Development of Carbon Fibre Reinforced Natural Rubber Composite for Vibration Isolation

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Abstract. This study is based on readily available materials within the locality. The extraction of carbon fibre from periwinkle shell is to reduce the high cost of processing carbon fibre from petroleum pitch and to serve as reinforcement to the natural rubber resin. The fibre was activated using potassium hydroxide (KOH) followed by characterization through XRF, tensile test, hardness and impact test. On forming the composite, the reinforced material was calculated on percentages: 10%, 20% and 30% and added differently to 220 grams of natural rubber resin. The samples were then prepared for various tests analysis based on ISO and ASTM standard, (ISO 527 for tensile test, ISO 179 for impact test and ASTM D2240 for hardness test) to determine the composite strength in comparison with the natural rubber for vibration isolation. The basis for this comparison is because natural rubber is widely used as a vibration isolator. The result shows an increased in tensile strength of the composite to 0.20 mega Pascal as against 0.09 mega Pascal of natural rubber resin, good strain rate for improved isolator life and high resistance to thermal expansion.

Keywords: Activated Carbon Fibre, Composite Materials and Vibration Isolators

1. Introduction

Vibration emanating from machinery during operation is a normal phenomenon that occurs in all equipment, ranging from high precision machine to the least electronic components. The effects of vibration are quite disastrous if not control. It accelerates wear and tear in machine components, degrades and cause sudden breakdown of machine equipment and renders the environment unfavourable for habitation.

Carbon fibre on the other hand has good mechanical properties such as high stiffness, good tensile strength, fatigue resistance, corrosion resistance, wear resistance and environmental stability [1]. The formation of composites arising from the interface between reinforced fibre and matrix tends to increase the damping capacity and also increases the stiffness effects. Traditionally, isolators are manufactured using natural rubber, to meet functional requirements
such as vibration isolation and durability, carbon fibre is added into the rubber matrix as reinforcement which further increases the strength of vulcanized rubber more than tenfold [2].

Carbon fibre reinforced natural rubber composites is a composition of resins and fibre. The stiffening agent is the carbon fibre activated from periwinkle shell, while the resins are the natural rubber matrix. Periwinkle shell is used in this study because they are cheap and readily available. The shell contains volatile matter and moisture that are removed through heat method [3]. Periwinkle shells are waste materials that have no competing demands and environmental concerns. The high carbon content of periwinkle shell has necessitated the use of it for the production of activated carbon [4].

The damping strength of any vibration isolator depends largely on the composite used (the fibre and resin). The resin being the natural rubber matrix has low stiffness that result to low strength and loose modulus [10], low resistance to solvent that causes material swelling, softening and failure. Another major concern of natural rubber matrix is its vulnerability to high temperature, sunlight and oxygen, which cause stickiness that result to deformation [11]. The rubber matrixes need reinforcement to improve its mechanical properties to effectively subdue vibration.

To overcome vibration, a material composite must combine high strength with high stiffness which is the properties of a reinforcing fibre. The carbon fibres which act as a reinforcement carry most of the load. The resin helps to maintain the relative position of the fibre within the composite, and transfer load from the bottom fibre to the inner fibre [5]. These strengthen the interfacial properties of the fibre/resin composites.

The use of carbon fibre activated from periwinkle shell, with natural rubber is to control excessive effects of vibration on equipment and environment. The composition of these materials is based on their bonding nature and good mechanical properties. Carbon fibre on the other hand has good tensile strength, high stiffness and high resistance to fracture. While natural rubber is widely used as damping material, owing to its high resilience (elasticity) and resistance to corrosion.

This study is aimed at increasing the low stiffness of natural rubber to increase its damping ability, to cure the deterioration of natural rubber to withstand solvent, petroleum derivatives and to increased/improved the low resistivity of rubber matrix to harsh weather condition.

