for his grace and countless blessings.

Secondly, I would like to thank my supervisor, Dr. Danyuo Yiporo, for his constant support and guidance throughout this work. His knowledge and skills in this research proved to be very needful for the completion of this work.

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To myself, I'm just proud that I was able to achieve this. This work is indeed for God, Family and Country. Thank you, God.

ABSTRACT

This project presents an extensive characterization of laterite-cement-based matrix composites, reinforced with chemically modified bamboo fibres. The project is aimed at reducing the cost of building blocks, thereby reducing the amount of cement used through the addition of the bamboo fibres and laterite soil as potential substitutes. Fibre removal and chemically modification was first explored by soaking slabs of bamboo in 5 wt.% NaOH for 14 days. Mechanical characterizations were also carried out with MTS universal testing machine to explore the optimal properties of the composites. Optimum results were obtained at 80 wt.% laterite (L) to 20 wt.% cement (C). Both (80 wt.% L+ 20 wt.% C) were mixed and fused with 20 wt.% of bamboo fibres. This mixture ratio produced the best tensile and compressive results. It also provided as well, a good water absorption rate. Results were then discussed for possible structural applications such as enhancing low building blocks for rural communities in Ghana.

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1.0 Chapter One

1.1 Introduction and Background Studies

Composite materials are generally obtained through the combination of two or more different materials. The different combinations then give rise to different phases, which are often separated by a distinct interface and the overall effect enhances the mechanical properties of the new structures [5,6]. Composite materials are therefore characterized by; high fatigue strength, low weight, good resistance to corrosion [5,6], resist abrasive wear, improved hardness and impact strength [7].

Composites materials have been used in most engineering structural applications. For instance, Asian countries like India, Indonesia, China and Japan have made great use of fibre reinforced components in their modern building technologies [1,2,3]. The developments in composite materials after meeting the challenges of the aerospace sector have cascaded down for catering to domestic and industrial applications [3,4]. Composites, the wonder materials with light-weight; high strength-to-weight ratio and stiffness properties [2] have come a long way to replace conventional materials like metals, wood, etc. Material scientists and engineers all over the world focused their attention on natural composites reinforced with fibres obtained from jute, pineapple, coir, bamboo, sisal, banana, etc. primarily to cut down the cost of raw materials. The efficiency of fibre reinforcement depends on achieving a uniform distribution of the fibres in the concrete. [3]

1.2 Problem Definition

Several industrial processes result in carbon dioxide (CO_2) emissions. CO_2 emissions can occur during cement production, primarily through the calcination of limestone ($CaCO_3$) into lime (CaO). This is shown in the reaction equation (1). These two compounds ($CaCO_3$ and CaO) are basic materials used in the production of cement, iron, steel, and glass [8].

$$Limestone\ (CaCO_3) + Clay\ or\ Sand\ (Si) + Heat \rightarrow Cement\ (CaO, SiO_2) + CO_2 \quad (1)$$

The concerns for the emission of greenhouse gases into the stratosphere therefore calls for a reduction in the utilization of cement products and hence the possibility of using alternative materials in structural construction [8].

Concrete materials are heavily used as a building apparatus. Though concrete materials have outstanding features, [1] the material or composite begins to develop cracks on its surfaces [1,2] These cracks, in the long run, propagates deep down into the material until they overcome the micro strain limit [1,3]. Due to the cracks, water vapour and aggressive materials penetrate and cause the corrosive attack to the steel reinforcement [1]. Prolong hours of this demise can damage the composite.

The current research work is focused on harnessing local materials (chemically modified bamboo fibres) as reinforced materials for Earth-based matrices building materials the mechanical properties of the concrete-based composites, would be optimum to enhance the strength of building materials.

1.3 Objectives of the Project Work

The main goal is to explore the use of chemically modified (treated) bamboo fibres as a reinforced phase into Earth-based matrices (concrete with low cement content) to a desired hybrid composite material for building and construction purposes. This work would be carried out by achieving the following specific objectives:

- Kinetics of chemically modified bamboo fibres with NaN OH and KOH.
- Mechanical optimization of chemically modified bamboo fibres for reinforcements.
- Determination of critical fibre length through fibre pull-out test to optimize the mechanical properties.
- Mechanical characterization of composite-based materials: stiffness, tensile strength, flexural, harness, impact test, modulus of resilience, etc.
- Chemical stability studies of composite-based materials at different ph.
- Determination of sound reduction and thermal resistance of composite-based materials.
- Crack bridging and fracture toughness of reinforced composites.
- To evaluate the post-cracking load carrying capacity.
- Optical characterisation and failure mechanisms of fractured surfaces.
- Test and evaluate the water absorption rate of the bamboo fibre reinforced composites.
- Discuss the implications of the mechanical properties for the design of low-cost building materials.

1.4 Motivation and Project Justification.

In other to compete with the global world in building and structural developments, material selection and reinforcement is very important. There is growing importance in the field of research on the use of natural fibres for building [9]. Cutting down cost in this growing industry of building is becoming a needing demand. Plant fibres are generally more environmentally friendly as compared to synthetic fibres such as polymers. Significantly, the cost of bamboo fibres is cheaper as compared to concrete composites [5].

It must be acknowledged that Ghana has a growing housing financing sector as reported by the Centre for Affordable Housing Finance in Africa [10]. The report also suggests that with an urbanisation rate of 3.51 percent, the demand for affordable housing will continue to rise for both rental and buying purposes [10]. The depreciation of the Ghana cedi has also led to a high cost in building materials. This is due to the high cost of importing-raw materials and machines [9,10,11]. These figures running along with alarming birth and growth rate of the country's populace, there is a need for intervention concerning a reduction of housing units and building costs. Ghana statistical information regarding population shows growth rate and birth rate of 2.17% with 30.5 births/1000 people in the population [12]. The major highlight of concern is the fact that the age structure of the country has more than half of the populace between age 15 – 54. Therefore, a relevant conclusion can be made on the fact that housing need projections will be on an upscale [11,12].

The bamboo sector in the country faces a lot of challenges currently attributed to deforestation, farming activities as well as cutting down of bamboo for constructional activities. The pharmaceutical, chemical and water treatment fields transform bamboo fibres into activated carbon used in the treatment and purification of medicinal elements in the health centre. Other rural settings have also successfully used bamboo raw materials for soil stabilisation, furniture, household wares, weaving, carving, etc. [12]. These activities though create employment for the Ghanaian people, it still does not provide much economically to the state, hence making it clear that the skill and technology gap in the bamboo sector needs to be addressed.

Bamboo is a natural plant that is in readily available in Ghana, mostly in the Western Region of Ghana. It is majorly used as scaffolds during construction due to its higher stiffness. Most farming communities' use mud and thatch housing type and reinforcement with bamboo fibres could offer great help in extending the shelf life of the local housing system in Ghana. However, its utilization as natural fibres for Earth-based structures has not been properly explored. Currently, the country can boast of about 400,000 hectares of the bamboo plant [9].

In building green economies, bamboo can serve as a step to achieve this model. Currently, cement is the dominant material used in building and making concrete. Cement industries across the continent are making great strides in their businesses. Nevertheless, this has taken a great toll on the environment as cement production produces a lot of carbon dioxide into the atmosphere. The process involves the use of limestone and clay to produce cement. The tons of carbon dioxide being released into the atmosphere every day affect the global temperatures also known as global warming. This is caused by the depletion of the ozone layer from the emission of carbon dioxide. The equations below show the process in their chemical form [8]:

$$CFCl_3 + UV\ Light \rightarrow CFCl_2 + Cl \qquad (2)$$

$$Cl + O_3 \rightarrow ClO + O_2 \qquad (3)$$

$$ClO + O \rightarrow Cl + O_2 \qquad (4)$$

From equation (3), the Chlorine atoms

In the long run, the increase in the global temperatures will affect weather patterns and hence affect the climate [8].

CHAPTER TWO

2.0 Literature Review

2.1 Background Study of Composites

The term composite is used to describe a composition of various materials, where one of the materials is primarily a matrix also referred to as continuous phase. This matrix is enclosed or covered with another reinforcement which is the secondary phase. Usually referred to as the discontinuous phase [13,14]. Composites and its usage have been in existence ever since and have existed in various forms. We have natural composites, existing in both animals and plants. The human bone is a type of composite made up of hard but brittle material called hydroxyapatite or calcium phosphate [14].

