ASHESI UNIVERSITY

PRODUCTION OF CORRUGATED ROOFING SHEETS FROM EPOXY-BASED MATRIX REINFORCED WITH TREATED COIR FIBERS

CAPSTONE PROJECT

B.Sc. Mechanical Engineering

Cybil Tinemiishe Mupazviriwo

2019

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CAPSTONE PROJECT

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

Cybil Tinemiishe Mupazviriwo

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: ……………………………………………………

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Abstract

Green roofing is a relatively new approach toward constructing environmentally friendly and sustainable roofing structures. Not only are these structures environmentally friendly, but they can be manipulated for the purposes of energy harvesting, thermal insulation or cooling while saving cost in the long run. Much like the green roof approach, this project seeks to create, for an African setting, with a case study in Ghana, a less costly alternative to durable roofing options such as roofing shingles and composite tiles.

Coir fibers were chemically modified at different concentration and at different durations to establish the kinetics of potassium hydroxide (KOH) in the fibers. Pullout test confirmed the length of the fiber to be used in the composite material. Epoxy-based structures were then formed (by casting into fabricated molds) with reinforced treated coir fibers. Mechanical characterization was carried out with a universal testing machine. From the result, a composite with 10 wt% of coir proved to serve the same purpose as the roofing tiles and shingles. Thermal and optical characterizations were also investigated. The implications of the results were discussed for the production of a relatively lower cost roofing sheets.

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Chapter 1: Introduction

1.1 Introduction

Composite materials have gained popularity over the years due to their excellent properties as compared to traditional materials [1, 2]. According to Scout et al., (2015) the ability of composites to bear extensive loads without failing and many other characteristics have led to their application in industries such as aerospace, construction and automobile industry [3]. More specifically, natural fiber composites have been known to be gaining more popularity compared to other classes of composites due to their natural availability and remarkable strength. Their ability to perform differently in various matrices has influenced their varied applications. As outlined by Saba et al, (2015) some natural fibers are specifically considered for bridge construction since 1982 in countries like China and even in cement beams reinforcement [4].

Composites also have a vital use in the roofing and construction industry in Ghana and many other African countries. According to Ghana statistical service (2005), 40.6% of the population in Greater Accra, Western, Central and Volta Region in Ghana use corrugated metal sheets, slate, and black earth tiles as a roofing material. Slate and earth tiles are composites which are costly but durable roofing options. The rest of the population in these areas and other regions such as Northern Ghana use thatch, palm leaf, and mud as a roofing material. These options are also composites prepared the traditional way without much industrial processing [5]

Natural fibers such as coconut coir have been greatly underutilized in Ghana and most often are left to degrade on farmlands. However, desirable characteristics of natural fiber composites can provide durable and affordable materials for the manufacturing of high quality roofing sheets that could serve a pressing need in Africa and Ghana in particular.

1.2 Problem Statement and Motivation

Current roofing materials used in Ghana for housing construction can be classified into conventional and unconventional (traditional) materials [6]. According to Setrana (2018), formal construction industry uses conventional (quality) ceramic materials for roofing such as roofing shingles and slate that can last up to 100 years [4]. Moreover, solar tiles which have the ability to harvest solar energy are also used for roofing, [6]. All these options, though preferable, are either costly or heavy and delicate to handle and install. Also, attempts to mitigate the effects of global warming do not favor the production of most materials. This is due to the fact that some of the processes of production are not environmentally friendly for instance the production of roofing shingles from rubber causes carcinogenic emissions. [2]. The informal sector, which constitutes the majority of the Ghanaian population, unfortunately, are middle to low-income earners, and cannot afford expensive products as earlier mentioned. [6] [5] Hence, they resort to the use of unconventional (traditional) roofing materials such as thatch and mud. Houses roofed with thatch, do not last long and therefore fail to stand the test of time and some other materials such as metal sheets have little or no heat insulations [2]

This poses the need for affordable but durable and quality roofs with lightweight from readily available material, accessible to the average Ghanaian. This can be solved by the use of natural fibers such as coconut coir, which is readily available, cheap and environmentally friendly. This research proposes a cheaper and environmentally friendly way of producing high-quality epoxy-corrugated roofing products, reinforced with natural fibers (coir)

1.3 Objectives

Fabrication of the epoxy-coir-based composite material will consider the following specific and core objectives:

- Chemical modification of extracted coir fibers to completely remove undesirable properties such as moisture, and hence optimize the kinetics of treated fibers.
- Fibers would be characterized to determine the contents of lignin, cellulose, and hemicelluloses which are indicated factors that contribute negatively or positively to the strength of the fibers.
- The composite design would include materials selection with Cambridge Engineering Selector for competing and alternative materials for product design.
- Fiber pullout tests would be conducted to establish the magnitudes of shear forces between interfacial bonding between fibers and the matrix and hence guide to determine the fiber critical length for reinforcement test bond strength between the matrix and the fiber

Composite formations will determine the optimum fiber length, fiber orientation, mass/volume fraction. Hybrid products could also be investigated by adding particulates of sand to the epoxy resin matrix, with coir fibers are included. Sample characterization will be done through various tests which include;

a. Fourier transform infrared spectroscopy for detailed analysis of functional groups on the modified fibers.
b. Mechanical characterization would be involved to investigate failure loads and strength, hardness, as well as stiffness of the product with triaxial loads.

c. Analysis of thermal resistance measurement relating to thermal coefficient and noise reduction would be investigated.
d. Mechanical degradation due to corrosion and thermal resistance would equally be investigated in different corrosion media including outdoor environmental conditions, respectively.
e. Optical characterization and failure analysis would also be studied.
f. Thermal gravimetric analysis (TGA) would also be conducted to examine the thermal degradation limits of the composites.

- Mechanical simulations would be ascertained for real-life hazards and failure conditions using Solidworks.
- Implications of the result would then be discussed for the application of coir fiber reinforced epoxy composites for affordable housing.
- Results on measured values would be validated with the Cambridge Engineering Selector by comparing with other structural engineering properties.

1.4 Expected Outcome

The expected outcome from this project is a corrugated roofing sheet that is made from natural fiber reinforced into epoxy resin matrix, with the following desirable attributes

- High fracture toughness which is durability of the sheets
- High thermal insulation
- High noise reduction tendencies

- High corrosion resistance
- Lightweight
- Easy to install with little brittle behavior, etc.

Chapter 2: Literature Survey

2.1 Natural Fiber

Natural fibers have become popular in composites formation due to their relatively low cost, lightweight, availability, and strength. As such they have found various uses, especially in the construction industry. According to Darsana (2016) [7], natural fibers have different compositions in cellulose, hemicelluloses and lignin and these are determining factors for fiber strength. The common characteristic of lightweight influenced the development of lightweight structures [7], high tensile strength and high flexibility [8], [9]. However, natural fibers suffer a great deal of moisture which can affect their application during reinforcement, if not properly dried. This calls for chemical modification of fibers.

2.2 Types of Natural Fiber and Uses

Coconut fiber, popularly known as coir is a plant-based fiber that is readily available in Ghana. It is obtained from coconut shells and can be classified into two types; brown coir derived from ripe coconut and white coir which is derived from unripe coconut [8]. Brown coir is known to have more lignin and less cellulose. Also, the brown coir is stronger but less flexible, while the white coir is known for its flexibility and low strength.

Darsana et al., (2016) [7] reported the possibility of 10% weight reduction in concrete roofing tiles reinforced with coir. Through mechanization of manufacturing processes, even more, weight reduction via the addition of coir has been proven to be possible [7]. In this research, an increase in the breaking load and ductility was also recorded in concrete due to the addition of coir as compared to the conventional concrete tiles.

LiLijing (2006) [10] reported coir fibers to have a higher flexural strength as compared to synthetic fibers such as glass and carbon. Recent work reported an increase in both flexural toughness with flexural toughness index greater than 10 times in a coir reinforced cement tiles [7].

2.3 Concerns Associated with the Use of Natural Fiber

There are various concerns associated with the use of natural fiber in composites structures. The major concern is the incompatibility of natural fiber with a matrix which result in a weak composite. Natural fibers are also known to have high moisture absorption tendencies. These result in swelling and void creation which in turn affects their mechanical properties and reduces their dimensional stability [11]. Natural fibers are also prone to microbial attack and are susceptible to rot. This may result in difficulties in storage and processing [9]. Natural fibers are also known for their variation in properties of the same type of fiber. According to Jacob et al., (2008) [11] natural fibers also have the tendency to degrade under high temperature. Most of these shortcomings can be overcome through chemical modification.

2.4 Chemical Modification of Natural Fiber

According to Fernando and Jalali (2010) [9], natural fibers, including coir are prone to degradation in alkali conditions. Their research showed that the higher the concentration of sodium hydroxide (NaOH) in coir, the lower its tensile strength [12]. However, alkali conditions were found to increase the roughness of the fibers which aided in the interaction between the matrix and the fibers showing higher adhesive strength in the composite materials.

Thus, in composite formation, fiber matrix interaction could be increased by the chemical treatment with NaOH and or potassium hydroxide (KOH). Calado and Barreto (2000) [13] discussed the effects of surface treatment of coir fibers in increasing compatibility with thermoset matrices such as epoxy resin. In the surface treatment, lignin on the surface of coir fiber is removed by treatment with 2% sodium sulphite followed by a treatment of the lignin free fibers with acetic anhydrous to reduce polarity. [13]. This was also found to increase interaction with the matrix. In another research done by Jael et al., (2017), low-pressure plasma surface modification of coir was performed using oxygen and air. This was found to increase the adhesiveness and roughness of coir fiber, increasing the compatibility factor between the matrix and the fiber from a factor of 0.0087 to 0.2847 [14]. According to Fernanda et al., (2006), coir and other fibers such as sisal can also be treated with bitumen to reduce their moisture absorption tendencies for use in construction and even in naval engineering. [9] [15]

2.5 Loopholes

Even though much work has been done on fiber reinforced composites, more work can be done to improve the composite properties. Much research has been focused on chemical modification of fiber surfaces with the aim of increasing composite strength. However, the kinetic effect of chemical modification of fibers has not been fully investigated [9] [12]. Ramakrishna et al., (2011) [16] studied the geometry and shape effects on the strength of the composite, to optimize performance [16]. The use of natural modifying agents can also be explored. This as suggested by Maya (2008) [11], can help to reduce the cost of composite formation. In a matrix, there are possibilities of natural fibers affecting crack formation in composites. Detailed research can also be done on the effect of plant-based fibers on crack bridging.

