Mechanical Property Evaluation of Coconut Fibre

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This thesis work is submitted for the award of Master of Science in the Department of Mechanical Engineering with Emphasis on Structural Mechanics, Blekinge Institute of Technology, Karlskrona, Sweden.

Abstract:
This thesis work is on eco-friendly, agricultural material. Examples of some non-wood fibre material are also discussed briefly but with emphasis on coconut fibre to evaluate its mechanical properties. Experiments were carried out and the result analyzed to calculate its young modulus, yield stress and stress and strain at break. The results obtained from the test machine were analyzed. Finite element model was created with a commercial software ABAQUS to compare the results obtained from the tensile test (experiment) to arrive at meaningful results for validation.

Keywords:
Coconut Fibre, Young modulus, Stress and Strain at break, Yield stress, Tensile test, MTS, FEM, ABAQUS and MATLAB.
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Afa Austin Waifielate
Bolarinwa Oluseun Abiola
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## 1 Notation

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<tr>
<td>A</td>
<td>Area</td>
<td>(mm^2)</td>
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<td>E</td>
<td>Young modulus</td>
<td>(\frac{N}{mm^2})</td>
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<td>(\nu)</td>
<td>Poisson’s ratio</td>
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<td>(\varepsilon)</td>
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<td>(\sigma)</td>
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<td>(\sigma_y)</td>
<td>Yield stress</td>
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<td>(\sigma_b)</td>
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## Abbreviations

<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>MTS</td>
<td>Mechanical Testing and Simulation</td>
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<td>PALF</td>
<td>Pineapple Fibre</td>
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<tr>
<td>OLP</td>
<td>Oil Palm Fibre</td>
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<tr>
<td>SI</td>
<td>Standard International</td>
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<td>FEM</td>
<td>Finite Element Method</td>
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<td>S.D</td>
<td>Standard Deviation</td>
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2 Introduction

2.1 Background of Study

Agricultural or biodegradable materials have played a major role in human life. This can be dated back in the primitive age where these agricultural resources such as wood, is used to make shelter, cook food, construct tools and make weapons. The advantage of using such resource is that, they are widely distributed in all zones of the world, its multifunctionality, strength, and also biodegradable [1]. But with the incoming of plastic, and especially the leading material in the 21st century that provide comfort and other uses in modern day life, which are derived from irreplaceable fossil fuels and other mineral ore from the earth crust [2]. Due to these plastics, high performance metals, ceramics and other synthetics materials, the use of biodegradable materials lost its place. When environmental degradation stated to set in, where landfills are filling up, the resources are being used up, and our plants constantly being polluted, rivers and ponds are forming due to waste, the impact on green house gases, and carbon in the atmosphere. This level of waste made government to spend millions of dollars to land fill sites, and that was the reason there was a renewed effort in technology, which is aimed at using environmental- friendly, renewable, recyclable and above all, biodegradable material for production [1].

It is known that the plastics we use today are derived from petroleum product, which has contributed to several billions of pounds of plastic waste and are discarded each year, most end up in land fill, Renewable resources such as plant, animal and microbes through biochemical reaction offer good remedy to the problem of plastic waste [3]. The use of materials from renewable resource is attaining great importance because every organization tends to shift from petroleum based to composite derived from natural materials [4].
2.2 Overview and Aim of Work

This thesis work focuses on coconut fibre, a biodegradable, and an eco-friendly material in which the fibre was investigated in the lab using a tensile testing machine (MTS). A finite element method was carried out on the model using a commercial software ABAQUS. Data’s were collected and plots carried out and the results compared for validity between experimental and simulation work which is illustrated by the figure 2.1 below.

The Purpose of this thesis work is to carry out a simulation work by creating a model corresponding to the material under investigation. The Simulation and Experimental work forms the bases of the approach used in carrying out the work by.

- Investigating the Mechanical Properties.
- Performing the Mechanical Test on (MTS) Machine.
- Verification of the Mechanical Properties of the coconut Fibre by Simulating a finite Element Model in ABAQUS.
3 Definitions of Terms

In this chapter, several useful terms will be discussed, to enable us understand what are agricultural, eco-friendly material which are listed below.

- Renewable material
- Recyclable material
- Biodegradable material
- Sustainable material
- Natural material

3.1 Renewable Material

The term renewable material in general is the recovery and reuse of a material after its initial function has expired. When design considerations are made the reuse and collection process need to be looked properly and considered [5].

3.2 Recyclable Material

The word recycling has become the key issue in many business organizations, because of its cost-saving and environmental friendly aspects.

Recycling is not a new concept but can be said to be historic which is dated back from the realities of war years. According to Waite, "Recycling is a very broad term referring to the conversion of waste (as discarded materials with no worth) into a useful material". When these materials are recycled they provide economic benefits. Energy cost are saved, Conserve resources, protect the environment and also provide gainful employment [6, 7]. Typical recycling process as shown in figure 3.1.
3.3 Biodegradable Material

Biodegradable materials are environmentally acceptable and are receiving increasingly interest all over the globe. Increased environmental pollution from the consumption of petroleum product has made Biodegradable materials as alternative to petroleum plastics because of its abundance, renewable, eco-friendly nature to the environment. [4].