Example of some uses of composites is the use of mud for making bricks. Mud on its own has low tensile strength and will break when the least stretch is applied to it. By mixing it with straws, the strength of the composition increases greatly and can resist both squeeze and tear [14].

Not all composites are cheap though, as the various components used to achieve them are usually excessively expensive. A classic example of this is the making of cement production for concrete on a large scale is increasingly becoming expensive by the hour, giving relevance to this study of mechanically optimising bamboo fibre reinforced composites for building materials.

2.2 Composition of Composites and Natural Fibres.

Primarily, a composite is made up of a matrix and a reinforcement. The matrix can also be grouped into three materials. These groupings include; metallic matrix, macromolecule and inorganic matrix and the mineral-based matrix [13].

The reinforcement phases are grouped based on their particle geometry in their natural form. These groupings include; particulate reinforcement, fibre reinforcement and skeletal reinforcement [13,21]. For this research paper or study, we are going to discuss more on the fibre reinforcements. Naturally, fibres have more strength as compared to the dense materials of the same nature. The unique feature or characteristic of fibre is the fact that its strength depends mainly on its cross-section [13]. Decreasing cross-section of the fibre increases the fibre strength.

In perspective, Natural fibres have particulate properties that make them stand out. Some of these fibres include cotton, spider fibre, flax, jute, hemp, coconut, bamboo, etc. the spider fibre in perspective can achieve a tensile strength of 1.140 GPa when the diameter is 0.02-7 micrometres. Basically, these fibres are mostly made up of cellulose and are biodegradable.

Natural fibres have some advantages that made them relevant in production over time. Natural fibre composite to be precise [15] are fit for artefacts and designs that need minimum weight, finite tolerances and simplified production and operational techniques. The use of these fibres in automobile sectors is on the rise. An example is the use of coconut fibres in the automobile industry. It is used as cushions and other body restraints parts in vehicles [15,16]. Other notable merits of these natural fibres include the use of Abaca fibre in making carpets, tea bags, ropes, etc [15,16,17]. The sisal fibre which is majorly available in Southern Mexico is used to make ropes, footwear and hats for economic gains [15,16]. Bamboo is one of the world's fastest growing plant (in terms of growing time), it is highly becoming important in many production-based countries. Countries like Ghana have a wide land area bamboo.

2.3 Mechanical and Chemical properties and Treatments of Bamboo fibres

The research paper [15] explores the mechanical and chemical properties of modified natural fibre composites. The research was done to reflect parameters such as matrix materials, volume fraction of fibre, filler materials, surface treatments and orientation of fibres [15]. In perspective, this paper is also going to discuss bamboo fibre as a composite reinforcement for building materials and in so doing will highlight some of the mechanical characteristics as well as the chemical processes being used.

Bamboo fibres have low density, high stiffness and strength [15]. Chemical modifications through the addition of alkali treatment at elevated temperature was observed and recorded at room temperatures, 40 ℃, 80 ℃ and 120 ℃ with a ratio of NaOH (4-8% by weight) [16]. These results prompted comparison between treated and untreated bamboo fibre and it was observed that [15,16] there exist a poor bonding in the matrix and fibre alignments. This resulted in multiple loosed fibre pull-outs [16,15]. Another observation that resulted from the treatment was the presence of breakages in the matrix, but fibre collapse was low, highlighting the fact that the overall tensile strength of the composite was increased. [14,15,16]. The NaOH used in this experiment was tested between weight percentages between 4%-8%, with the optimum treatment that yielded the best results to be 6% weight [15,16]. At this percentage, the alkali treatment resulted in the best chemical properties. It is worthwhile to note that at 8% weight, it was observed that the mechanical properties of bamboo fibre undertook a heavy fall. This was due to delignification and degradation [15] which destroyed the bamboo fibres [15,16]. Delignification, as defined by the Mariam-Webster definition, is the removal of lignin from woody tissue by a natural enzymatic or industrial chemical process (Mariam-Webster, 2018). Fibre Degradation can also be defined as the mechanisms by which polymers or fibres degrade. This can occur through biodegradation, hydrolysis and photodegradation [19].

Using another chemical test for design altercations, another research work altered mechanical properties of bamboo fibres with solutions of KH560 solution and Maleic anhydride (MA) [15,16,17,18]. The stiffness of bamboo fibres was immediately increased after the treatment with the alkali solution whereas the MA grafting also helped to improve both the stiffness and ductility of the composites [15,17,18]. These improvements were valid due to the observation made from a scanning electron microscopy (SEM) analysis to show effective bonding between the matrix and fibre. The SEM analysis gave results of the tensile fracture of poly-L-lactide (PLLA) reinforced with untreated bamboo cellulosic fibre (PLLA-BCF) [15,17,18]. The surfaces of the samples became very smooth, with interfacial debonding [15,17]. Also, PLLA-NBCF (poly-L-lactide-reinforced NaOH-treated bamboo cellulosic fibre) and MA-PLLA-BCF composites resulted in well-trapped fibres which rather gave a better indication of interfacial bonding [15,17].

Another work was carried out with unidirectional bamboo reinforced epoxy and jute composites as the test samples. The samples were prepared by the vacuum technique [15]. After the process, observations made showed that the mechanical characterisation of the composites resulted in bamboo composites having a higher tensile and flexural strength than jute composites [15,17]. The recorded tensile strengths were 392 MPa in unidirectional bamboo whereas its flexural strength recorded in both longitudinal and transverse distributions of fibres were 226 MPa and 11.86 MPa, respectively.

With regards to heat treatments at elevated temperatures, the flexural and tensile strengths were improved minimally at 80 ℃ [16]. On the contrary, a significant decrease was observed in all mechanical properties for the bamboo composites at a temperature of 120 ℃ [17].

2.4 Loopholes and Limitations:

The use of natural fibre composites (NFC) has proved to be effective and can enhance most materials in their use in terms of mechanical properties [15]. However, considering the drawback in NFCs concerning their hydrophilicity (i.e. how it reacts to water), it limits the use of these fibres. In the chemical modification, deductions show that the presence of liquid in fibres could destroy the fibre composition hence limiting the testing procedures. The presence of lignin in these fibres also cause them to react to sound more and thus, causing them to vibrate to high-frequency applications [15]. This also limits its use in industries such as aeronautics, structures, automobile, etc. [15]. With this regard adding fillers such mud, clay and ash could vary the material composition of these fibres and will, therefore, go on to help change some of these defects.

2.5 Scope of Work

The goal of this project is to establish and optimize the mechanical properties of a chemically modified bamboo fibre reinforced composite. Chapter one presents a brief background relating to composite materials. The objectives of the projects were clearly outlined as a guide to achieve the various tasks in this work. The literature review was extensively presented in chapter two. Chapter two also presents some limitations with NFC (Natural Fibre Composites) and their use in reinforcements. In perspective, chapter three basically define materials and the different methodologies involved in composite design and fabrication, testing/characterisation.

In saying this, the scope of chapter three will range from the designing of the composite to fibre alignment, fibre length and the appropriate fibre pull-out test. Casting and moulding methods will also be described. Chapter four essentially describe, and present results of the tests and procedures carried out in chapter 3. Observations, discussions and conclusions on the specific tasks and objectives will be highlighted. The last chapter (five) discusses the implications of results, establish recommendations for future work for improvement as well as conclude on major findings in the work.

CHAPTER THREE

3.0 Materials and methods

3.1.1 Materials

Bamboo was sourced from farm lands in Accra, Ghana, in the Kwabenya district. The matrix, which was Laterite was dug from Berekuso in the Eastern Region of Ghana. Sodium hydroxide (NaOH) and distilled water were procured from chemical shops in Accra. Cement (Diamond) was also obtained from a wholesale shop in the Berekuso township.

3.2 Experimental Procedures

3.2.1 Bamboo Fibre Preparation

Bamboo sticks were treated with 6 wt.% NaOH for a week before obtaining their fibres by physically drawing them out (Fig. 3.1). These fibres were also resoaked in the same NaOH solution to remove excess lignin.-The newly obtained fibres were then dried in the sun for 7 days to completely remove the water content in the fibres. These samples were all tested for their mechanical properties using the MTS tensile test machine at the Mechanical Lab at Ashesi University.