2.6 Scope of Work

The end goal of this work is to produce epoxy-based corrugated roofing sheets reinforced with coconut fibers. The first chapter of this project presents background studies relating to composite materials. Specific objectives were also presented in the first chapter. Moreover, the literature survey on previous work has been presented in the second chapter. The second chapter, therefore, highlighted previous works done on chemical modifications of natural fibers for reinforcement. Unresolved issues relating to composite-based materials, especially, natural fiber-based composites were also presented in the second chapter.

The third chapter presented the materials and methods pertained with the project goal and core objectives. Thus, chapter three covered; a discussion on chemical modification of the natural fibers to increase compatibility with the matrix, reduce water absorption and moisture to make a durable composite. The composite will then be formed by first determining the critical length and the orientation of the fibers, followed by varying the fiber to matrix ratios, then finally, adding other phases to make a hybrid composite system. After the composite formation, shape effects would be investigated. The composite will then be characterized to optimize the process.

Moreover, the fourth chapter presents the results and discussion section. Implications of the results would also be discussed for the use of epoxy-fiber based structures for the development of low-cost corrugated roofing sheets with enhanced mechanical properties. The firth chapter then presents concluding remarks and recommendations for future works.

Chapter 3: Design and Methodologies

3.1 Materials

For material selection, Cambridge Engineering Selector (CES EduPack 2013, Granta Design, Cambridge, England) was used to sort out natural fibers with the required properties. SolidWorks 2016 (Dassault Systèmes, Vélizy-Villacoublay, France) was used to design and simulate the compressive and tensile response of various shapes of the end product. Origin 2017 (Origin Lab, Massachusetts, USA) was used as a tool for graphical data analysis, while statistical evaluations were carried out with MINITAB 15 (LLC, Pennsylvania, USA).

Coconut fibers (coir) were obtained from farms in the Western Region of Ghana. 100% pure 4oz-20 lb. Caustic Soda, Lye Food Grade KOH were obtained from (Research Lab Fine Chem Industries, Mumbai, India) were used for the surface modification. Acetic acid glacial was procured from (Research Lab Fine Chem Industries, Mumbai, India) and distilled water was also procured in laboratory chemical shops in Accra, Ghana. Coconut fibers (coir) were obtained from farms in the Western Region of Ghana. 100% pure 4oz-20 lb Caustic Soda, Lye Food Grade KOH were obtained from (Research Lab Fine Chem Industries, Mumbai, India) were used for the surface modification. Acetic acid glacial was procured from (Research Lab Fine Chem Industries, Mumbai, India) and distilled water was also procured in laboratory chemical shops in Accra, Ghana.

3.2 Material Selection

The primary objective of this project is to produce a low cost alternative material for roofing sheets that can still serve the same purpose as the normal roofing sheets or even better.

This objective thus informs the user requirements of the design which is documented in Table 3.1..

Table 3. 1*: User requirements and system property*

User Requirements	System property
1. Low cost	Locally available material
2. Durable	High tensile and bending strengths
3. Thermal Insulation	Low thermal conductivity
4. Light weight	Low density
5. Low noise	Noise reduction

Using the Cambridge Engineering Selector, (CES EduPack 2013), and the defined parameters for the design, material selection was done for competing and alternative materials for product design. In doing this; various files were opened in the software, classes of prospective material were selected, eg. fiber, composites and plastics. The following graphs were plotted and comparisons made against each material property.

- Young's modulus against price
- Density against price
- Thermal conductivity against price

The resulting graphs from the selections are documented in the result section. The materials that ran through the selection and their properties are rated on a scale of 1 to 5, and then quantified in total as shown (Table 3.2).

Table 3. 2 *: Material Selection Pugh Matrix*

Material	Low Cost	High Young's modulus	Low Density	High Thermal insulation	Average performance
1. Kenaf	4	5	4	5	17
2. Jute	5	5	4	4	19
3. Coir	5	4	5	5	19
4. Pine	3	3	4	4	14
6. Kevlar	1	5	3	3	12

3.3 Composite Design using SolidWork

The design for the composite was derived four performance criteria which then informed the design process factors. This includes flat sheet, corrugated sheet, and square sheet, while current solutions such as the ceramic roof tiles are used as a baseline. The design of prototypes for the roof profiles to be made out of the composite under development were done in SolidWorks as shown (Figure 3.1) for three different shapes.

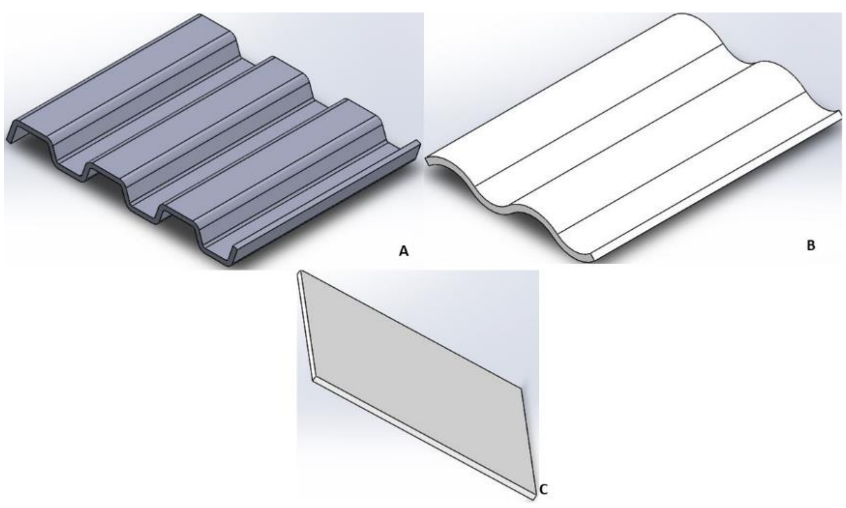

Figure 3. 1*: SolidWorks Models of the Roofing Sheet Profile Prototypes: (a) Rectangular Corrugated Sheet, (b) Corrugated Sheet, and (c) Flat Sheet.*

3.4 Experimental Procedures

3.4.1 Chemical Modification of fibers

3.4.1.1 Fiber Retting

Coir fibers were obtained from dried coconut husks. The fibers were extracted from the husks, manually separated and dried at normal room temperature and pressure for several days. Fibers were subsequently dried in the sun.

3.4.1.2 Fiber Pulping

Fiber pulping was achieved via chemical treatment with alkali solution to remove moisture in fibers, and to also increase compatibility with matrix. To improve on the compatibility of coir fiber with the matrix, alkali treatment with KOH solutions was done at concentration of 6 wt%, 7 wt%, and 8 wt% . Equal volumes of the various concentrations were poured into labelled containers. Coir fibers were soaked in the alkali solutions for 6 hour intervals of immersion. The setup is shown (Fig. 3.2) and the result was to be tracked as shown in the (Table 3.3) below.

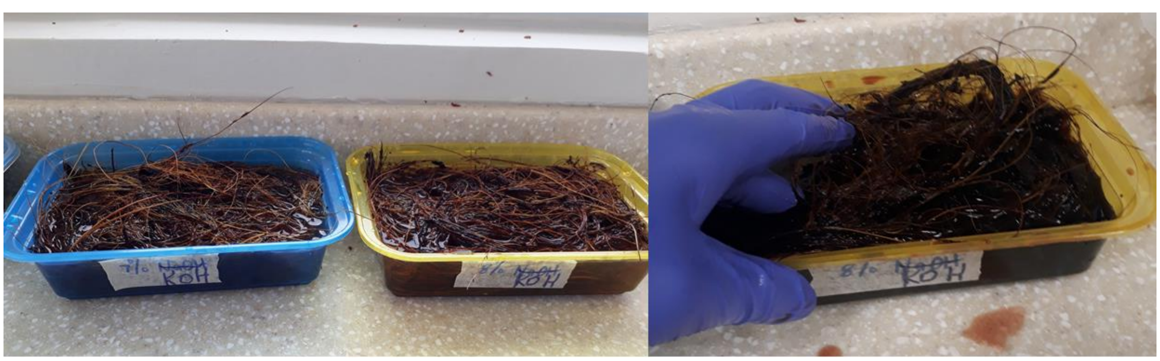

Figure 3. 2: *A setup of the chemical modification of coir fiber.*

Table 3. 3: *Table of chemical modification tracking by varying weight and time.*

Sample Name	**Time (h)**	**Concentration by wt.% of NaOH**		
		6	***7***	***8***
Fiber 1	6	6	7	8
Fiber 2	12	6	7	8
Fiber 3	18	6	7	8
Fiber 4	24	6	7	8

After the treatment, the coir fibers were taken out of the alkali and soaked in 2 v% of acetic acid with distilled water to neutralize the alkali on the surface of the fibers. Then, 2 v% of detergent solution in water was used to wash out any residual chemical. The fibers were then conditioned in 65 % relative humidity and allowed at 30 ℃ to dry off the water for about a week. The samples were then dried to ensure complete removal of moisture before further characterization and composite preparation.