Biodegradable materials are so important in the sense that;

- It does not cause adverse effect on our eco-system.
- They grow in any and different zones.
- Carbon dioxide in the atmosphere is recycled and thereby resuscitates these plants for better agricultural balance.
- Some of these plants are used to clean up the soils which are being polluted during extraction of metals on the earth crust.
The abundance of these natural biodegradable materials are renewable, low-priced and have good mechanical properties which make them to be used more often.

Natural Fibres show that they have less negative effects [8].

Therefore biodegradable materials are combination of more than two or more distinct materials to form a solid mass product. This can be decomposed by natural means such as bacteria or by its self naturally. It should also include a binding matrix for the purpose of keeping the Composite formed in place which gives the composite so formed a greater strength, impact resistance and other physical and mechanical characteristics to enhance its functionality [9].

3.4 Sustainable Material

Due to environmental degradation from fossil based resources, it is therefore important to reduce the burden from product that causes adverse effect on the environment. Since materials are used and are part of the product, its life-cycle design is necessary. Thus, the need for sustainable material will be focused on.

Sustainable material can be defined as those materials that are usable for the life-cycle product that will not cause the environment any harm.

Sustainable material can be categorized into several classes but what we are concerned here are sustainable materials with green environmental features which are from renewable resources. Examples are plant based material, bio plastics and bio ceramics. These materials have less environmental loads from its mining process to manufacturing of its product. Their waste or by-product during consumption and processing also have less effect on the environment by not releasing or consuming poisonous substance to the eco-system which makes them more for life-cycle design over depleting minerals and fossil fuels[10].
3.5 Natural Material

In the early years of man existence, it is a known fact that almost all the materials for production of variety of commodities like paper, ropes, textiles and general use, are obtained from natural materials. Therefore natural material in a broad sense can be stated as material that are either of plant origin or plant crops that are fundamental to human existence, such that they provide[24,25 ].

- Energy
- Food
- Raw materials
- Feed for livestock and above all pleasure is derived from them.

3.5.1 NATURAL MATERIAL CLASSIFICATION

Natural materials are basically classified as lignocellulose in nature, that is they contain;

- Cellulose
- Hemicelluloses
- Lignin
- Pectin
- Waxes
- Water.

But out of the six components the main constituent are cellulose, hemicellulose and lignin while pectin, wax and water are referred to as the Mino components of natural material.

3.5.2 NATURAL FIBRE

Natural fibres are obtained from its stem, leaves, roots and fruits of the plant and they are categorized into two distinct groups namely;

- Wood fibre.
- Non-wood fibre.

And the major group is divided into several sub-groups [26, 27].
4. Example of Non Wood Fibre

4.1 Oil Palm Fibre (OLP)

Oil palm originally came from the western part of Africa in the tropical rain forest where it is processed for its fruits for consumption as edible oil, often flavored and highly colored. The fruits of the palm vary in weight and are always in bundle [13]. Oil palm has a variety of product, which serves as food, medicine, and palm wine, raw materials for fertilizers, boiler fuel, and the production of various hand craft. The fibre is extracted from its oil and always in a dirty state; it has to be cleaned up before it can be used. The components that make up the oil fibre are cellulose and lignin. The fibres are porous and have varying diameter, which influence the mechanical property, it is ductile and have lower tensile strength than several plant fibres. The fibre length can be compared with those of hard wood and soft wood but some can be shorter but its chemical composition is liken to that of coconut fibre but has lower cellulose content to those of jute and flax [14].

Figure 4.1.Oil Palm Fruit Bunch [13].
4.2 Pineapple Fibre (PALF)

The plant pineapple was first seen in the southern part of Brazil and Paraguay; the species were known to be wild before the Indians domesticated them. Pineapple is one of the most valuable and commercial fruits of the tropics; the leaves are long, wide, and rigid. It also has short stem which is strong and silky. White fibre can be separated from it which is useful for the production of textiles, thread, stringing jewels, nets, wrapping and making of carpets [15]. The fibre is a multi-cellular lignocellulosic. Pineapple fibre is made up cellulose, Polysaccharides and lignin; it is hygroscopic and has a very good mechanical Property that can be attributed to its high cellulose content and the small microfibriller angle [14].

*Figure 4.2. Pineapple Fibre [29]*.
4.3 Kenaf Fibre

Africa was the first place was Kenaf was first cultivated and later introduced to Asia in the Year 1900. The leaf is used as food for human and animal, and the woody core as fuel. Kenaf is a crop that is gown annually. It is a short herbaceous plant that is like Cotton, okra, and hollyhocks. Kenaf is used for the production of paper, newsprint, and pulp. The best fibre quality is obtained from inception of the flowers. The plant can attain a height up to 12-18 feet say in about 150 days of planting. Kenaf has a very high fibre per acre, less lignin, therefore not too tough, and the chemicals heat processing time is less, which makes energy input low [16, 17]. Absorption of carbon dioxide in kenaf is more to any plant. The plant has two fibre types, a long fibre located at the cortical layer and a short fibre, located at the ligneous part and the fibres of kenaf are short and in the range of 1.5 and 6 mm which contains less non cellulosic material than jute [14].