2.0 Materials and method

The major materials for this study are natural rubber obtained from a species of trees known as *Hevea brasiliensis* and carbon fibre activated from periwinkle shell. The non-coagulated lumps of natural rubber were obtained in a liquid form from rubber plantation in Cross River State. While the periwinkle shell is a waste material collected from the coastal area of Creek town in western Calabar. The collected periwinkle shells were thoroughly washed in fresh water and allowed to dry in the sun for 48hours to drain off the water. It was further dried in a thermostatic drying oven at the geology department, University of Calabar at a regulated temperature of 100 degree Celsius for 24hours to completely remove water residue in the shell. The dried shell were then crushed
into smaller sizes by a jaw crusher and then pulverised in a rock pulverizing machine, geology department, University of Calabar. The pulverize particles of periwinkle shell were further sieve using a sieving equipment of 200µm mesh size to obtain a fine particle.

![Periwinkle shell](image1) ![Crushed shell](image2) ![Pulverize shell](image3) ![Sieved shell](image4)

The elemental composition of the sieve periwinkle shell was detected by X-ray Fluorescence (XRF) spectrometer at Centre for Solid Minerals Research and Development, Kaduna Polytechnic. The periwinkle sample was placed on the XRF machine and allowed to run for interval of 30seconds to detect each elemental composition of the sample.

### 2.1 Carbonization and Chemical Activation

420grams of the sieved periwinkle shell were measured using a digital mass scale (20kg 1g high accuracy digital analytical balance) and placed in a vecster LF3 muffle oven – Gemini BV at a temperature of $300^\circ$C for 2hours to have the char particles of the periwinkle shell. It was then cooled at a room temperature of $23^\circ$C for activation.

The carbonized periwinkle shell was then activated using Potassium Hydroxide (KOH) solution as the oxidizing agent. 100grams of Potassium Hydroxide (KOH) were added to the 420grams of the carbonized samples of periwinkle shell inside a plastic container and was then mixed thoroughly with a distilled water to dissolve all the (KOH) solution [6]. The dissolve solution was placed under Bunsen burner to remove water residue and then transferred to furnace were it was further heated to a temperature of $800^\circ$C for 2hours. The sample was collected and stored in an airtight container after being cooled at a room temperature of $23^\circ$C.

### 2.2 Forming the composite

The activated carbon fibre obtained from the periwinkle shell was calculated mathematically at a different percentage range of 10%, 20%, and 30% (as shown below) and added differently to 220grams of natural rubber resin and then stirred manually for 20minutes to minimize air or gas entrapment.
1. For 10%
\[
\frac{10}{100} \times 220g = 22\text{grams of fibre}
\]
2. For 20%
\[
\frac{20}{100} \times 220g = 44\text{grams of fibre}
\]
3. For 30%
\[
\frac{30}{100} \times 220g = 66\text{grams of fibre}
\]

| Calculated Percentage | Carbon Fibre (g) | Natural Rubber Resin (g) |
|-----------------------|------------------|--------------------------|
| 10                    | 22               | 220                      |
| 20                    | 44               | 220                      |
| 30                    | 66               | 220                      |

The mixture was then allowed to cure for 72 hours at room temperature, and then prepared for various characterisations according to their specific standard.

### 2.3 Preparation of samples

Samples were prepared based on standard for different test analysis. The sample were divided into sample A, B, C and D. Sample A is the natural rubber while sample B, C and D is the reinforced natural rubber with activated carbon fibre. The standard for the various test conducted was ISO 527 for tensile test, ISO 179 for impact test and ASTM D2240 for hardness test. Each sample was trim to sizes and dimension in regards to the International Organization of Standardization.