3.4.2 Mechanical Characterization of fibers

To characterize the fibers, tensile tests were done on the fibers using a universal testing machine. To prepare the sample to be tested, the fiber was glued to a 6 x 4 cm reasonably thin cardboard (Fig. 3.3 a), using super glue. Before testing the card board was split into two pieces by cutting horizontally across the cardboard. The bottom and top edges were then clipped to the machine for testing. The prepared samples for testing is shown below and tested on the machine as shown below. Load extension curves were obtained and subsequently calculated the stress-strain behavior according to:

$$\sigma = \frac{F}{A} \quad (3.1)$$

$$\varepsilon = \frac{\Delta L}{L_0} \quad (3.2)$$

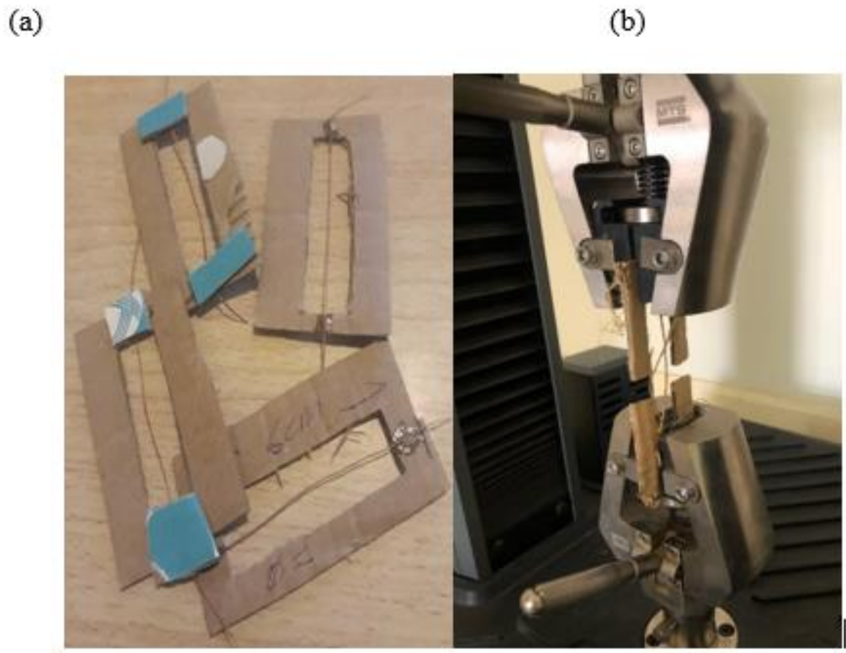

Figure 3. 3: Sample preparation: (a) Sample Preparation for Mechanical Test, and (b) Setup for the fiber sample on the tensile test machine.

3.4.3 Fiber Pullout Test

Illustration/picture of a test sample prepared for the fiber pullout test is presented (Fig. 3.4). This comprised of a coir fiber embedded into epoxy matrix at length h_e = 15mm [1] .Thus, before the matrix (epoxy resin), sets, fibers were aligned in such a way that some strands of fibers hang off the edge of the matrix, while taking note of the embedded length. The protruding fiber on the other end was glued to a thin cardboard to ensure maximum grip when loaded into the machine.

The fiber pullout test was used to determine the load at which the fiber de-bonds from the matrix in the composite. During pullout test, the matrix end of the sample was clamped to the bottom jaw of the universal mechanical tester, while the protruding fiber (glued to a thin cardboard) was held tight at the top jaw. Variable loads were applied in the tensile direction at (0.1N/s) until the fiber pulled out of the matrix. Fiber shear stress was then calculated from the pullout test according to

$$\tau = \frac{F_{\max}}{\pi d_f n h_e} \qquad \textbf{\textit{(3.3)}}$$

where h_e is the embedded length, F_{max} is the maximum load applied, d_f is the diameter of the fibers, and n is the number of fibers.

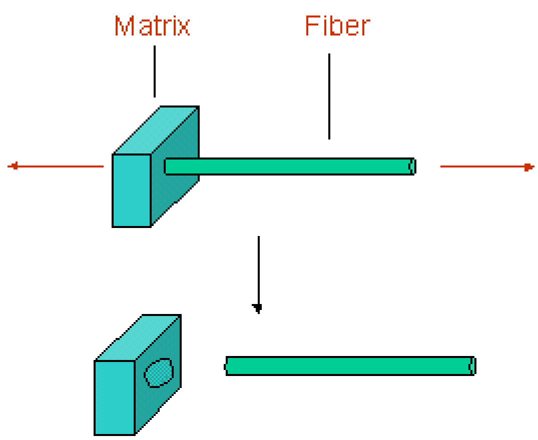

Figure 3. 4: *Illustration of Prepared Sample for Fiber Pullout Test.*
Source: Adapted from *[2]*

3.4.4 Determination of Critical Fiber Length

The critical length (l_c), which is the minimum length at which the composite will perform on average in terms of strength and stiffness was determined from the following equation.

$$\boldsymbol{l_c} = \frac{\boldsymbol{\sigma d}}{\boldsymbol{2\tau}} \qquad \textbf{(3.4)}$$

*Where d is fiber diameter, τ is fiber shear strength, and σ is the fiber ultimate tensile strength***.** The optimal fiber length used during the reinforcement was ($l > l_c, i.e. l = 10\ l_c$).

3.4.5 Composite Formation

The current composite material was made from coir and epoxy-resin. The liquid epoxy resin was mixed together with the hardener at 100:1 ml. Control samples were formed with only epoxy matrix (with no fiber inclusive), while the volume ratio of fiber: matrix was varied as shown (Table 3.4). From the pullout test, fibers were cut to an average length of 30 mm for reinforcement. The mixtures were manually carried out by vigorously stirring in clockwise, counterclockwise and forward and backward directions to ensure a near homogenous mixture. Blended samples were then casted into fabricated molds, to for dog bone shapes and then allowed to set for 24 h before carrying out further analysis. Prototypes of corrugated roofing sheets were also formed using the above method.

Table 3. 4: *A table of volume fraction by weight % of various samples.*

Composite Code	Epoxy Volume Fraction (wt%)	Coir Fiber Volume Fraction (wt%)
Control Sample A	100	0
Composite B	98	2
Composite C	94	6
Composite D	90	10
Composite E	88	12

3.4.6 3 Point bending Test

A 3 point bending test was also performed to help characterize both the matrix and the composite by finding other mechanical characteristics such as the flexural modulus. To perform the test, a sample of the matrix and the composite was set onto the universal testing machine with a 3 point bending setup (Fig 3.5). A load was slowly applied on the sample at a rate of (0.1N/s) until the sample failed. Load versus displacement curves were plotted and analyzed for mechanical property characterization

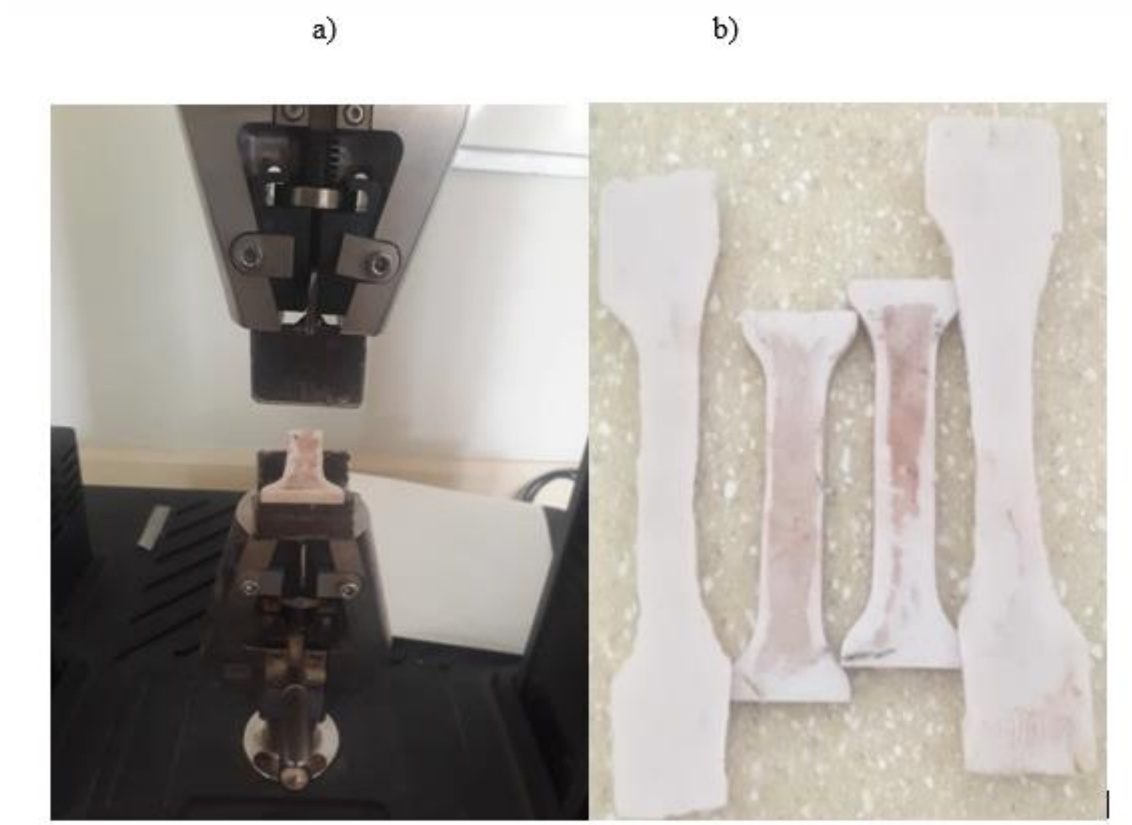

Figure 3. 5: Sample preparation: (a) Setup for the sample on the 3 point bending machine. (b) Sample preparation for 3 point bending.

3.5.0 Sample Characterization

3.5.1 Determination of Mechanical Properties

In this section, the mechanical properties of the composite were determined. Dog bone samples of the composites were clipped onto the universal testing machine at both ends, while a load was slowly applied (0.1N/s) to the samples until they fail. From the load extension curves, stress-strain curves were developed with the idea of the cross-sectional area and initial length of the samples.

3.5.2 Modulus of Resilience for Fiber and Composites

After the tensile test, the area under the elastic region of the stress-strain curves gave the modulus of resilience for both the fiber and the composite, respectively. For linear elastic behavior, the modulus of resilience, $\boldsymbol{Er}$ is given as (Callister, 2007) [3]

$$\boldsymbol{E_r = \frac{1}{2}.\sigma_y.\varepsilon_y} \qquad \textbf{\textit{(3.5)}}$$

Where $\boldsymbol{\sigma_y}$ is the yield strength and $\boldsymbol{\varepsilon_y}$ is the strain at yielding.

3.5.3 Stiffness

The stiffness (E) of the composite, which is its resistance to elastic deformation, was obtained from the slope of the stress versus strain curve.

$$\mathrm{E} = \frac{\Delta\sigma}{\Delta\varepsilon} \qquad \textbf{\textit{(3.6)}}$$

3.5.4 Ultimate Tensile Strength and Strain at Necking

The ultimate tensile strength is the stress obtained at the maximum applied load on the sample. On the engineering stress-strain curve obtained from the tensile test, it was extrapolated and the point of highest stress was obtained. The strain at necking was also extrapolated.