![Kenaf fibre](image)

*Figure 4.3. Kenaf fibre [29]*.
4.4 Bamboo Fibre

Bamboo is a tropical, sub-tropical and temperate plant where it is used as a non-wood material. Its abundance, availability, rapid growth, easy handling as made it to be used in our daily life for various domestic uses. For the production of papers, paper board, fishing poles, musical instrument, for food, furniture and local craft, which can be attributed to good strength, its straightness, smoothness, lightness, hardness and its hollow features which can be broken down into various shapes, size, length and thickness. It has been established that the mechanical properties of the plant has significant difference along its length that is from top to bottom, the strength of bamboo also increase with its age. This also depends on the thickness, diameter, moisture content and its density [18, 19].

Figure 4.4. Bamboo Plants [19].
4.5 Cassava Fibre

Cassava is a crop that is mostly grown in the tropical areas of the world. Countries that are engaged in its production are Nigeria, Cameroun, Indonesia and Brazil. The crop is grown in all season and a major commercial crop which derives, economic returns and processed for its chips, raw material for making textiles, adhesive and paper for the industries. It’s the third most important food commodity in the tropics, it’s very high in calorific content and the leaves are very rich in protein [30, 31].

Figure 4.5. Cassava Plant[32].
4.6 Coconut Fibre

Coconut palms are mainly cultivated in the tropical regions of the world and the product from the palm is applied in food and non-food products, which sustains the livelihood of people all over the globe. The coconut palm comprises of a white meat which has a total percent by weight of 28 surrounded by a protective shell and husk which has a total percent by weight of 12 and 35 respectively as shown in figure 4.7. The husk from the coconut palm comprises of 30% weight of fibre and 70% weight of pith material. The fibre are extracted from the husk by several methods such as retting, which is a traditional way, decortications, using bacteria and fungi, mechanical and chemical process, for the production of building and packaging materials, ropes and yarns, brushes and padding of mattresses and so on[10,11].

Figure 4.6. Coconut Fibre.
In the following chapters coconut fibre will be chosen and investigated to ascertain its relevance and important qualities it posses, which are listed below.

- It’s a renewable resource and CO2 neutral material.
- The fibre is abundant, non-toxic in nature, biodegradable, low density and very cheap.
- The fibre has a high degree of retaining water and also rich in micronutrients.
- The fibres instead of going to waste are explored for new uses, which in turn provide gainful employment to improve the standard living condition of individuals [10, 11, 12, and 34].
5. Chemical Composition of Coconut Fibre

5.1 Constituents of Coconut Fibre

The main constituents of coconut fibre are

- cellulose,
- Hemicelluloses
- lignin and other vital substances,

Which are known as the building block of the cell structure, Coconut fibre is practically multicellular naturally and its diameter and length ranges from different dimensions and it’s usually very thick at the middle of the fibre length.

- Coconut fibre has the highest percentage by volume of lignin, which makes the fibre very tough and stiffer when compared to other natural fibre. This can be attributed to the fact that the lignin helps provide the plant tissue and the individual cells with compressive strength and also stiffens the cell wall of the fibre where it protect the carbohydrate from chemical and physical damage.

- The lignin content also influences the structure; properties, flexibility, hydrolysis rate and with high lignin content it appear to be finer and also more flexible [20].
5.2 Fibre Structure

The fibre structure is determined by the dimension and arrangement of various unit cells, and which also influence the fibre properties. “Fibres are elongate cells with tapering end and very thick lignified cell wall ‘as shown in figure 5.1. Fibre dimensions of the various individual cells are said to be dependent on the type of species, location and maturity of the plant. The flexibility and rupture of the fibre is affected by the length to diameter ratio (l/d) of the fibre and this also determines the product that can be made from it. The transverse sections of the unit cell in a fibre have a central hollow cavity known as lumen and that its shape and size depends on two factors such as the thickness of the cell wall and the source of the fibre. The hollow cavity serves as an acoustic and thermal insulator because its presence decreases the bulk density of the fibre [9].

![Figure 5.1. Section of a fibre Cell [22].](image)

5.3 Fibre Property

The structure and property in a fibre is determined by the quantity of cellulose and non cellulosic constituents and this influences the crystalline and moisture regain. Properties like tensile strength, density and young modulus are related to the composition by the internal structure of the fibre. Fibres that have high cellulose content, with degree of polymerization that is high and low microfibrillar angle gives better mechanical properties while those with higher contents of lignin, lower length to diameter ratio and microfibrillar angle that is high gives lower mechanical strength and young modulus but have better and higher extensibility. Mechanical properties such as young modulus, stress and strain of a fibre are influenced by the composition, structure and number of defects in a fibre. When tensile failure occur under stress by intercellular or intracellular modes, the fibres
with high cellulose crack causing intercellular fracture without the removal of microfibrils and those with low cellulose crack causing intracellular fracture with the removal of microfibrils. The factors that affect elongation of a fiber can be attributed to the orientation, high degree of crystallization and the angle of the microfibrils to the axis of the fibre [9].
6 Mechanical Testing

6.1. Tensile Test by MTS Machine

Mechanical simulation was carried out using MTS QTEST 100 machine and the result were stored and also displayed by a software package known as MTS Test Work4. The test machine consists of a cross head in which the load cell and grippers are mounted on it as shown in figure 6.1.