#### 2.3.1 Tensile test

The tensile test was done using a universal test machine, TIRA-test 2810. The machine was set for test in an initial rate of 5mm/min. Each sample was aligned to a uniform size of 7mm × 17mm based on ISO527 standard. The end of test criterion was 85% with a gauge length of 52mm across all samples. The test parameters are summarized as follows:
**Test parameters**

Test: Universal Tensile/Compression Test  
UTM type: TIRAtest 2810  
Load cell: 1kN  
Clamping device: 01-  
Test area: Lower test area  
Sample dimensions: a = 7mm; b = 17mm  
Gauge length: 52mm  
Test rates: V0 = 5mm/min; V1 = 10mm/min  
Rate switch points: F0 = 0N  
End of test criterions: 85%

**2.3.2 Impact test for resilience**

The impact test for resilience of all samples was done at a regulated temperature of 23°C. The dimension of each samples were fixed at 4mm × 12.4mm based on ISO179 standard. The notched hammer was set at a free swing at an angle degree of 150. The pre-test condition is summarized as follows:

- **Testing temperature**: 23°C  
- **Standard**: ISO179

**Samples dimension**

- **Thickness (mm)**: 4.00  
- **Width (mm)**: 12.40  
- **Equipment type**: Pendulum  
- **Serial number of equipment**: 20008380  
- **Serial number of hammer**: 0232.060  
- **Energy at free swing (J)**: 1.969

| Nominal values | Test values |
|----------------|-------------|
| Energy (J):    | 2.000       |
| Speed (m/s):   | 2.900       |
| Angle (degree):| 150         |

**2.3.3 Hardness test**

This test was done using Shore D durometer scale to determine the hardness of the samples. The durometer scale has a scale values from 0 to 100, the higher the number, the higher the hardness of the materials. While Shore D hardness test measures the depth of penetration of an indenter using ASTM D2240 test method. The sample was measured at 8mm radius and placed under the indenter foot of the durometer before pressure was applied. The pressure load used for the Shore D hardness test was 50N, positioned over an area with enough space to allow the pressure of the durometer’s foot to easily come in contact with the specimen. Reading was taken at interval of
three seconds each at varying test conducted. The indentation reading all show how flexible or hard each samples are.

3. Results and Discussion

Figure 5 shows the elemental composition of a periwinkle shell, indicating counts/sec on the vertical axis and kev (energy) on the horizontal axis. The figure below shows calcium as the dominant element with highest peak of 700-750 counts/sec at a lesser energy of 3 to 4 kev. Other traces of elements found are phosphorus, ferrous, nickel, manganese, bromine, strontium, cadmium, silica and antimony. Elements such as calcium, ferrous, silica, nickel and manganese gives the shell the much needed strength it requires to overcome vibration. The high calcium content of the periwinkle shell indicates a high resistivity to thermal energy; which also extend the life of isolator for efficient use.

![Figure 5: XRF Spectra of Periwinkle Shell](image-url)
Periwinkle shell also form a compound of oxide with one or two elements, the percentage of each oxides it forms with other element is illustrated in Figure 6 below;

![Oxide compound in periwinkle shell](image)

**Figure 6: Oxide composition of periwinkle shell**

Figure 6 show that calcium oxide (CaO) has the highest percentage of concentration in periwinkle shell, with 97 percent (%) of the total oxide composition. This is a clear indication that periwinkle shell is predominantly calcium oxide. The high content of calcium oxide in periwinkle provides the shell with enough strength which is needed in overcoming vibration. Calcium oxide (CaO) is used in cement production (Abdullahi et al 2015).

### 3.1 Material strength analysis

The composite strength of the carbon fibre reinforced natural rubber are determine in comparison with natural rubber by the various test conducted. The basis of this comparison is because natural rubber is generally used in isolating vibration. The results of these comparisons between the two materials are analysed as follows;
3.1.2 Tensile strength of natural rubber

Figure 7: Tensile test (sample 1 of natural rubber)

Figure 8: Tensile test (sample 2 of natural rubber)
Figure 7, 8 and 9 is the stress-strain curve of a tensile test conducted on three samples of natural rubber. The result shows that natural rubber deform easily at a minimal load, it is flexural and lack the strength to withstand stress. From the above diagram, the highest load it bears before deformation is 0.09 mega Pascal (figure 9). Others are 0.06 and 0.07 mega Pascal respectively (figure 7 and 8). Natural rubber has high extension rate, the highest in this category is 75% strain rate (figure 9). The entire figure shows a linear stress-strain curve up to a certain point where deformation begins, beyond this point, the curve decreases slightly as deformation continues.