3.5.5 Yield Strengths and Strain at Yielding

The yield strength was found at the stress point extrapolated parallel to the linear portion of the engineering stress-strain curve, at 0.2% offset strain value. The strain at the yield point is extrapolated at the point of the stress-strain curve where the material yielded.

3.5.6 Hardness

This was done with a hardness tester (Digital Shore D Hardness Durometer, 16HDM002-D100HD-06, Yescom USA, California, USA) using the setup shown in Figure 3.5. The hardness tester was pressed into the sample to test for the hardness value.

Figure 3. 6*: Setup of the Hardness test.*

3.5.7 Thermal Properties

Thermal behavior of the composite was investigated upon exposure to changing temperatures. The roofing sheet with surface temperature sensors on the top and bottom surface was placed on a box simulating a building as shown in the setup (Figure 3.6). The setup was placed in the daylight sun for 24hrs and data of temperature variations for time recorded. Using results, thermal conductivity, K is then calculated using the following equation:

$$\boldsymbol{K} = \frac{(\boldsymbol{Q}\Delta \boldsymbol{x})}{(\boldsymbol{A}\Delta \boldsymbol{T})} \qquad \textbf{\textit{(3.7)}}$$

where ΔT is the change in temperature and Δx is the sample thickness. A is the sample area and Q is the heat supplied to the sample which is estimated to be the solar constant.

Figure 3. 7*: A setup for the roofing sheet thermal properties study.*

3.6.0 Optical Characterization

Optical characterization is heavily dependent on the use of photons of light to investigate a property in the composite material. In this case, an portable USB digital microscope (digital microscope model U800X, Jingou-tech, Shenzhen,China) was used to investigate the effect of the chemical modification on the fibers. Pictures of both the modified and unmodified fibers were captured to compare the changes.

Chapter 4: Results and Analysis

4.1 Material Selection

From the selection done with CES, the best materials to use ranked by their thermal conductivity, density, Young's modulus and price are Jute and coir. The graph below, (Figure 4.1) shows the selections made by the CES for young's modulus against price. More graphs are presented in the Appendix.

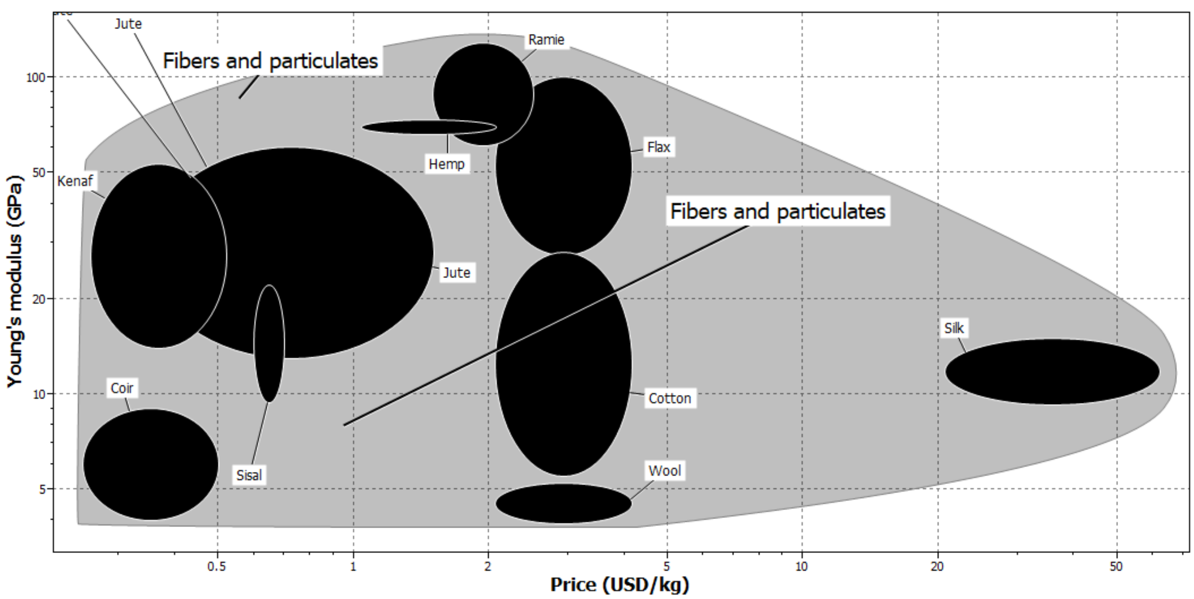

Figure 4. 1*: Selection Chart for Natural Fibers Based on Young's modulus versus Price.*

The performances of jute and coir are fairly similar as summarized in the material selection summary below. Jute is in abundant in India, in the Ganges Delta. Fortunately, coconut is in abundance in Ghana, especially coconut plantations are found in various regions of Ghana, especially in the Western Region, Central Region, and Eastern Region. This explains why coir fibers only are considered in this study.

4.2 Composite Sheet Simulation

The simulation result from the SolidWorks, compression test indicate that all three shapes experience the most stresses at the edges, as shown in the displayed result (Fig. 4.2). As indicated in the figures, the rectangular profile sheet experiences the least stress of 4.4666 x 10^{-1}MPa as compared to 4.585 x 10^{-1} MPa. It can be observed that there is no much difference in this two data. The rectangular sheet has the functionality of guiding the flow of rain water from the roof top. Hence, the rectangular sheet has the potential to serve for the epoxy-based roof sheets. On the other hand, the corrugated sheet experienced the greatest stress, indicating that, it is most likely to fail.

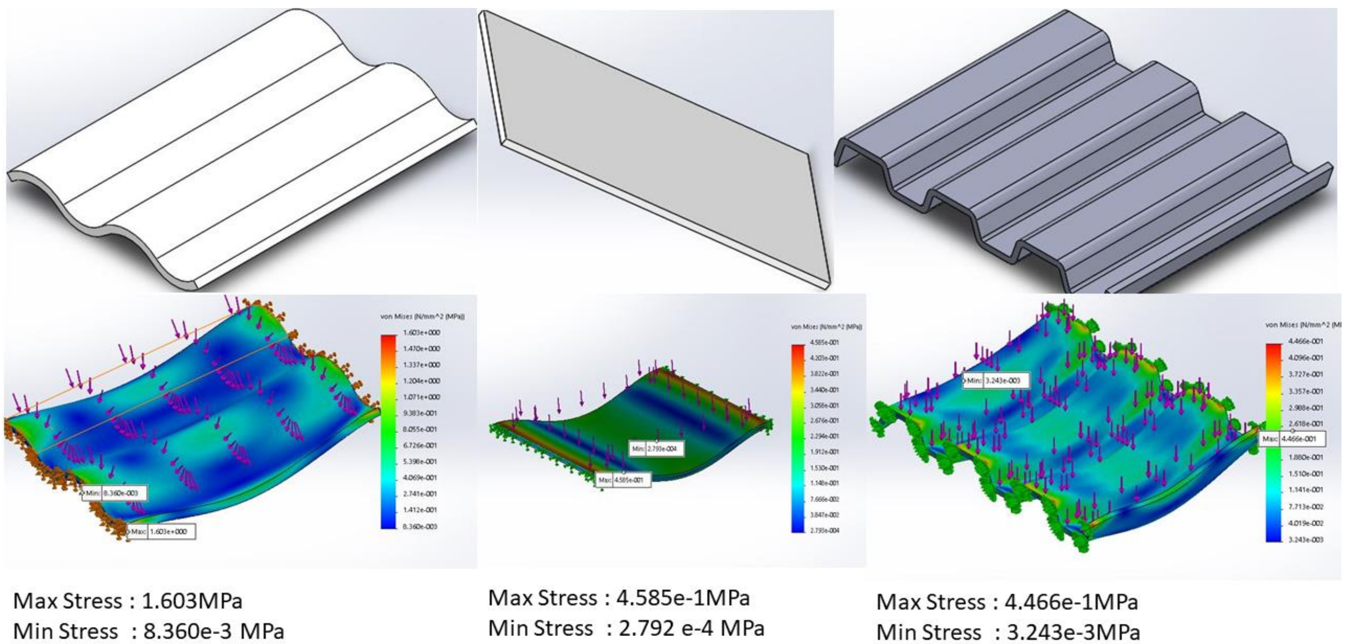

Figure 4. 2*: Compression Test Simulation Result with Respect to Each Roof Sample Model.*

4.3 Optical Characterization of Fibers

The optical characterization of the fibers before and after modification showed a change on the surface of the fibers (Fig. 4.3). Generally, the trend is that before characterization, the fibers had a lot of dirt and debris on their surface. Upon addition of the alkali, the surface begins the peel off with an increase in both concentration and time. As a result, with the increase in concentration of the alkali the lignin in fibers removed, while the content of cellulose increases the mechanical properties of the fiber. This is consistent with the findings of Mwaikambo et al (2002) who also reported smother surfaces for alkalized fibers by the scanning electron microscope method owing to the removal of lignin. [4] [5]

Figure 4. 3: *An image of the optical test result from unmodified fiber, to modified fibers with an increase in concentration of alkali.*

4.4 Fiber Mechanical Characterization

4.4.1 Tensile Properties

After the chemical modification with 6 wt%, 7 wt% and 8 wt% on a 6 hr interval, the result obtained proved that coir fiber modified with 7 wt% alkali for 24 h performed better with respect to the Young's modulus as summarized in the bar graphs (Fig. 4.4) below.