The machine is designed in such a way that the upper gripper can move in the vertical direction while the lower gripper is fixed. Different types of grippers are available such as the pneumatic and rectangular grippers. In this experimental work a load cell of 100N was used. The fibre specimen were subjected to tension by applying displacement and using the pneumatic gripper of pre separation length of 30mm with external values of thickness and width of 1 and 6mm respectively and strain rate(cross-head speed) of 1.2mm/min is applied.

Figure 6.1. Specimen under Investigation on MTS.
6.2 Specimen Preparation

The specimen used for this experiment was gotten from the southern region of Nigeria, where the coconut husk was retted carefully to obtain the fibre mechanical property. The fibres were sorted in two categories according to inner and outer fibre sample with different diameters and a constant length. Five specimens of each outer and inner fibre were used for the experiment under room temperature.

6.3 Area Measurement

The fibre cross sectional area is a very important parameter to determine the mechanical properties such as the tensile strength and its young modulus. The fibre area from test conducted to investigate the shapes of different fibres like bamboo, banana, coconut, date palm, sisal and vakka fibre.It was found that the area of these fibres are approximately circular except of vakka fibre which has different shapes, that is from circular to oval depending on the geographical location [27]. The fibre cross sectional area is practically calculated from the fibre diameter. Once the fibre diameter is obtained the Cross sectional area is then calculated with the equation (6.1) shown below.

\[ A = \frac{\pi d^2}{4} \]  

(6.1)

The fibre diameter can be obtained by using either the micro meter screw gauge or the vernier caliper. Since the fibres have external diameters the micro meter screw gauge was used to calculate the diameters and it is the most accurate gauge that can be used.Its measurement capacity is of the range of 0-25mm [28].
6.4 Experimental Steps carried out on (MTS) Machine

Before the experimental work was carried out using the test machine MTS, we made sure that the correct procedure was adhered to so that useful results will be obtained.

The steps carried out are as follows;

- The MTS machine was initiated and the software Test Work4 activated on the computer.
- The test method to be used is chosen with constant grip separation method.
- Basic SI units were used.
- Grip separation of 30mm was used for the experiment.
- The input on the MTS machine were set according to METHOD>EDIT METHOD >GLOBAL UNITS SI>ITEMS>INPUT.

The inputs required are specimen thickness, width and test speed according to the specimen under investigation.

- There should be no pre load or slacking when mounting the specimen.
- The test is carried out by using the play button from the computer or the MTS test machine.
- The result are then obtained from the review window and then exported as test file for analysis.

6.5 Mechanical Property Characterization

For the mechanical property to be described properly, it is not wise to describe the material verbally because it does not give precise information about the material for useful qualitative application.

- For this reason we use simple mechanical formula to arrive at useful result for their suitability in application purpose.
• So one of the properties we are going to look at is deformation where the material obeys Hook’s law, which can be said that the deformation is proportional to the applied force.

• For us to really specify the property we have to define the quantity stress and strain and this can be illustrated by the stretching experiment figure 6.2 where a bar of length \( L_0 \) and cross-sectional area \( A \) is stretched by a distance \( \Delta L \) by an applied force \( F \) [21].

![Diagram 1](image.png)

*Figure 6.2. Illustration of Hook’s Law[23 ].*

### 6.5.1 Stress

This is a measure of the force that causes the deformation and is mathematically represented by:

\[
\text{Stress} = \frac{\text{Defor min gForce}}{\text{AppliedArea}}
\] (6.2).
6.5.2 Strain

The amount of stretch \( L_1 \) depends on the original length \( L_0 \) of the bar so it can be defined as the change in length per the original length, Mathematically defined as:

\[
Strain = \frac{\text{Distortion}}{\text{Original Length}}
\]  \hspace{1cm} (6.3)

\[\varepsilon = \frac{\Delta L}{L_0}\]

Where \( \Delta L = L_1 - L_0 \)

6.5.3 Modulus of Elasticity

Since we say the material obeys Hook’s law the stress and strain are related by the equation:

Stress = constant \( \times \) Strain

Where the constant of the equation is known as the modulus of elasticity and mathematically represented by:

\[Modulus = \frac{\text{Stress}}{\text{Strain}}\]

The modulus of elasticity is how difficult the material can deform.

The modulus of Elasticity can also be written as equation (6.4).
6.5.4 Yield Stress

The yield stress is the transition point between the elastic and the plastic region of a material or it can be said to be the stress required to produce a small amount of plastic deformation. The Yield stress is obtained by the equation (6.5) or it is assumed to be in the range of 0.05 to 0.1 % of the material modulus.

\[ \sigma_{true} = \sigma_{nom} (1 + \varepsilon_{nom}) \]  
(6.5)

\[ \varepsilon = \ln(1 + \varepsilon_{nom}) \]  
(6.6)

Where

\[ \sigma_{nom} = \text{Stress from experiment.} \]

\[ \varepsilon_{nom} = \text{Strain from experiment.} \]
6.6 Experimental Results

The experimental results obtained from the test machine (MTS) was used and plots were carried out between Load against Extension, Stress against Strain curves were also plotted and are shown below according to inner and outer fibre specimen.