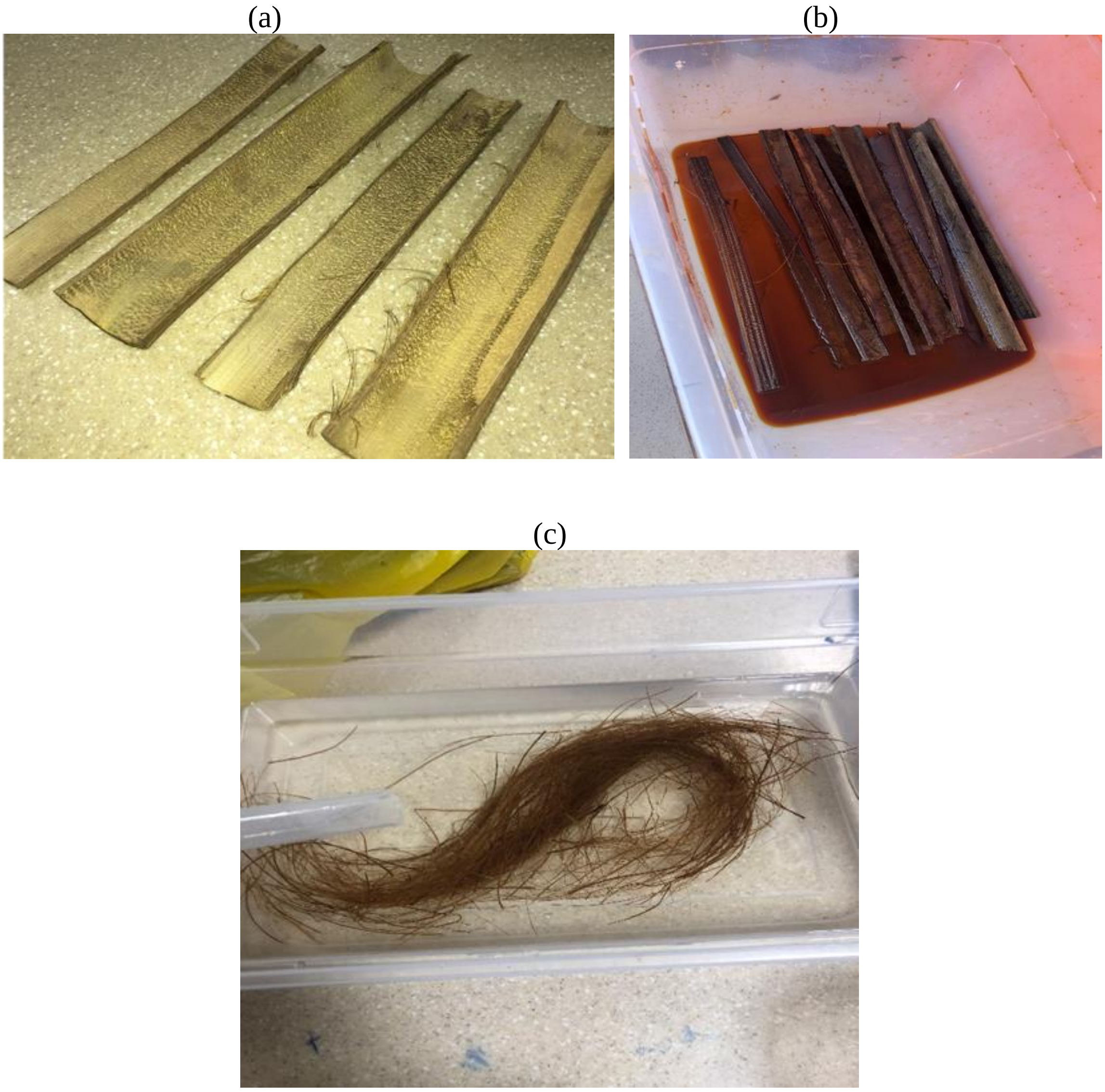


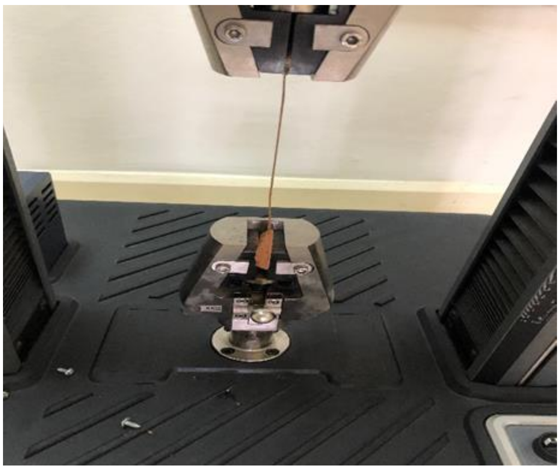
Figure 3.1: Fibre Preparation and Removal: (a) Bamboo Cut into Logs and (b) Prepared with 6 wt.% NaOH for the Fibre Treatment, and (c) Removed Fibres.

3.3.1 Fibre Pull-out Test

Fibre pull-out tests are carried out in this work to determine the critical length or debonding length of the fibres. During the pull-out test, the fibre matrix composite samples undergo three different phases which will be investigated. These three phases are the initial debonding and sliding phase, the load drop at maximum fibre stress and lastly the sliding and pull-out phase. The mentioned phases above describe the different stages during the pull-out of the fibre. The setup of the pull-out test had one end of the matrix clamped in the tensile test machine, with the opposite free end glued to cardboard in a whole of about 0.2 mm held by the two jaws of the tensile machine with the extensometer and load cell connected. The speed for the pull-out was set at 0.2 mm/min. This gave a graph of the pull-out resistance over the period in which the pulling was achieved. Further analyses on the results produced can lead to a study of residual stresses in the fibre-matrix component and other interfacial bonding properties of the bamboo fibre placed in the matrix. For the purpose of this work, the effects of the debonding energy, the sliding shear and Poisson effects will be neglected to make the modelling the mathematical calculation for the critical length easy, since that is our focus for this test.

(a)

(b)



(c)

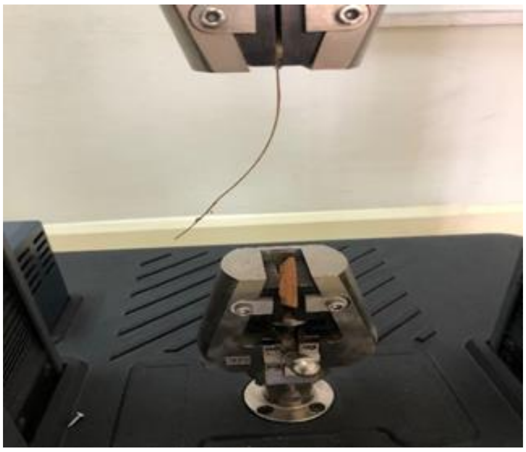


Figure 3.2: Fibber Pull-out Test: (a) Specimens with Embed Fibbers in Laterite-Cement Matrix, (b) Sample Under Mechanical Test, and (c) Fibre Pull-out at Maximum Load.

3.3.2 Determination of Fibre Critical Length

Fibre Critical length can be obtained after a successful pull-out test. Here we take into consideration the shear yield strength of the fibre and the ultimate tensile strength of the fibre. For a given area the critical fibre length can be obtained by considering the diameter of the body as it expands. To determine the critical length, by mathematical modelling and other deductions, the equation was arrived at [31]:

$$l_c = \frac{\sigma d}{2\tau} \quad (3.1)$$

where d is the diameter, σ is the fibre ultimate tensile strength and τ is the fibre yield strength. The fibre shear strength is also obtained from [31]:

$$\tau = \frac{F}{2\pi dnh} \quad (3.2)$$

where n is the number of fibres F is the maximum debonded load, h is the fibre embedded length.

3.4.1 Matrix and Composite Preparation

The laterite was crashed from their lumpy state to almost fine course using a sieve of about 180 µm. The cement was also obtained in its rightful temperature for use in this experiment. The mould used to make the bricks was made of wood with dimensions 10 cm x 10 cm x 10 cm for the brick used for the compressive test, whiles bricks used for the flexural test, had their moulds dimensioned to be 60 cm x 10 cm x 10 cm. The matrix composition comprised of 80 wt.% laterite plus 20 wt.% (Table 3.1). Summary of the contents of laterites, cement and fibre compositions in the designed composites are presented (Table 3.2)

Table 3.1: below shows the Cement – Laterite Matrix composition by weight.

Sample	Laterite (% weight)	Cement (% weight)
1	80	20

Table 3.2: Cement – Laterite Matrix weighted against Bamboo fibres.