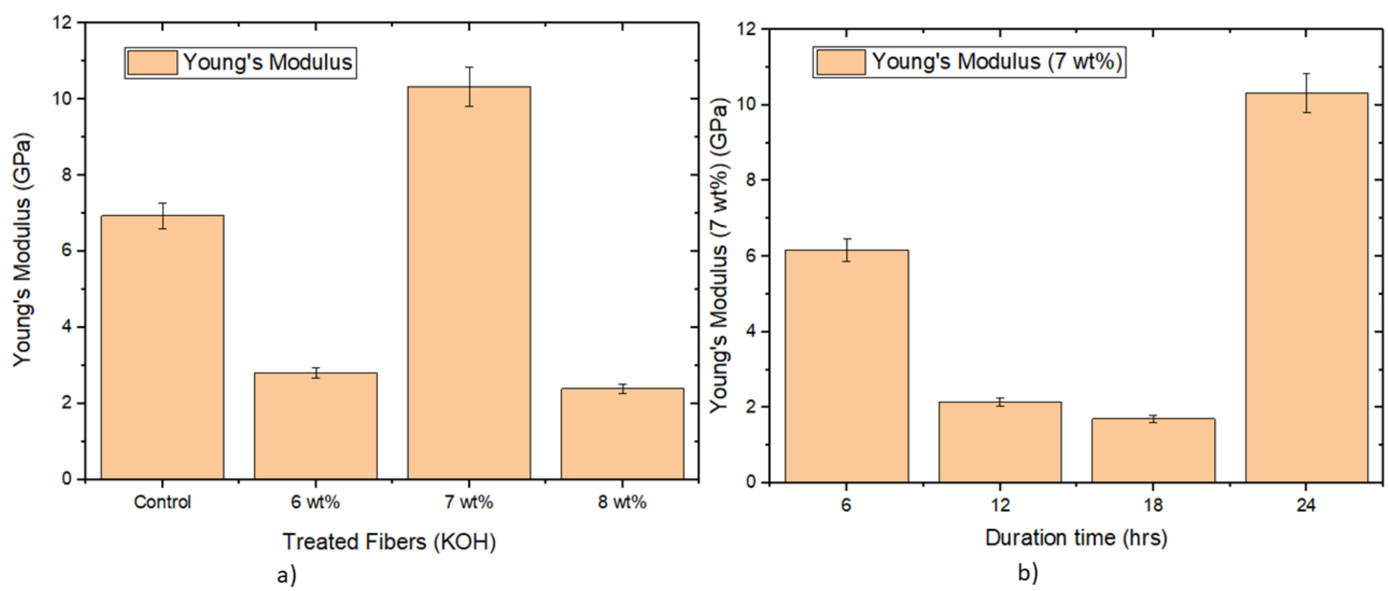

Figure 4. 4*: Effect of KOH Concentration on the Young's Modulus, and (b) Kinetics of KOH on the Young's modulus. Error Bars are at 5 % of data (95% confidence interval).*

The Stress-strain curves of the various fiber samples, superimposed on each other show much detail of the Young's modulus given by the slope of the elastic region of each curve. Generally, as is reported by literature survey, the Elastic moduli of coir fibers increases with an increase in the concentration of modification alkali up to a certain maximum concentration, then drops. As show on the graph a), 7 wt% proves to be the optimum concentration. Any further increase in alkali concentration after that reduces the performance. A discrepancy in the trend is noticed on the 6wt% fiber group which has a drastic drop in Young's modulus. This may be due to experimental errors or other factors, distorting the trend. This is also seen in the graph of the effect of kinetics on the young's modulus. Figure 4.5 below shows a comparison of all the fibers, in terms of the stress strain curve

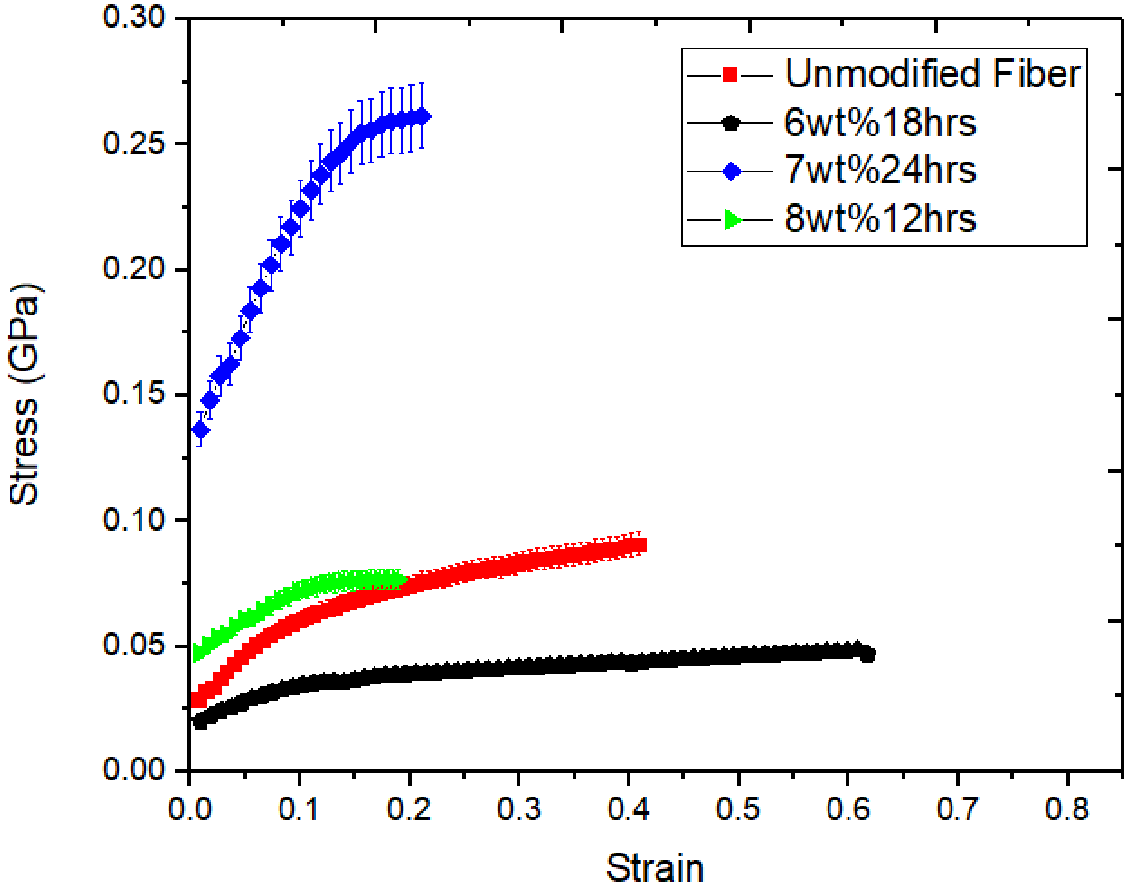

Figure 4. 5: *Graphs of Stress against Stress for the Average Best Samples from Various KOH %.*

The chemically modified fiber used for the composite formation was the coir modified with 7 wt% KOH for 24 h because of its performance on the stiffness relative to the other samples. Figure 4.6 below shows a graph of stress against strain for the sample in question.

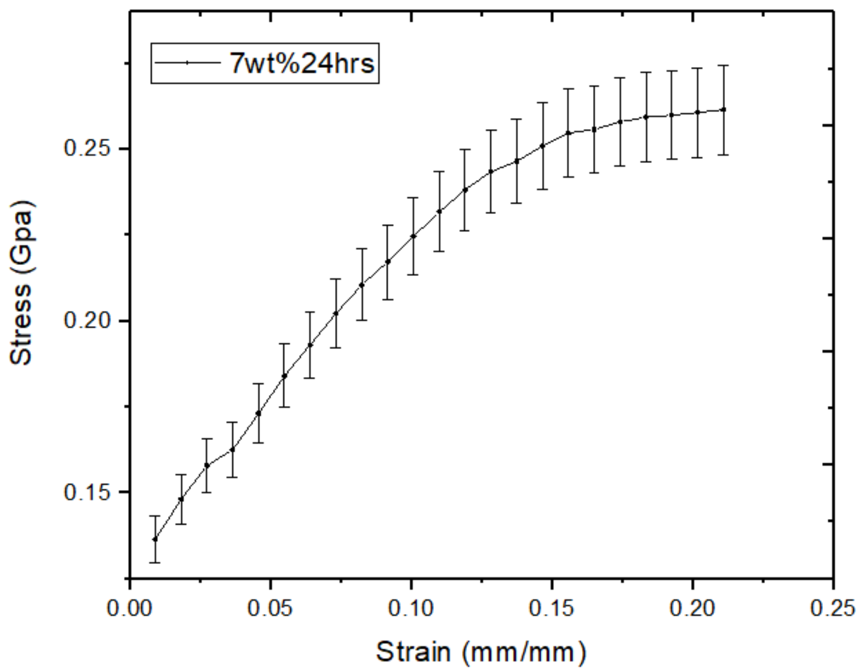

Figure 4. 6*: Graphs of Stress against Stress for the Average Best Samples from Various KOH %.*

In summary, the optimum mechanical properties of interest obtained from the 7wt% concentration at 24hrs is shown in the table 4.1 below. The graphical computation of the summaries properties of the fiber shown in Table 4.1 below are attached in the Appendix for Reference.

Table 4. 1*: A summary of the mechanical properties of the best modified fiber*

Property	**Value**
1.Critical length	**30 mm**
2.Modulus of resilience	**5.779e-4 GPa**
3.Ultimate Tensile Strength	**0.25 GPa**
4.Strain at necking	**0.57 mm/mm**
5.Yield Strength	**0.15 GPa**
6.Strain at yielding	**0.021 mm/mm**

4.5 Composite Mechanical Characterization

4.5.1 Tensile Properties

Various composite samples of epoxy-resin and coir fibers of 2 wt%, 6 wt%, 10 wt% and 12 wt% were also tested and characterized mechanically. The 10 wt% composite samples emerged to have the highest Young's modulus of all the samples. This is shown by Figure 4.7. With the exception of 6 wt%, the result indicates a growing trend with increase in the Young's modulus of the composites structures with increase in fiber concentration. The optimum results were obtained at 10 wt%, while increasing the fiber content beyond that to 12 % caused a reduction to the Young's modulus. This is clear that, saturated fibers in the matrix causes fiber-fiber to interact instead of fiber to bond with a matrix. Hence, it weakens the structure.