6.6.1 Inner Fibre Curves for Load vs. Extension

The Load against Extension curves of the five inner specimen coconut fibres are plotted as shown in figure 6.3.

![Figure 6.3 Load vs. Extension curve for Inner Fibre.](image)
6.6.2 Outer Fibre Curves of Load vs. Extension:

The Load against Extension curves of the five outer specimen coconut fibres are plotted as shown in figure 6.4.

![LOAD VS. EXTENSION](image)

*Figure 6.4 Load vs. Extension curve for Outer Fibre.*
6.7. Fibre Property:

6.7.1 Inner Fibre curve of Stress vs. Strain

The stress versus strain curves of the inner fibres specimen are displayed in figure 6.5 below, two points were taken along the linear portion on the stress-strain graph of each fibre specimen to calculate the modulus of elasticity, yield stress, stress and strain at break values are obtained from the figure and are tabulated below the stress vs. Strain curve.

Figure 6.5 Stress vs. Strain curve for Inner Fibre.
6.7.2. Outer Fibre Curves of Stress vs. Strain:

The Stress versus strain curves of the five outer specimen coconut fibres are displayed in figure 6.6 below, two points were taken along the linear portion on the stress- strain graph of each fibre specimen to calculate the modulus of elasticity, properties like yield stress, stress and strain at break values were also obtained from the figure and tabulated below in the stress vs. Strain curves.

![STRESS VS. STRAIN](image)

*Figure 6.6 Stress vs. Strain curve for Outer fibre.*
6.8 Inner and Outer Fibre Comparison:

The values of yield stress, young modulus, stress and strain at break that were obtained from the inner and outer fibre specimen were used and plots of the mechanical properties were carried out in a bar chat for comparison as shown in the figures 6.7, 6.8, 6.9 and 6.10.

Figure 6.7. Young Modulus comparison.

Figure 6.8. Yield Stress comparison.
Figure 6.9. Stress at break comparison.

Figure 6.10. Strain at break comparison.
7 Finite Element Modeling and Result

7.1 Brief introduction to ABAQUS/CAE Model
The simulation work was carried out using commercial software called ABAQUS/CAE which is an engineering tool for programming that is used to solve various degrees of engineering problems ranging from linear to non-linear problems that are complex. The software is used all over the globe in industries and also by academicians.

ABAQUS/CAE enables models to be solved as quickly as possible by simply importing the geometry under investigation with the right physical and material properties associated to it, meshing it, loading and also by applying the boundary conditions to the material to be modeled [33].

7.2 Pre-processing
In the pre-processing, the specimen was modeled and the input file stored which is illustrated by the following steps below.

Creating the Part
The part module was used to create each part that will be carried out on, a three dimensional, deformable shell body was created and sketcher size of 2 was selected which represents the largest dimension of the model under test and we begin by picking an end point for the line.

Property Selection
This involves by defining and assigning material and section properties to the part, each region of the deformable body must refer to a section property which must include the material definition. In defining the section, the young modulus, Poisson’s ratio and yield stress were assigned to the material part.
Creating an Assembly

Assembly contains all the geometry included in the finite element model. The assembly is initially empty, even though you have already created a part module. So you have to create an instance of the part in the assembly module to include the model.

Step

In the step module, analysis step and output request were defined, since interaction, load and boundary condition can be step dependant. So the analysis step has to be defined before these can be specified. For the simulation static and linear perturbation are defined.

Boundary Condition and Applied Load

For the model, we apply boundary conditions on the two ends by making sure that one end is fixed and also displacement was assigned to the other end of the model to create room for movement.

Mesh

This is the module used to create the finite element mesh where a T3D2 Element Type was used as a choice type.

7.3 Simulation

The Module here is done by creating a Job. When all the parameters that are involved in the Model are accomplished in the Job Module we select submit, to submit the job for analysis.

7.4 Post-Processing

In the post-processing, the Visualization Module is used to view the results of stress and strain distribution.
7.5 Results

The results from the Finite Element Method of the stress distribution and the strain values of the specimen of the inner and outer fibres are displayed as shown in Figure 7.1 and 7.2.

![Figure 7.1. Stress vs. Strain curves of Inner Fibres.](image1)

![Figure 7.2. Stress vs. Strain curves of Outer Fibres.](image2)
7.6 Comparison of Experimental Work and FEM

The summary of the result obtained from the Finite Element Method and the experimental calculations for the coconut specimen for both the inner and outer fibres as shown in table 7.1 and 7.2.