Sample	Cement + Laterite (% Weight)	Bamboo Fibre (% Weight)
1	95	5
2	90	10
3	85	15
4	80	20
5	75	25

Laterite and cement were first measured, prior to adding bamboo fibres, carefully and strategically to the mixture before water was added. Thorough mixing of all three components were done to achieve uniform mixtures. The mortar was then placed in a head pan and taken in batches to fill up the given mould. Blocks were moulded with bamboo fibres, varying from 5 wt.% to 25 wt.% (Table 3.2). Blocks with no fibres served as controls samples and thereafter, allowed to be cured over some time.

3.5.1 Swelling Kinetics/Water absorption rate

The swelling test is done to verify the amount of water the bricks can hold or absorb over a given time. For this work, the water absorption test was performed on the reinforced blocks with the bamboo fibre by immersing the blocks in water for 15 hours. The percentage by mass of the absorbed water in the reinforced block is verified as compared to its dry state. The equation below was used to calculate the water absorption rate [30].

$$W = \frac{M_2 - M_1}{M_1} \text{ x } 100\% \qquad (3.3)$$

where M_2 is the mass of the dry block, M_1 being the mass of the wet block and W is the water absorption rate in percentage.

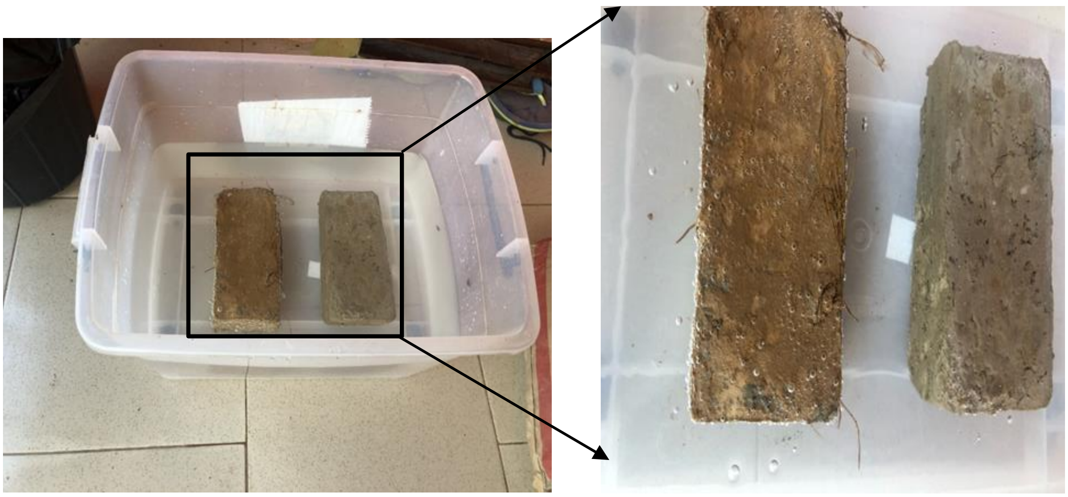


Figure 3.3: Composite Blocks Undergoing Water Absorption Test.

3.6.1 Mechanical Characterisation

For the mechanical characterisation, we undertook various mechanical tests on the fibres, matrix as well as the composites. Test on compressive and flexural strength were carried on the fibre reinforced composites. The dimensions for the composites used in the various tests was 100 x 100 x 100 mm as the standardized sizes for blocks. The compressive and flexural strengths of the composites were, respectively given by [refs]:

$$\sigma = \frac{\mathrm{F}}{\mathrm{A}} \quad (3.3)$$

$$\delta f = \frac{3\mathrm{FL}}{2\mathrm{BD}^2} \quad (3.4)$$

where F is the applied load in KN, L is the Length of the fibre, B is the breadth of the sample and D is the thickness of the sample, and A is the cross-sectional area of the sample.

The fracture toughness was also found using the formula below [refs]:

$$K_I = Y\sigma\sqrt{\pi \mathrm{a}} \quad (3.5a)$$

$$Y = f\,\frac{\mathrm{a}}{\mathrm{w}} \quad (3.5b)$$

where Y is the crack length, w is the width of the sample and a is the total notch length.

For the bamboo fibres, mechanical tensile tests were carried on the extracted bamboo fibres in the bamboo stick. For the sample size, we had various chemical solutions as well as concentrations to verify the effects on the fibres when these different conditions are applied to them.

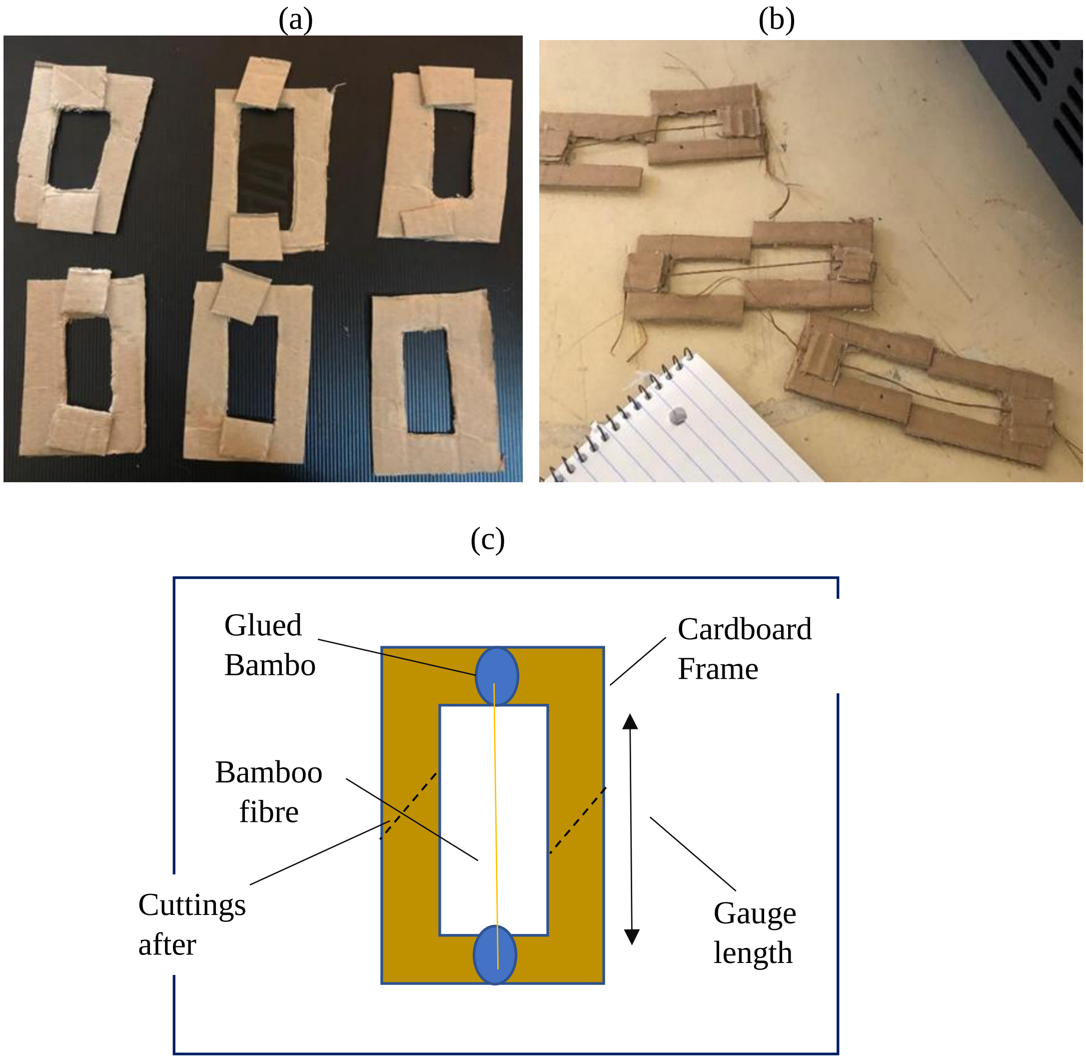


Figure 3.4: Schematic representation of the paper frame for the single-fibre tensile test: (a) Design of cardboard, (b) Fibres glued on Cardboard, and (c) Illustration of Test Sample.

3.7.1 Optical Characterisation

Optical images were taken with a microscope (digital microscope model U800X, Jingou-tech, Shenzhen, China). It was used to study the nature of both the bamboo fibres, the bamboo fibre reinforced laterite blocks and the raw concrete blocks. Morphological studies on these samples were discussed. These studies were used to analyse and study the nature of the fractured samples used in the study.