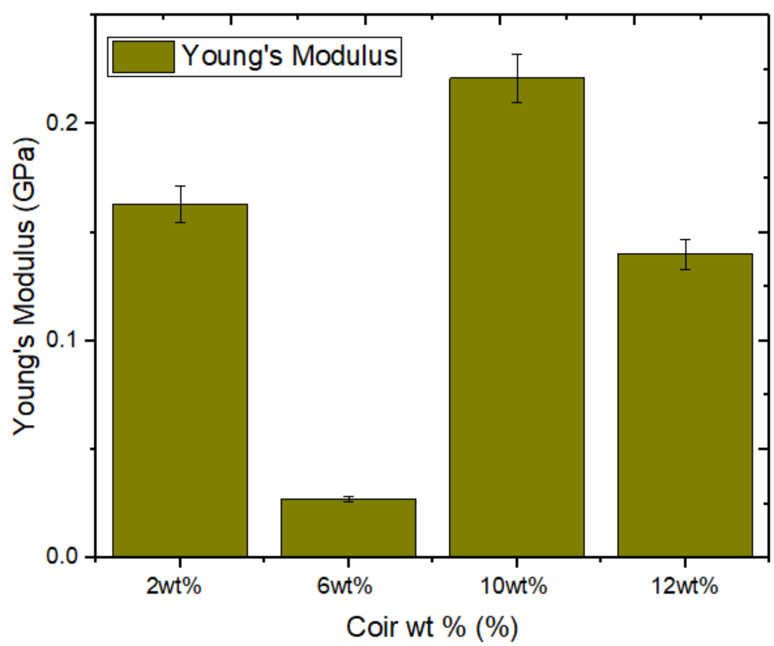

Figure 4. 7: *A graph of the effect of varied weight % coir on composite young's modulus. Error Bars are 5 % of data.*

The various stress against strain curves for the various samples are shown in Figure 4.8 below. As per the shown trend and also the young's modulus data, the 10wt% fiber composite proves to be the best compared to the other composites. A discrepancy that disobeys the trend is noted on the matrix stress versus strain curve which may be attributed to experimental error or significant defects in the tested samples.

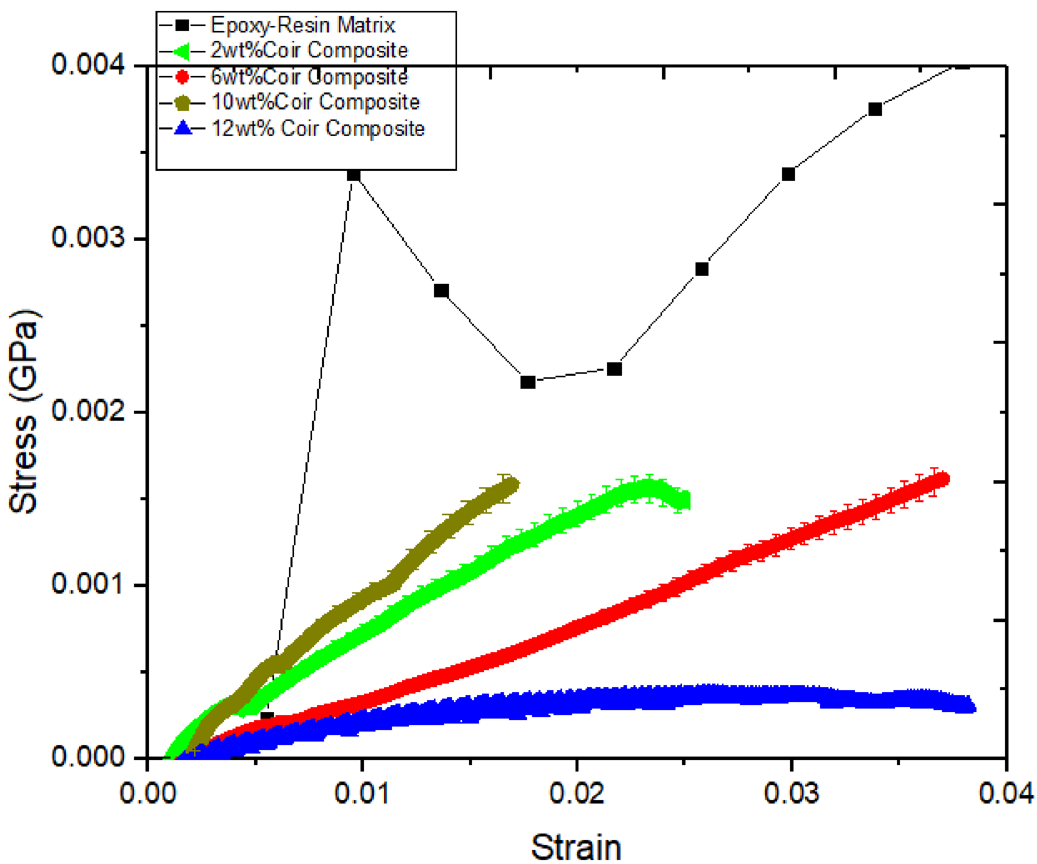

Figure 4. 8: *Graphs of stress against strain for different composite samples with varied fiber content.*

4.5.2 Hardness Properties

The result for the hardness test showed that the matrix, without the reinforcement is generally harder than the composite. The hardness of the composite was averagely 82.5 HD, while that of the matrix alone was 87.5 HD. This also informed us that the fibers help to enhance ductility in the structure and hence, reduced brittleness since hardness is associated with the stiffness of the material.

4.5.3 Bending Properties

The results comparing the composite bending properties are presented (Figure 4.9) by a summary of the load against deflection curve and in terms of Flexural modulus and Flexural strength.

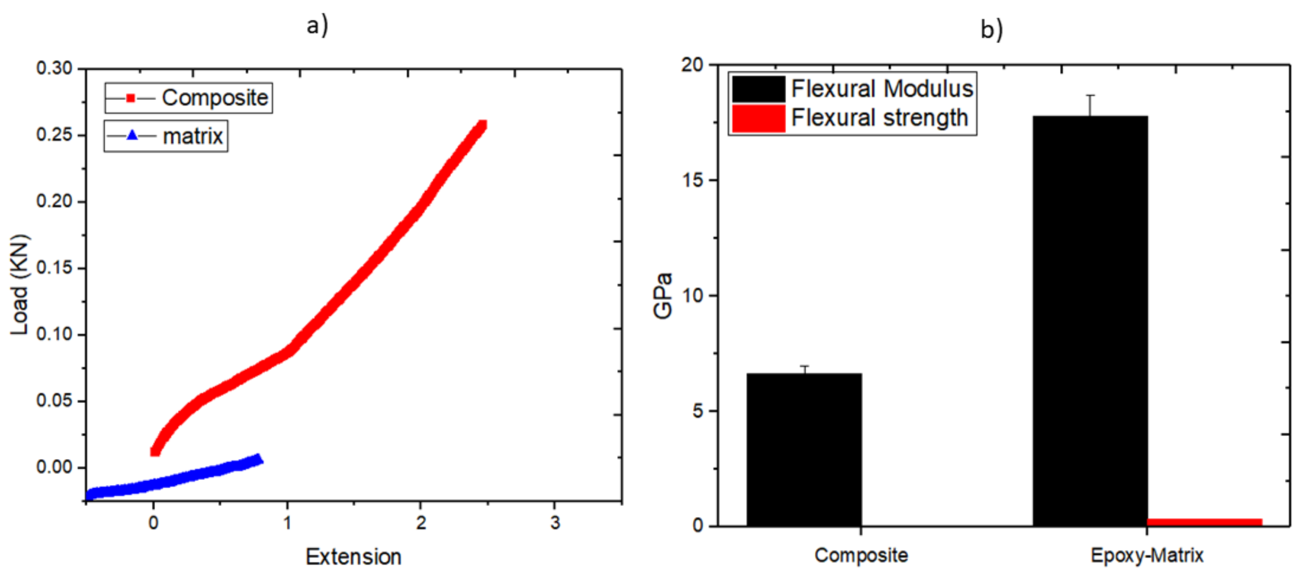

Figure 4. 9*: Three point bending result of a) Load against extension b) Flexural modulus and flexural strength of epoxy-resin matrix and composite*

As shown by the load vs extension curve, the epoxy-resin matrix alone is a brittle material which withstands a lesser maximum load compared to the composite. By adding coir fiber the material becomes less brittle, deforms more and can withstand more bending moments. The flexural modulus of the Epoxy-resin is also significantly higher than that of the composite, corresponding to it being stiffer, and of less deflection than the composite. Thus, the addition of the coir fiber to the matrix reduces the brittleness of the material significantly making it a better fit for a structural use, to make roofing sheets.

To summarize all the properties of the designed composite, Table (4.2) below gives all the determined mechanical properties of the composite as found from the mechanical characterization.

Table 4. 2: *A summary of the composite mechanical characteristics*

Property	**Composite Value**
1.Critical length	30 mm
2.Modulus of resilience	$5.77E^{-8}$ GPa
3.Ultimate Tensile Strength	0.0015 GPa
4.Strain at necking	0.0985 mm/mm
5.Yield Strength	$9.5E^{-4}$ GPa
6.Strain at yielding	$6\ E^{-4}$ mm/mm
7.Hardness	82.5 HD
8. Flexural Modulus	6.64 GPa
9. Flexural Strength	0.0634 GPa

4.6 Corrugated Sheets

Using a composition of 10 wt% Coir fiber, the designed profiles of the roofing sheets were made via solvent casting. Figure 4.10 below shows an image of the prototypes of the sheets produced. A series of iterations were done to produce the perfect prototype free of defects and near net shape.

Rectangular Corrugated Profile **Round Corrugated Profile**

Figure 4. 10*: An Image of the Roofing Sheet Prototype: (a) Rectangular Profile and (b) Round Profile.*

4.7 Composite Thermal Characterization

4.7.1 Thermal Conductivity (K)

The thermal studies done on the sample for 24hrs are documented in Figure 4.11 below, as a graph of temperature against time, measured on the top and bottom surface of the roofing sheet. The graph is bell shaped, showing the peak and drop hours of temperature during the day. The inner surface of the roofing sheet is observed to be cooler compared to the outer surface during the hot hours of the day while in the cooler hours of the day, the inner surface is warmer than the outer surroundings. This shows the significant insulation properties of the composite material, restricting heat entrance and exit easily through the roof, thus maintaining the simulated room temperature fairly constant, and suitable for both hot and cold climate conditions.