Table 7.1 Comparison between Experiment and FEM of Inner Fibres

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>EXPERIMENTAL VALUES</th>
<th>FINITE ELEMENT METHOD VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stress(MPa)</td>
<td>Strain</td>
</tr>
<tr>
<td>Inner Fibre</td>
<td>21.59</td>
<td>0.01768</td>
</tr>
</tbody>
</table>

Table 7.2 Comparison between Experiment and FEM of Outer fibre

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>EXPERIMENTAL VALUES</th>
<th>FINITE ELEMENT METHOD VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stress(MPa)</td>
<td>Strain</td>
</tr>
<tr>
<td>Outer Fibre</td>
<td>12.10</td>
<td>0.01714</td>
</tr>
</tbody>
</table>

Considering the results obtained from Experiment and FEM, the values of the stress distribution, Strain and the displacement values of both the FEM and experimental work shows no significant differences. Therefore the result is considered to have good agreement and the material is assumed isotropic, that is they have the same mechanical properties in all direction.
8 Conclusion and Future Work

This thesis work was carried out to evaluate the mechanical property of coconut fibre and also by verifying the results obtained by finite element method using a commercial software ABAQUS. The experimental work was carried out on both inner and outer fibre specimen and the results obtained were compared with simulation results and it was in good agreement. Plots of load vs. Extension and Stress vs. Strain were carried out and the Young modulus, Yield Stress; Stress and strain at Break were calculated. From the results obtained, we found out that the inner coconut fibre has a higher Mechanical strength compared to the outer coconut fibre, but on the other hand the outer coconut fibre has a higher elongation property which can make it to absorb or withstand higher stretching energy to the inner coconut fibre.

Also from the above experimental work we can say that the surface area of the fibre influences the mechanical property evaluation of the fibre specimen which gives the spread in the curves when plotted for both inner and outer fibre.

The results can be improved upon and future work can take into consideration the following:

- Measuring increased number of points on the fibre.
- The fibre length should be reduced.
- Since the fibres are very light and delicate, high precision is really needed during the experimental work.
- Care should be taken when the retting process is carried out.
- Investigating the fractured zone of the fibre microscopically.
- Surface modification of both inner and outer fibre and then comparing compare the result with the inner and outer fibre without surface modification using finite element method.
9 References


[22] Fibers, For Paper, Cordage & Textiles.  
http://waynesword.palomar.edu/traug99b.htm

[23] Topic 3.2-Stress, Strain & Hook’s Law-II, physics. uwstout.edu/statstr/strength/stress/strs32.htm.7k


[33] ABAQUS Version 6.6 Documentation.
### Appendix A-Experimental work

#### A.1 Mechanical Property of Inner Fibre Specimen

<table>
<thead>
<tr>
<th>Sample</th>
<th>Diameter D(mm)</th>
<th>Area A [mm$^2$]</th>
<th>Young Modulus E ($\frac{N}{mm^2}$)</th>
<th>Yield Stress $\sigma_y$ ($\frac{N}{mm^2}$)</th>
<th>Stress at Break $\sigma_b$ ($\frac{N}{mm^2}$)</th>
<th>Strain at Break $\varepsilon_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.49</td>
<td>0.1886</td>
<td>784.21</td>
<td>18.29</td>
<td>34.93</td>
<td>0.1410</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>0.1964</td>
<td>1193.15</td>
<td>17.67</td>
<td>50.56</td>
<td>0.1530</td>
</tr>
<tr>
<td>3</td>
<td>0.60</td>
<td>0.2828</td>
<td>1534.01</td>
<td>30.82</td>
<td>100.12</td>
<td>0.3017</td>
</tr>
<tr>
<td>4</td>
<td>0.57</td>
<td>0.2552</td>
<td>1568.51</td>
<td>28.90</td>
<td>107.03</td>
<td>0.2800</td>
</tr>
<tr>
<td>5</td>
<td>0.53</td>
<td>0.2206</td>
<td>1065.15</td>
<td>14.25</td>
<td>42.11</td>
<td>0.0666</td>
</tr>
<tr>
<td>Mean</td>
<td>0.54</td>
<td>0.2287</td>
<td>1229.01</td>
<td>21.99</td>
<td>66.95</td>
<td>0.1885</td>
</tr>
<tr>
<td>S.D</td>
<td>0.05</td>
<td>0.0397</td>
<td>329.50</td>
<td>7.21</td>
<td>33.98</td>
<td>0.0996</td>
</tr>
</tbody>
</table>
### A. 2 Mechanical Property of Outer Fibre Specimen

*Table A.2. Mechanical Property of Outer Fibre*

<table>
<thead>
<tr>
<th>Sample</th>
<th>Diameter D (mm)</th>
<th>Area A ( \text{[mm}^2 )</th>
<th>Young Modulus ( E \left( \frac{N}{mm^2} \right) )</th>
<th>Yield Stress ( \sigma_y \left( \frac{N}{mm^2} \right) )</th>
<th>Stress at Break ( \sigma_b \left( \frac{N}{mm^2} \right) )</th>
<th>Strain at Break ( \varepsilon_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.55</td>
<td>0.2376</td>
<td>525.61</td>
<td>13.77</td>
<td>59.09</td>
<td>0.5837</td>
</tr>
<tr>
<td>2</td>
<td>0.53</td>
<td>0.2206</td>
<td>785.35</td>
<td>15.86</td>
<td>63.18</td>
<td>0.4902</td>
</tr>
<tr>
<td>3</td>
<td>0.54</td>
<td>0.2291</td>
<td>563.19</td>
<td>8.22</td>
<td>39.16</td>
<td>0.4425</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
<td>0.1386</td>
<td>869.23</td>
<td>16.11</td>
<td>53.40</td>
<td>0.4093</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
<td>0.1452</td>
<td>987.01</td>
<td>7.66</td>
<td>17.79</td>
<td>0.0229</td>
</tr>
<tr>
<td>Mean</td>
<td>0.49</td>
<td>0.1942</td>
<td>746.08</td>
<td>12.32</td>
<td>46.52</td>
<td>0.3897</td>
</tr>
<tr>
<td>S.D</td>
<td>0.06</td>
<td>0.0482</td>
<td>198</td>
<td>4.11</td>
<td>18.46</td>
<td>0.2153</td>
</tr>
</tbody>
</table>
Appendix B-ABAQUS/CAE Models