3.1.2 Tensile strength of carbon fibre reinforce natural rubber

Figure 10: Tensile test of 10% Carbon Fibre Reinforced

Figure 11: Tensile test of 20% Carbon Fibre Reinforced
Figure 12: Tensile test of 30% Carbon Fibre reinforced

The figure above (10, 11 and 12) is the stress-strain curve of a tensile strength conducted on the composite of carbon fibre reinforced natural rubber. The result of the test shows an improvement in the material strength. The addition of fibre in the rubber matrix gives the composite the strength it requires to withstand load. The highest load in this category before fracture is 0.20 mega Pascal (figure 12) as compare to 0.09 (figure 8) of natural rubber. Carbon fibre reinforced natural rubber is a brittle material; it breaks with no well defined shape, and do not deformed as in the case of natural rubber. Lastly, the composite of carbon fibre reinforced natural rubber exhibits low strain rate (figure 10, 11 and 12), which shows high resistance to thermal expansion and further extend the life of the isolator.
3.2 Resilience

Figure 13: Resilience result on 10% Carbon Fibre reinforced natural rubber

Figure 14: Resilience result on 20% Carbon Fibre reinforced natural rubber
Figure 15: Resilience result on 30% Carbon Fibre reinforced natural rubber

Figure 13, 14 and 15 shows the resilience of natural rubber and the composite of carbon fibre reinforced natural rubber. From the result it shows that natural rubber has high resilience to impact and can absorbed more energy than carbon fibre. The 30% carbon fibre reinforcement shows very poor resilience (Figure 15) and being a brittle material; it shatters easily on high impact. Its energy absorption during impact is poor. The 10% fibre reinforcement on the other hand gives the materials the much needed strength to high resilience on impact (toughness) and cannot shatter easily as compared to 30% fibre reinforcement. Figure 14 shows 20% carbon fibre reinforcement, its energy absorption is poor as compared to 10% reinforcement and can shatter on high impact test.
3.3 Hardness

![Hardness Test Graph](image)

Figure 16: Hardness of natural rubber/carbon fibre reinforced natural rubber composite

Figure 16 shows that, the addition of fibre into the natural rubber matrix cures the flexibility of rubber and improved the material strength of the composite. The hardness of the material depends largely on the reinforced fibre. The figure above shows an increased in the hardness of materials in relation to an increased percentage of reinforced material.

3.4 Discussion of result

The results analysed indicates that carbon fibre reinforced natural rubber composite is a brittle material with high strength rate and improved hardness to withstand vibration. The composite of carbon fibre reinforced natural rubber also shows low strain rate to failure that posed high resistance to thermal expansion, this is more sufficient in extending the isolator life for effective use. The result analysed also show 10% reinforcement as the most effective proportion for high impact test in reducing the brittle nature of the carbon fibre.

4. Conclusion and Recommendations

The use of carbon fibre from periwinkle shell as a composite material shows an improvement in the material strength of carbon fibre to withstand vibration. This assessment was done in comparison with natural rubber owing to the fact that natural rubber is widely used as a vibration isolator. The result of the conducted experiments also reveals that reinforcing agent increases the physical, mechanical and durability of the isolator. The analysed result shows;
i. There is an increased in stiffness of natural rubber from 0.09 to 0.20 mega Pascal.
ii. The low strain rate of the reinforcing materials to failure can cure the deterioration of rubber matrix to withstand solvent and to extend the isolator life.
iii. The presence of carbon fibre increased the resistivity of natural rubber matrix to temperature and thermal expansion.

Carbon fibre obtained from periwinkle shell shows high contents of calcium oxide at 97 percent which is evidence of the material strength for vibration absorption. This oxide is also useful in cement production and so more research can focused on this aspect by annexing the abundant calcium contents found in periwinkle shell as:

- Alternative methods of reducing sulphur dioxide (SO₂) emission
- Alkaline for water treatment
- Animal feeds
- Exhaust gas cleaning system

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