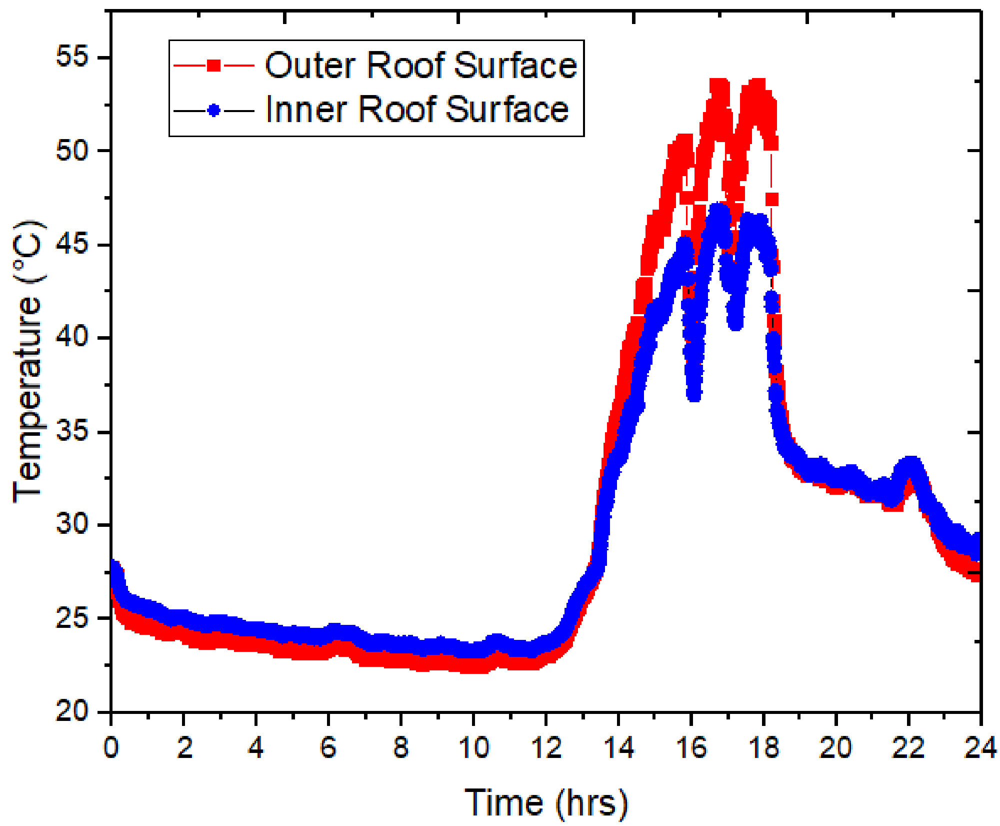

***Figure 4. 11**: Temperature variations against time*

Using the temperature versus time data, the value of the thermal conductivity (k) of the composite was calculated as given by Equation, and the result is tabulated in Table 4.3 below. The rate of heat transfer, Q• was obtained from the average solar radiation constant as given by the Ghana energy commission, for studies between 1993 and 2002. (Ghana Energy Commission, 2002) [6]

Table 4. 3: Thermal conductivity calculation

Time Interval (hrs.)	Q• ($KW/m^2 . kg$)	∆x(thickness) m	Area m^2	∆T (℃)/K	K ($kW/m^2 .k$)
0 - 8	0.2375	0.025	0.061104	0.80	0.121
8 -16	0.2375	0.025	0.061104	0.75	0.1296
16 -24	0.2375	0.025	0.061104	1.09	0.089
Average					0.113

The experimentally obtained value of K, 0.113 kW/m^2 .K is fairly agreeable as it is close to values of K obtained in literature for various epoxy resin composites. Subagia et al (2017) reported values of 0.187 kW/m^2 .k in Basalt fiber reinforced epoxy. [7]

4.7.2 Thermal Property Summary

From the thermal studies, the properties of the material resulting from the tests are summarized below (Table 4.4). The relatively low density shows that the composite is a lightweight material with good insulation properties shown by the K value. The Poisson ratio range as obtained from summary shows the remarkable strength of the material in compression and its ability to deflect after addition of the fiber.

Table 4. 4*: Thermal properties of the composite.*

Property	Value
Coefficient of thermal conductivity (K)	0.113 kW/m^2 .k
Young's modulus	0.221 GPa
Ultimate tensile strength	0.0015 GPa
Yield Strength	$9.5E^{-4}$ GPa
Poisson's ratio	0.26-0.35 [8]
Density	1.243g/cm^3 [9] [7]

4.8 Cost Implications

The production cost of an average ceramic roofing tile is made up of various elements. Rizos et al (2013) [10] used a case study of ceramic and flat glass tiles to show a breakdown of the production cost composition into various elements. Raw material cost was found to constitute 20-25 % of the production cost, labor costs 25-30% and energy costs constituting 30-35 % [10]. The cost of epoxy-resin almost parallels the cost of the raw materials for ceramic tiles ie, porcelain, quartz and clays, depending on the composition. However, the production cost of ceramics gets higher than that of the epoxy composite due to the high energy required in ceramic production which is quite destructive and expensive to supply. The epoxy-based composite subject to characterization in this paper requires no energy to produce. With enough skill and training, the composite can be done in a small scale without much capital as no heavy plant and machinery is required, except for packaging, casting and mold release, if done at commercial level.

Chapter 5: Conclusion, Remarks and Recommendations

5.1 Conclusions

The scope of this project aimed at producing a composite material out of epoxy resin, which was reinforced with coconut fiber (coir), for the sole purpose of producing roofing sheets that can serve the same purpose as durable roofing shingles or tiles but at a lower cost in a sustainable way. Coir, which was used as a reinforcement was modified using different percentages of the alkali KOH and at different time intervals. The tensile test results indicated that coir fibers modified with 7 wt% for 24 h had the highest performing Young's modulus compared to the rest of the other sample groups. The 6 wt% and 8 wt% did not show much statistical difference but the 7 wt% for 24h was significantly of a higher Young's modulus compared to the rest of the groups at an $\alpha = 5$ %.

A varied composition of coir fiber was also used to form the composite. As reported in the results section of this work, the Young's modulus of the 10 wt% coir sample proved to be the highest of all the other samples. Between 6 wt% and 8 wt% coir fiber, not much statistical difference was shown. However, the 10 wt% shows much statistical difference from the rest of the groups at a confidence interval of 95%.

Using these findings, through various iterations, a number of prototypes were made of the roofing sheet. The Hardness test of these samples, as reported in the results gave values of 82.5 HD.

From the cost analysis, it is safe to predict that the fiber reinforced epoxy composite is likely to be of a lower cost compared to the conventional ceramics since its production is less labor intensive and as well utilizes green technology (no demand for any heat supply).

5.2 Limitations

This study has revealed a number of limitations in the production of the composite and in turn the roofing sheets. Epoxy, as a raw material is expensive, which may inflate the cost of producing the roofing sheets on a large scale, even though they may be cheaper than roofing tiles or shingles. This may hinder the low cost production of sheets using it as a matrix to meet the objective of subsidizing the quality roofing sheets.

The main manufacturing process involved in sheet formation is casting. Although this is good since it can be easily done with minimal machinery and capital, it poses limitations of accuracy on the product, due to the inevitable defects that come with casting, more commonly to such a case, gas cavities, pinholes and penetration defects. This, may pose a need for machining, to produce the right shape for the sheets, which may not be advisable as it may weaken the composite. However, it will require degassing to remove gas bubbles if a vacuum oven and a pump are available. Also, restriction to casting as the only method of manufacturing makes it hard to mass produce. Due to its adhesive behavior, epoxy tends to stick to the mold, if the mold material is not carefully selected. As a result, expendable casting may be better to use, such that the mold is destroyed, to ease the process of removing the cast. This is time consuming and unfavorable for cases of mass production as new molds need to be made for each side. However, with the required mold releasing agent, it could solve the above challenge.

Finally, epoxy due to its chemical composition may pose health hazards if not handled correctly. Its pungent smell can also be a health hazard during production. However, it the smells disappears one the substance is formed.

5.3 Recommendations for Future Works

Much more can be invested in performing more tests to characterize the material, both mechanically and chemically, which could not be covered in the scope of this project. Fracture toughness test can be done to investigate the effect of flaws in the material. A fiber pullout test can also be done to confirm the strength between the fiber and matrix as shown in literature.

Further optical characterization would be useful to observe the fracture mechanics and also to view the composite microstructure after the two phases had been fused together to examine the distribution of fibers within the matrix.

Since Composite roofing sheets characteristics are likely to change with exposure to corrosive mediums such as water, acid rain, or weak acid such as carbonic acid, it is vital to investigate the effect of these corrosive by way of the mass loss experiment. This would help characterize the corrosion tendencies of the material.

To optimize production and minimize costs, the use of another thermoset of similar behavior such as epoxy can be explored as a matrix, provided it is cheaper and more affordable.

To reduce defects in casting process and or to aid in mass production, mechanization and automation of the manufacturing process is recommended. In the future, a machine can be designed to cast and remove the product with less human intervention at high speeds.

Finally, more safety precautions can be taken to improve on the epoxy-base products. The pungent smell can be eliminated with additives without affecting the composition of the matrix.