Appendix B.1 Inner Fibre Specimen from ABAQUS

The results obtained from ABAQUS using the average values of the Stress vs. Strain curve for both Inner and outer Fibre is shown in Figure B.1 and B.2.

Figure B.1: Stress vs. Strain for Inner fibre.

Appendix B.2 Outer Fibre Specimen from ABAQUS

Figure B.2: Stress vs. Strain for Outer Fibre.
Appendix C- ABAQUS/CAE Input Files

Inner Fibre Model
*Heading
   Inner Coconut Fibre
** Job name: Fibre1 Model name: Model-1
*Preprint, echo=NO, model=NO, history=NO, contact=NO
**
** PARTS
**
*Part, name="Inner Fibre"
*End Part
**
**
** ASSEMBLY
**
*Assembly, name=Assembly
**
*Instance, name="Inner Fibre-1", part="Inner Fibre"
*Node
   1, -0.200000003, 0.0500000007, 0.
   2, -0.192499995, 0.0500000007, 0.
   3, -0.185000002, 0.0500000007, 0.
   4, -0.177499995, 0.0500000007, 0.
   5, -0.170000002, 0.0500000007, 0.
*Element, type=T3D2
   1, 1, 2
   2, 2, 3
   3, 3, 4
4, 4, 5
*Nset, nset=_PickedSet2, internal, generate
  1, 5, 1
*Elset, elset=_PickedSet2, internal, generate
  1, 4, 1
** Region: (Fibre1Section: Picked)
*Elset, elset=_PickedSet2, internal, generate
  1, 4, 1
** Section: Fibre1Section
*Solid Section, elset=_PickedSet2, material=Fibre1
  2.29e-07,
*End Instance
**
*Nset, nset=_PickedSet4, internal, instance="Inner Fibre-1"
  1,
*Nset, nset=_PickedSet5, internal, instance="Inner Fibre-1"
  5,
*End Assembly
**
** MATERIALS
**
*Material, name=Fibre1
*Elastic
  1.23e+09, 0.3
*Plastic
  2.199e+07, 0.
** ---------------------------------------------------------
-------
**
** STEP: Apply load
**
*Step, name="Apply load", inc=10
*Static
1., 1., 1e-05, 1.
**
** BOUNDARY CONDITIONS
**
** Name: Fixed Type: Symmetry/Antisymmetry/Encastre
*Boundary
_PickedSet4, ENCASTRE
**
** LOADS
**
** Name: Force Type: Concentrated force
*Cload
_PickedSet5, 1, 28.8
**
** OUTPUT REQUESTS
**
*Restart, write, frequency=0
**
** FIELD OUTPUT: F-Output-1
**
*Output, field, variable=PRESELECT
**
** HISTORY OUTPUT: H-Output-1
**
*Output, history, variable=PRESELECT
*End Step
Outer Fibre Model

*Heading
Outer Fibre2
** Job name: Fibre2 Model name: Model-1
*Preprint, echo=NO, model=NO, history=NO, contact=NO

** PARTS

**
*Part, name="Outer Fibre"
*End Part

**

** ASSEMBLY

**
*Assembly, name=Assembly

**
*Instance, name="Outer Fibre-1", part="Outer Fibre"

*Node

  1, -0.200000003, 0.0500000007, 0.
  2, -0.192499995, 0.0500000007, 0.
  3, -0.185000002, 0.0500000007, 0.
  4, -0.177499995, 0.0500000007, 0.
  5, -0.170000002, 0.0500000007, 0.

*Element, type=T3D2

  1, 1, 2
  2, 2, 3
  3, 3, 4
  4, 4, 5

*Nset, nset=_PickedSet2, internal, generate

  1, 5, 1
*Elset, elset=_PickedSet2, internal, generate
  1, 4, 1
** Region: (Fibre2Section:Picked)
*Elset, elset=_PickedSet2, internal, generate
  1, 4, 1
** Section: Fibre2Section
*Solid Section, elset=_PickedSet2, material=Fibre2
  1.88e-07,
*End Instance
**
*Nset, nset=_PickedSet10, internal, instance="Outer Fibre-1"
  1,
*Nset, nset=_PickedSet11, internal, instance="Outer Fibre-1"
  5,
*End Assembly
**
** MATERIALS
**
*Material, name=Fibre2
*Elastic
  7.5e+08, 0.3
*Plastic
  1.232e+07,0.
**  -----------------------------------------
-------
**
** STEP: Apply load
**
*Step, name="Apply load", inc=10
*Static
  1., 1., 1e-05, 1.
**
** BOUNDARY CONDITIONS