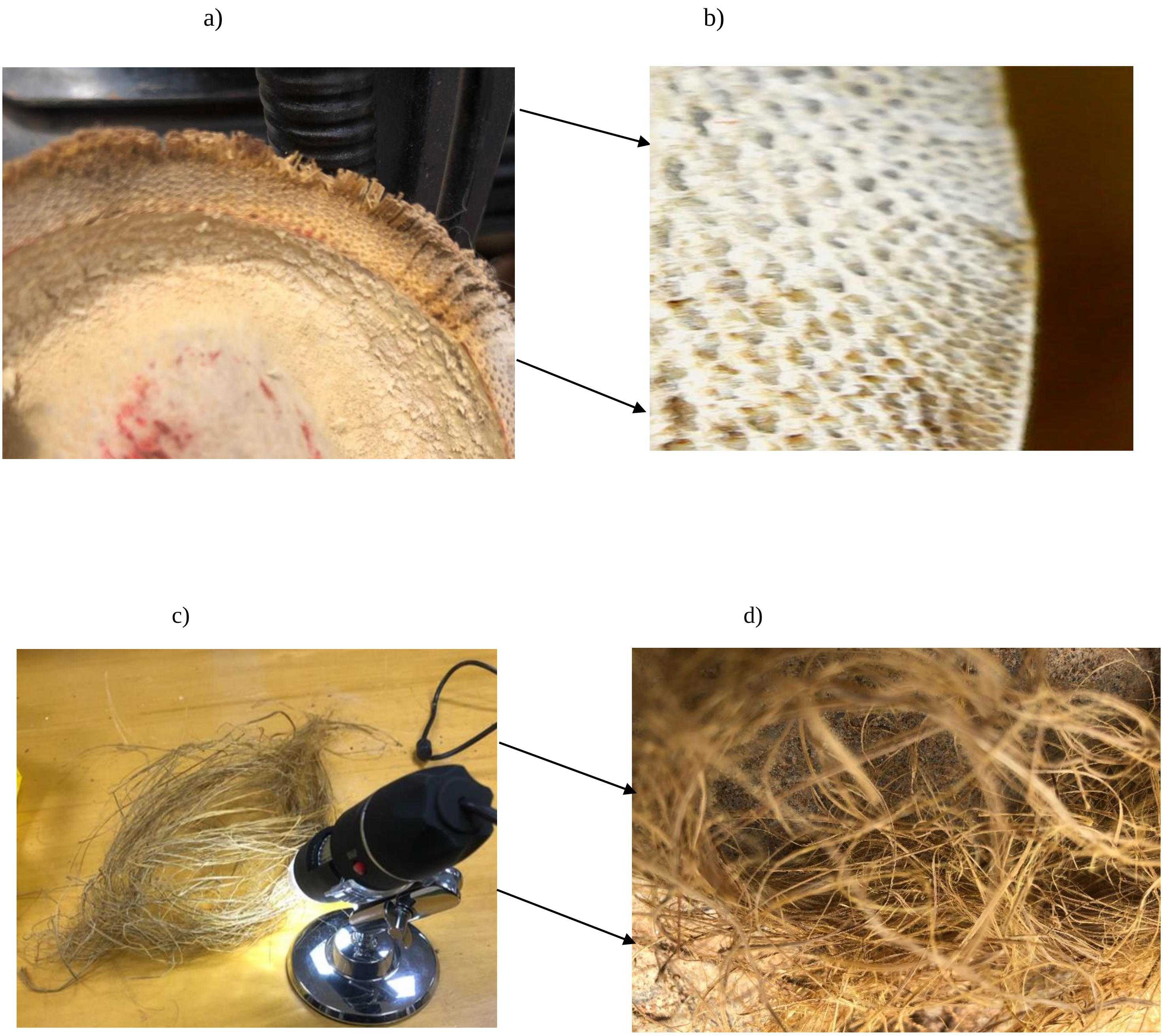


Figure 3.5: Optical imaging: (a) Cross-sectional View of Bamboo and (b) Optical Image of Bamboo Fibres. (c)Cross-sectional View of fibres and (d) Optical Image of fibres.

3.8.1 Thermal Characterisation

The value of heat transfer by radiation (Q) in Accra Ghana was obtained from to be 5.060 kwh/m^2 (from the atmosphere) or 5.180 kwh/m^2 (from satellite point) [29].

The conduction equation used was given by [28]:

$$Q = \frac{kA\Delta T}{\Delta x} \quad \text{………………….} \quad \text{(Equation 3)}$$

where A is the area of the block, ΔT is the change in Temperature, k is the thermal conductivity and Δx being the thickness of the block. The area of the block calculated from finding the surface area (L x B = 10 cm x 6 cm) was 60 cm^2 . Converting this to squared metres gives 0.0006 m^2 as the area. The thickness of the block was 0.006 m^2. The outer temperature represents the temperature recorded as Temperature 1 from the graph and the Temperature 2 was the temperature recorded below the block from the inner surroundings as shown in (Fig. 3.2.8a and 3.2.8b) This was done for the composite block, as well as the normal block.

(a) (b)

Figure 3.6: Illustration of Experimental Setup for the Determination of Heat Transfer Coefficient.

For the composite block, k was found from the rate of heat conduction (equation 3). The Change in temperature at the top of the block and at the bottom were 48 ℃ and 41 ℃, respectively.

$$k = \frac{Q\Delta x}{A\Delta T} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (3.)$$

The value for k was for the normal block was also obtained following similar calculations.

3.9.1 Hardness Test

Hardness test was performed on the blocks to determine how they resist indentation when pressed. The level of the indentation shows how strong the material can be. The hardness test was executed by use of a High Definition (HD) tester. This tester ranges from 0-100HD max. For this test, various indents will be made at different points across the same surface of the block; then an average will be taken to get a more accurate value of the hardness of the composite material.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.0 Mechanical Characterisation.

The removal of the fibres achieved proper interfacial bonding between the matrix (Laterite) and the fibres.

4.1.1 Effect of NaOH on Fibre Properties

From the tensile tests performed on fibres that were soaked multiple times and fibres that were washed with two percent detergent after treatment. Bamboo fibre samples, it was observed that the resoaked samples after removal in NaOH had a steeper gradient as compared to the extra soaked samples. These samples were all worked within 5 wt.% concentration of NaOH solution for different periods. The Young's modulus was obtained from the gradient of the elastic regime of stress versus strain. The resoaked in NaOH had Young's modulus of 28MPa, while the rewashed reported a Young's modulus of 13.7MPa. Samples that were soaked in NaOH after 20 days failed to show a proportional graph in the study, thereby were not plotted. That also shows that when a NaOH salts diffuses with higher concentration onto the fibres, it turns to lower the strength and the Young's Modulus.

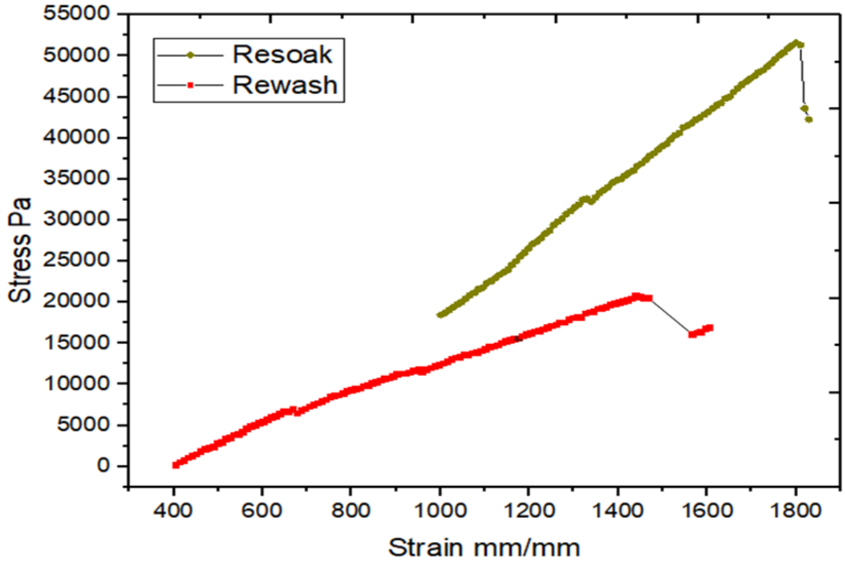


Figure 4.1: Mechanical Tensile Test of Fibres and the Effect of NaOH.