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Appendix

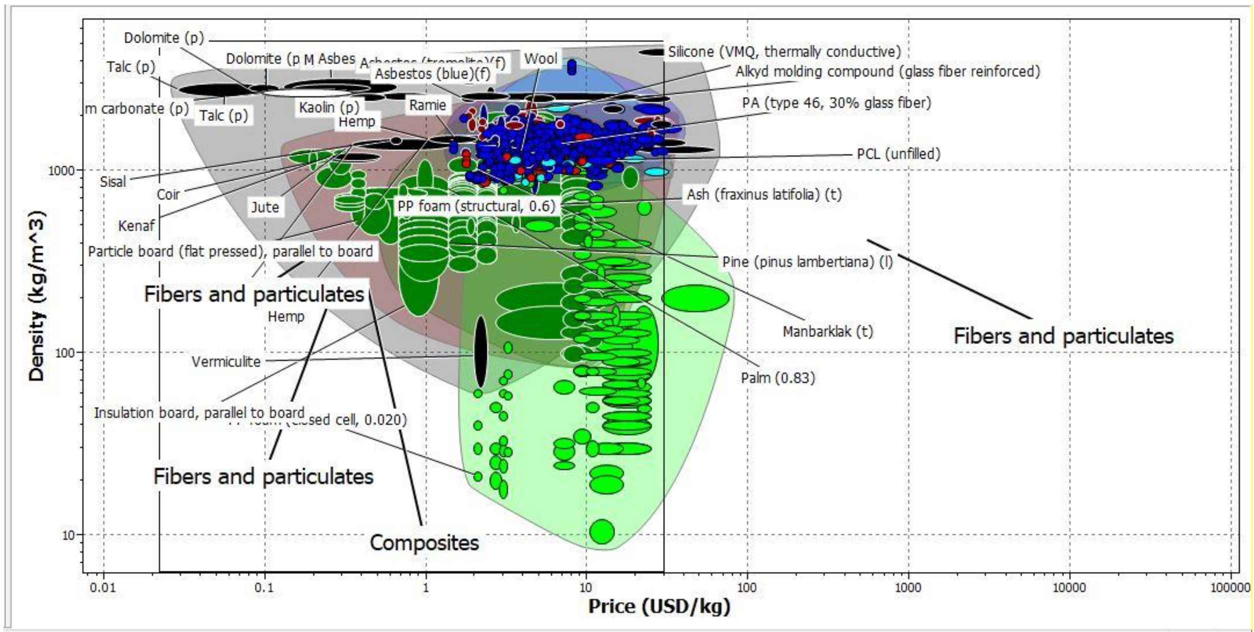

Figure A1: Material selection graph of density against Price

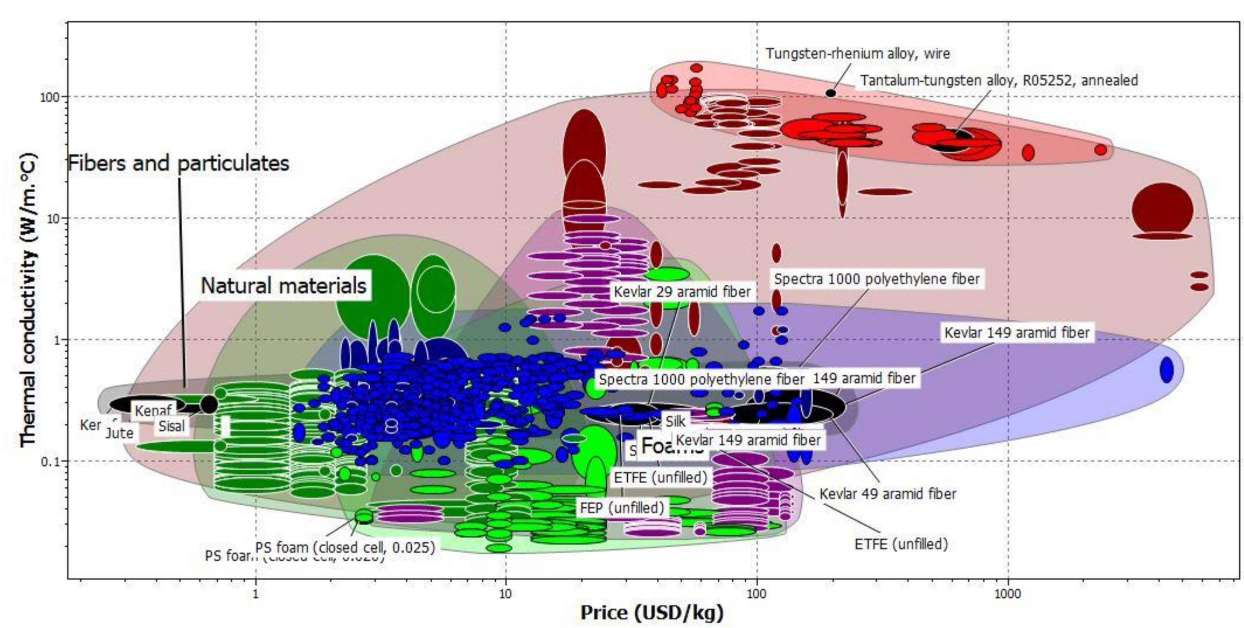

Figure A2: Material selection graph of thermal conductivity against Price

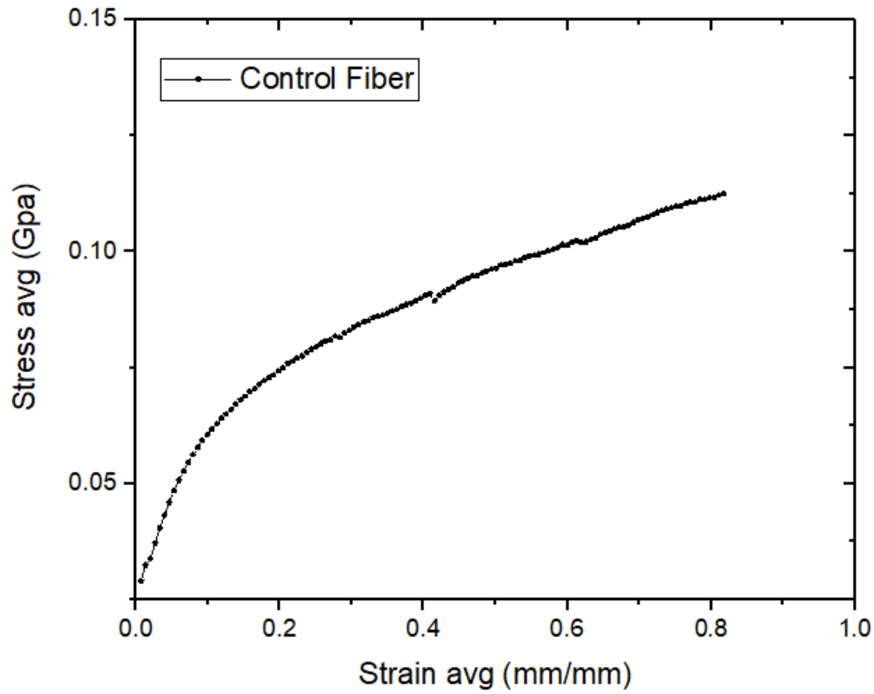

Figure A3 *: Graph of Unmodified fiber stress against strain*

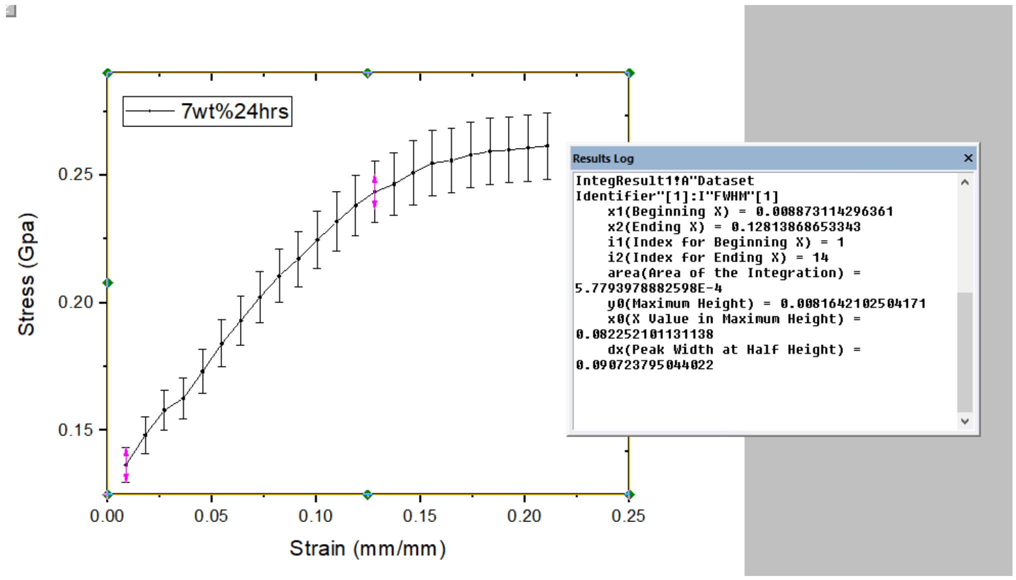

Figure A4: *Computation of area under stress vs strain curve, elastic region for modulus of resilience for7%24hrs*

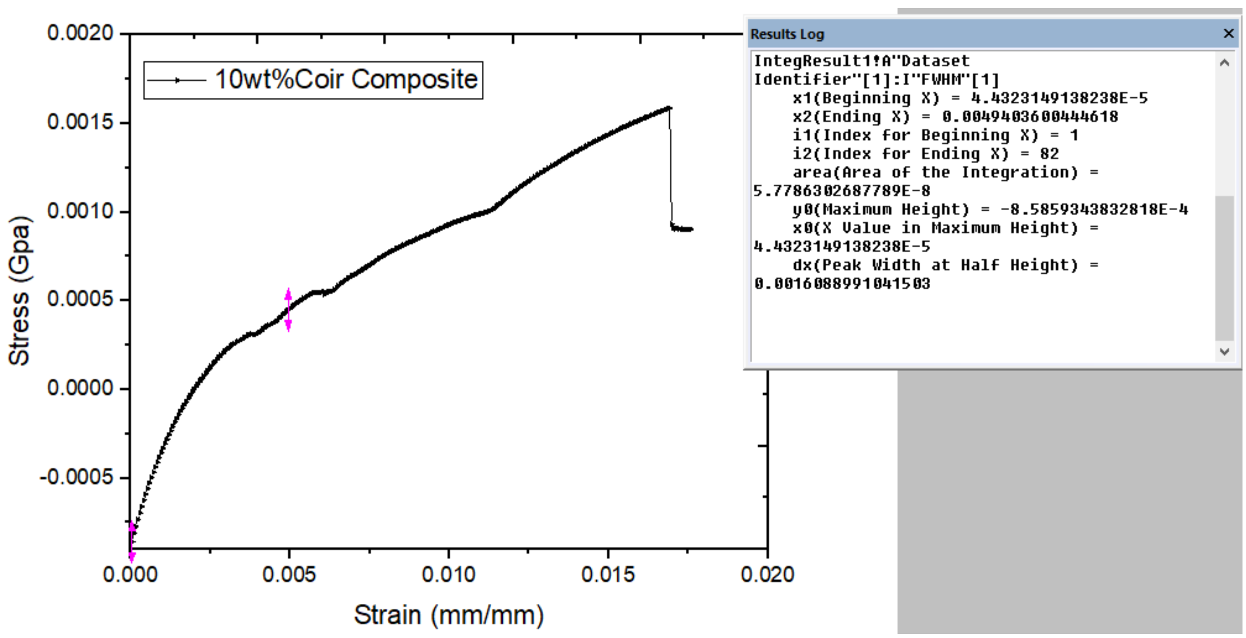

Figure A5*: Computation of area under stress vs strain curve, elastic region for modulus of resilience for7%24hrs*