**

** Name: Fixed Type: Symmetry/Antisymmetry/Encastre

*Boundary
_PickedSet10, ENCASTRE

**

** LOADS

**

** Name: Force Type: Concentrated force

*Load
_PickedSet11, 1, 14.4

**

** OUTPUT REQUESTS

**

*Restart, write, frequency=0

**

** FIELD OUTPUT: F-Output-1

**

*Output, field, variable=PRESELECT

**

** HISTORY OUTPUT: H-Output-1

**

*Output, history, variable=PRESELECT

*End Step
MATLAB SCRIPTS

INNER FIBRE

clear all;
close all;
clc;
%%
x1=[0 0.01886525 0.0177305 0.0221631 0.0229942 0.0233059
0.0235397 0.023790 0.023799 0.02382];
y1=[0 0.691489 1.38298 1.72872 1.79355 1.81786 1.829 1.829
1.829 1.829 1.829];
z1=x1.*y1;
plot(z1,'r+-')
%%
x2=[0 0.00857486 0.0128623 0.0144701 0.0147715 0.0148846
0.0149058 0.0149098 0.0149127 0.014915 0.014982];
y2=[0 1.02041 1.53061 1.72194 1.75781 1.767 1.767 1.767
1.767 1.767 1.767];
z2=x2.*y2;
hold on
plot(z2,'O--')
%%
x3=[0 0.0127809 0.0159761 0.0171744 0.0176237 0.0177922
0.0179186 0.0179422 0.0179511 0.0179578 0.0180388];
y3=[0 1.57 1.97 2.17 2.19 2.20 2.20 2.20 2.20 2.20];
z3=x3.*y3;
hold on
plot(z3,'m')
%%
x4=[0 0.00764656 0.0114698 0.0129036 0.0131724 0.0132732
0.0133488];
y4=[0 0.818182 1.22727 1.38068 1.40945 1.42023 1.425];
z4=x4.*y4;
hold on
plot(z4,'g-O')

x5=[0 0.013211 0.0198164 0.0199255 0.0199356 0.0199404];
y5=[0 2.02128 3.03191 3.14125 3.20544 3.21632];
z5=x5.*y5;
hold on
plot(z5,'b-V')

x6=[0 0.013738 0.0171725 0.0184604 0.01854232 0.01864410];
y6=[0 2.15686 2.69608 2.89 2.89 2.89];
z6=x6.*y6;
hold on
plot(z6,'b--')

title('M-STRESS VS STRAIN');
xlabel('STRAIN');
ylabel('M-STRESS[10^7]');
legend('fibre 1','fibre 2','fibre 6[AVE]','fibre 5','fibre 3','fibre 4');

OUTER FIBRE

clear all;
close all;
clc;

x1=[0 0.0227689 0.0241919 0.0247256 0.0255261 0.0258262 0.0259388 0.025981 0.0259822];
y1=[0 1.20675 1.28217 1.31046 1.35288 1.36879 1.37476 1.37699 1.37705];
z1=x1.*y1;
plot(z1,'r+-')

x2=[0 0.0163406 0.0173619 0.0188938 0.0194683 0.0196837 0.0200069 0.0201281];
y2=[0 1.29091 1.37159 1.49261 1.538 1.55502 1.58054 1.586];
z2=x2.*y2;
hold on
plot(z2,'O--')

x3=[0 0.01138298 0.012766 0.0151596 0.0160572 0.0163938 0.0164253 0.0165187 0.0165688];
y3=[0 0.478723 0.957447 1.13697 1.20429 1.22953 1.2319 1.232 1.232 1.232];
z3=x3.*y3;
hold on
plot(z3,'m')

x4=[0 0.00417973 0.00522466 0.00679206 0.00737983 0.00760025 0.0076829 0.0077139 0.00772552 0.00772988 0.00773642];
y4=[0 0.413793 0.517241 0.672414 0.730603 0.752425 0.760608 0.763676 0.764827 0.765258 0.765906];
z4=x4.*y4;
hold on
plot(z4,'g-')

x5=[0 0.0143481 0.0165443 0.0178325 0.0191825 0.0192834 0.0193588 0.0194475];
```matlab
y5=[0 0.803493 1.21625 1.37557 1.40835 1.41012 1.41432 1.41544];
z5=x5.*y5;
hold on
plot(z5,'b-V')

x6=[0 0.0126603 0.0158254 0.0170123 0.0174574 0.0181251 0.0183754 0.0184693 0.0185045 0.0185177 0.0185189];
y6=[0 1.10145 1.37681 1.48007 1.5188 1.57688 1.59866 1.60683 1.60989 1.61104 1.61115];
z6=x6.*y6;
hold on
plot(z6,'b--')

title('M-STRESS VS STRAIN');
xlabel('STRAIN');
ylabel('M-STRESS[E+007]');
legend('fibre 1','fibre 2','fibre 6[AVE]','fibre 5','fibre 3','fibre 4');
```