The Stress-Strain graph shown in the above shows the peak or ultimate tensile strength value of bamboo fibres that were resoaked in an extra solution of NaOH of 55 MPa and fibres which were washed with 2% detergent after treatment had peak stress of 20 MPa. From figure 4.1 it is visible that the Modulus of the resoaked fibre is higher than that of the rewashed fibre. This can be deduced from the steepness of the graph produced.

With respect to the type of fibre bonding bamboo fibres illustrate, the resoaked bamboo fibres presents clean fractures in dominant parts as compared to splitting or defibrillation. For the acidified fibres which were not graphed, they were all fractured through the defibrillation process which made them break after some few seconds from subjecting them to the tensile stresses. Discussions at the fibre pull-out test section of this chapter will illustrate and talk more on the various types of bonding failures the fibres can exhibit.

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	1.81522E10	9.07609E9	176.21713	0
Error	591	3.04396E10	5.15052E7		
Total	593	4.85917E10			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

R-Square	Coeff Var	Root MSE	Data Mean
0.37357	0.61976	7176.71049	11579.81027

Means Comparisons

Tukey Test

	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
Strain 2 Strain 1	13172.64285	721.28654	25.82736	0	0.05	1	11477.9049	14867.3808
Strain 3 Strain 1	3870.13277	721.28654	7.5881	3.41931E-7	0.05	1	2175.39482	5564.87072
Strain 3 Strain 2	-9302.51008	721.28654	18.23926	0	0.05	1	-10997.24803	-7607.77213

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

Homogeneity of Variance Test

Levene's Test(Absolute Deviations)

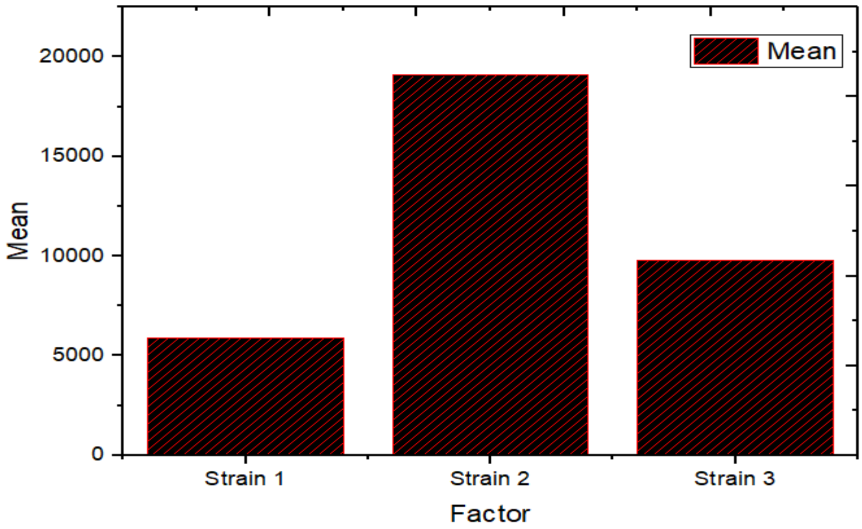
	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2.08447E9	1.04224E9	71.91845	0
Error	591	8.56472E9	1.44919E7		

At the 0.05 level, the population variances are significantly different.

Fig. 4.10 Shows Statistical data amongst the various Stress values of different the different fibre samples.

The results from the (Fig 4.10 above shows the major findings in the One way Anova test, as well as the Tukey test.

For the Variance Test amongst the three fibres used, the population variance for all fibres showed that they were all significantly different. The one way Anova test, at 0.05 level, it showed that the mean values for the various fibres also had a significant importance since they were all different.



Fig(4.11) summarises the mean values of the various fibres that were used for this test.

The graph was produced from the statistical tests done on Origin graph pad Pro bit 2017.

4.1.2 Compressive Strength

The results (Fig. 4.2), shows the outcomes of the compressive test performed on the reinforced composite blocks. These blocks were tested after 14 days of curing. It appears that at 0 wt.% bamboo fibre (control sample) in the block, had a higher compressive strength as compared to the fibre block at 5 wt.%. From 5-10 wt.% and beyond, an increase in the fibre content led to an increase in the compressive strength in general (Fig. 4.1.2a). However, the data recorded lower values of compressive strengths for 5 and 10 wt.% fibre compositions in the composite. The 25 wt.% bamboo fibres had the highest compressive strength meaning it is highly resistant to compressive forces and any applied stress. NaOH is meant to develop surface roughness that can prevent debonding. It then means that until such surfaces are formed, possibly beyond 15 wt.%, fibre pull-outs will be resisted

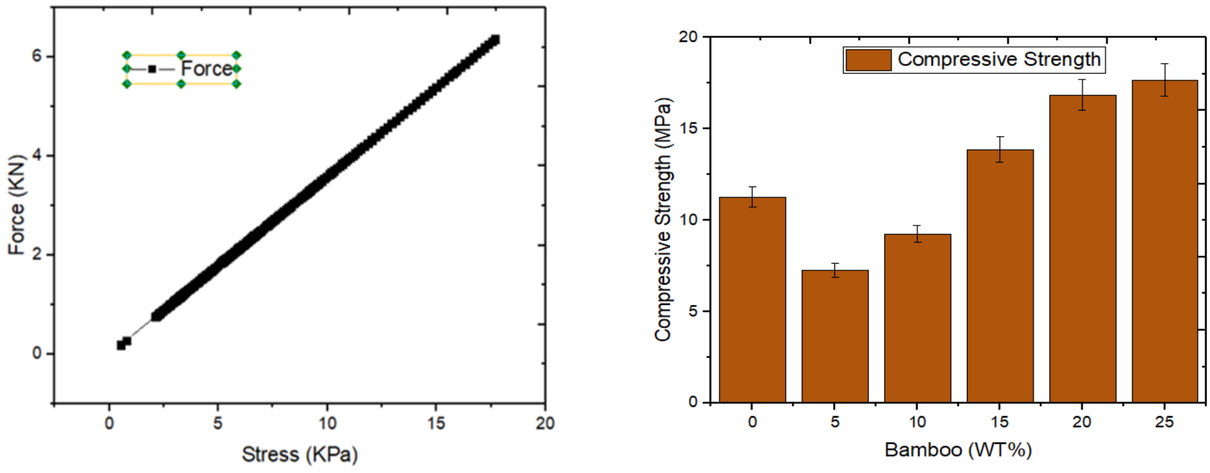


Figure 4.2: Effect of Fibre Weight Fraction on the Compressive Strength: (a) Force Applied Over the Various Samples and (b) Compressive Strength of various bamboo wt.%.

4.1.3 Hardness

Results from the hardness test was graphed (Fig. 4.6). The hardness values increase steadily from 15-20 wt.% fibre in the composite blocks. However, there was no significant difference in the hardness values. In the case where the hardness of the composite is higher than the control sample, it can be attributed to the presence of bamboo fibre mixed with the laterite soil, making the overall hardness of the composite relatively higher than that of the normal block. This also confirmed that the stiffness of the material is most likely affected by the fibres.

Another alternative way to verify this test is by use of the Mohr table or use of the Mohr scale where concrete has a hardness value of 3. The range of laterite and granite sand can be found between the ranges 5 to 7 as its hardness value.

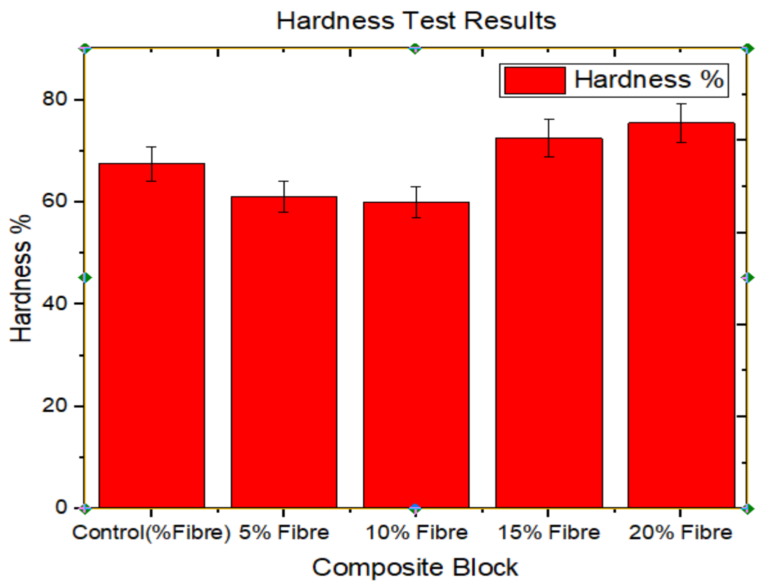


Figure 4.3: Hardness of Laterite-Based Composites.

4.1.4 Flexural Strength

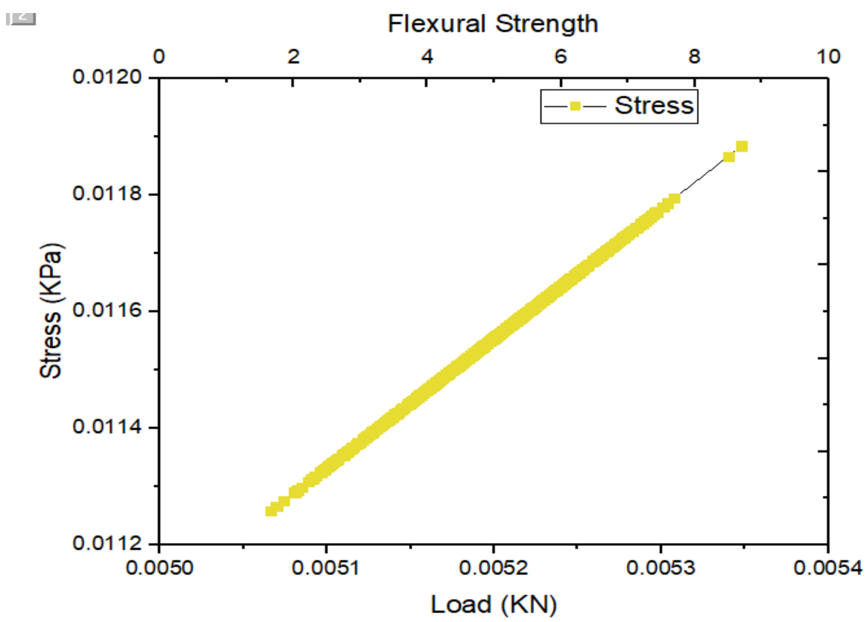


Figure 4.4:

Flexural Strength of Laterite-Based Brick.

The graph above illustrates the flexural properties of the fibre block at 20% wt. fibre. The composite block recorded 11.9 KPa. In ideal terms, an increase in fibre percentages shows a general increase in the flexural strength. The results compared to the work of Kalu[32] and Kolawole[29] shows a similar trend in the properties of fibres used as composites. The fibres in the block also arrested cracks thereby increasing the strength.

4.2 Optical Characterisation

Optical microscopy was performed on both Bamboo fibres and laterite-based composites, incorporated with bamboo fibres. The optical image of the fibres (Fig. 4.2) presents the bamboo fibres after chemical treatment with 5% NaOH. The diagram also reveals how some weak points in the fibre were broken down due to long hours of treatment.

Figure 4.5: Optical Image of Bamboo Fibres.

The figures below (Fig. 4.3 a-b) show the various properties and nature of the different type of blocks after they have been made with different compositions of fibres and other raw materials used. Homogenous structures were formed with even distribution of the fibres in the matrix. The matrix protects the fibres from direct exposure to environmental conditions, while the fibre, on the other hand, absorbed most of the lords transmitted by the matrix.

(a) (b)

Figure 4.6: **Composite Materials:** (a) Control Block Sample (with no Bamboo fibres) and (b) Sample Block with bamboo fibres.

In this composition, the absence of bamboo fibres created pores inside the cement block (Fig. 4.6a), making it relatively easier to break as compared to the sample with fibres as shown in Figure 4.6b. The total bulk density of the fibre reinforced laterite block was greater than that of the non-fibrous sample in a block (Fig. 4.6a). The lightweight of the fibres reduced the overall density of the composite material.

4.3 Water Absorption Test

Table 4.1 shows the results on the percentages of water absorption after the after 24 h periods. The results revealed a general increase in water absorption from 5% to 11%, which corresponded to the addition of bamboo fibres increment in the blocks. The absorption increased steadily from 5.8 (%) at 5 wt.% fibre to 10.38 % at 20 wt.%. There was little absorption (10.89 %) at 25 wt.% with no significant difference when compared with the 20 wt.% fibre composition. Figure 4.4 represents the plot of composite composition and water absorption (%). The trend shows that as bamboo fibres increases in the laterite-based blocks, the absorption rate increased. This means that, bamboo fibre increases the chances of water absorption in the blocks. The generally acceptable rate by governing standards of block production in Ghana is a maximum of 12 % and therefore the block does not exceed this rate since the highest was 10.9 %.

Table 4.1: Water Absorption.

Test	%Bamboo Fibre	Weight of Wet Block (g)	Weight of Dry Block (g)	Water Absorption (%)
1	0	2618	2478	5.6
2	5	2684	2537	5.8
3	10	2703	2549	6.04
4	15	2789	2555	9.1
5	20	2828	2562	10.38
6	25	2965	2668	10.89

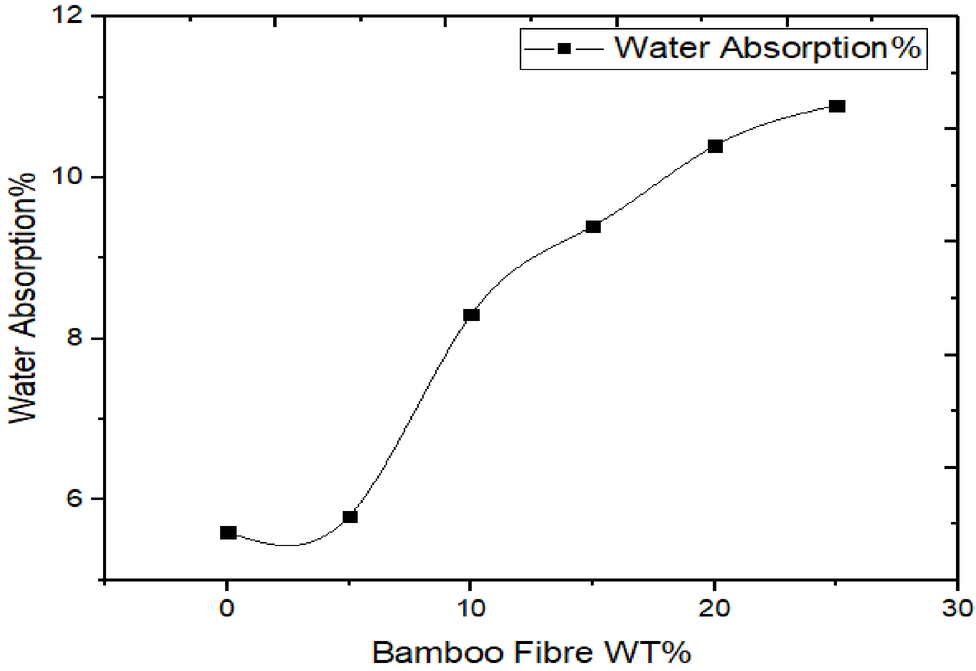


Figure 4.7: Weight Percentage of the Various Bamboo Fibre Reinforced Blocks.

4.4.1 Fibre Response to Pull-out Test

Fibre pull-out test (Fig. 4.6) revealed many results which defined the nature at which the fibre pulled out or break out occurred during the pull-out test. Three major failure modes are known to occur when fibre pull-out is carried out. These failures are matrix shear failure, fibre de-bonding mechanism, mixed failure mechanism. Concerning this work, the best fit mechanism which occurred was the mixed failure mechanism type. This meant that the energy absorbed by the fibre during the pull-out test reflects as the area under the graph of the stress to strain graph. This area under the graph mechanically represents the toughness of the bamboo fibre placed in the laterite matrix during the pull-out test. This paper will concentrate more on the modulus of resilience; thus, the toughness at the yielding point or the energy the bamboo fibre can absorb without getting distorted. To achieve that, we take the linear part of the graph and calculate the modulus of resilience by using the peak stress given by the graph. From the graph, the peak stress at the linear region is recorded as 51Mpa. This value will be used together with the Young's modulus equation to find the toughness of the material.

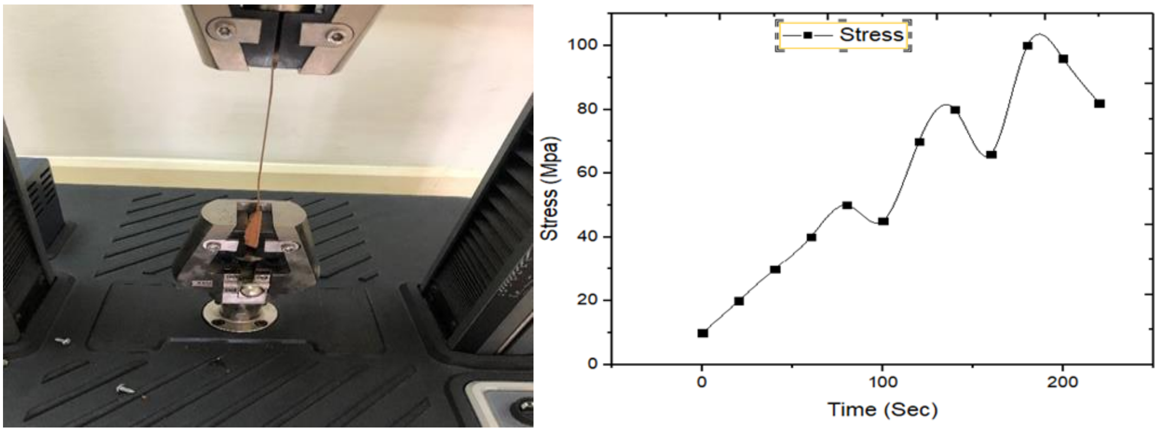


Figure 4.8: Fibre Response to Load During Pull-out Test.

Taking the yield stress (σ_y) as 51MPa, the yield strain was given as 0.103 mm/mm by the M.T.S tensile test machine. The Young's modulus of the fibre was estimated to be ~4.85 GPa. At the yield point, there's 0.2 % offset, factoring this value into the Young Modulus value gives a value of: 9.7Mpa. This value represents the modulus after the 0.2% offset. The new modulus value after the offset was used to calculate the elastic modulus of resilience. Thus, the modulus of resilience is 51.4Kpa, meaning the treated bamboo fibre can potentially absorb at the elastic point before it distorts.

4.4.2 Critical Length

For a single strand bamboo resoaked bamboo fibre, the diameter measured was 0.75mm, the ultimate tensile strength from the raw data provided was 6.722Gpa, with the yield at 0.2% offset being 13.4 kPa. From the methods described in chapter three, the critical fibre length was reported to be 19.4 cm.

This value gives an indication of the fibre length of bamboo that can be used in making the composite block to harness optimum strength from the fibre material. The embedded length of 19.4 cm was then used in the composite preparations.

4.4.3 Thermal Conductivity and Insulation

Results from the thermal test were plotted with Origin Pro bit 2017. Below are the graphs (Fig. 4.9) produced from the characterisation of the normal brick and the composite block. With the temperature time-dependent graphs for the day, the area of the block and the change in temperature over the 5h period when the blocks were exposed to the Sun were reported.

Though temperature at the top of the samples exposed to the Sun fluctuates with time because of clouds covering the Sun, the readings below the samples were steadier. In all, the data attained peak values between the hours of 1:00 and 2:00 pm on a normal day. The readings could be affected by changes in Whether conditions of the place or the hour of the day.

(a) (b)

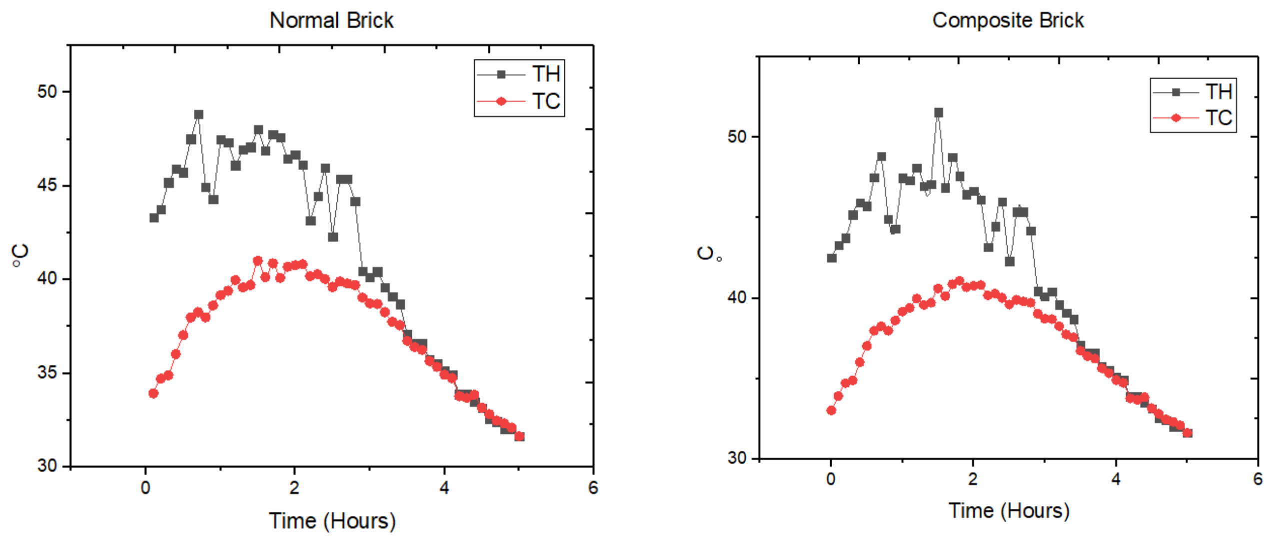


Figure 4.9: Temperature Graph for Composite: (a) Normal Block (control) and (b) Laterite-Based Composite.

The values derived for k, the thermal conductivity coefficient of the blocks were 5.36 W/m.k for the composite block and 10.36 W/m.k for the normal block. The values for the k for normal and experimental blocks suggested that, the laterite block a better insulator of heat. The deviation from the normal and the experimental data were recorded with a percentage error of 5%. However, in building, plastering and painting can further change the heat transfer of the entire system. Creating hollow blocks could also enhance the reduction of heat transfer through the system.

Chapter 5

5.0 Conclusion Remarks, Limitations and Recommendations

5.1 Conclusion Remarks

The study presented the effect of chemically modified bamboo fibres, as reinforced materials in a laterite-cement matrix composite. Mechanical characterization was used to optimize the best performing bamboo fibres composites. The strength of the composite blocks increased from 7.2 kPa for 5 wt.% bamboo fibre to a maximum of 17.67 kPa for the 25% fibre block. The presence of the fibres in the composite structures indeed increased the strength and stiffness of the materials. The fibre also helped to reduce cracks in the samples and hence help in crack bridging.

Optical characterization showed a homogenous distribution of bamboo fibres in the laterite-cement-based matrix.

The thermal conductivity coefficient of the blocks was 10.36 W/mk and 5.36 W/mk for a normal block and the composite block, respectively. The values for the k for normal and experimental blocks suggested that, the laterite block was a better insulator of heat. This can also be used as a signal to determine the heat retention rate of both blocks.

The test for water absorption also showed a similar trend where the composite with the highest fibre percentage could retain water better as compared to the blocks without the fibres. The highest water absorption rate recorded was 10.89 % at 25 wt.% bamboo fibre and 5.8 % at 5 wt.% bamboo fibre. The presence of the fibres helped in the water retention abilities of the block, which serves as a good feature for all blocks produced. It also indicates the porosity of the structures were enhanced with the fibres. This suggests the thermal coefficient of the structures were surely reduced by the incorporation of the bamboo fibres which serves as thermal insulation.

5.2 Limitations

Manual removal of bamboo fibres was challenging. Any machine tools to enhance this process could be of great importance.

Due to limitations with supplies, experiments were delayed. Coupled with limited time to finish up, curing of composite blocks were done in 14 days instead of the usual 28 days. This could have influenced the results.

During the mechanical characterisation of the bamboo fibres, there was a limitation to the required fibre diameter. Fibres were then doubled before the test. This affects the normal curve of the failure modes since different fibres failed at different loads.

5.3 Recommendation

It is recommended that fibres should be dried with an oven to ensure complete removal of moisture. This could be done at temperatures close to 100 ℃ for several hours.

Optical microscopy could be enhanced with a higher definition microscope such as the scanning electron microscope (SEM). This can provide more details at the micron scale for a better analysis.

A recommended pressing machine could be used to enhance samples are moulded with similar pressure. A wooden mould was improvised in this case. Also, mould releasing agent could also enhance easy removal of blocks.

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