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# Examination of the Effects of Potassium Permanganate Chemical Modification on Bamboo Fiber Reinforced with Natural Honey Bio Resin and Paw-Paw Leaves Extract

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**Abstract**: Bamboo fibers are modified to improve their interfacial bonding and reduce moisture absorption. This can be achieved through the various treatments it undergoes. The mechanical and chemical properties of bamboo fiber were examined with a Tensile machine and FTIR Instrument. Natural fibers generally have many advantages over man-made fibers like low density, low cost, biodegradability, etc. Moreover, natural fibers have significant disadvantages in composites, such as their poor compatibility with the matrix and relatively high moisture sorption. Therefore, chemical treatments are vital to modify the surface properties of natural fibers. Among the various chemical treatments usually given to fibers, permanganate ($KmnO_4$) was used in this study. The FT-IR analysis of Untreated Bamboo fiber shows the presence of Hydrogen-bonded O-H stretch, H-C-H Asymmetric and symmetric stretch, C-H stretch of C=O, Hydrogen-bonded O-H stretch, C≡ stretch, N=O Bend, (C-O stretch). The FT-IR Analysis of potassium permanganate treated bamboo fiber shows Hydrogen-bonded O-H stretch, H-C-H Asymmetric and Symmetric stretch, C-H stretch of C=O, C≡N stretch, and C=O stretch. The FT-IR results of permanganate-reinforced bamboo fiber show hydrogen-bonded O-H stretch, C-H stretch of C=O, C≡C stretch (C-O stretch), N=O stretch, and N-H bend. Bamboo fibers were treated chemically with potassium permanganate at varying concentrations, Treated Bamboo fiber was reinforced with a bio-resin (natural honey and pawpaw extract), and mechanical testing (tensile test) and Fourier transform infrared spectroscopy were used to know the effects of chemical treatment on the fibers. Potassium permanganate treatment improved the properties with increased concentration.

**Keywords**: Bamboo fiber; Potassium permanganate treatment; Tensile strength; Fourier transform infrared.

## 1. Introduction

The environmental and conservativeness of bamboo fiber is unquestionable as a natural fiber and incomparable to other plants. For this reason, it stands tall among others in research applications and developing engineering alongside different processing methods for fibers [1]. Due to the rise in ecological anxieties, scientists and researchers have been forced to find new environmental materials. It is good to tap the knowledge of bamboo fiber properties in expanding the range of fiber applications [1]. Many researchers have studied composites based on natural and synthetic fibers, the two types of fibers we have [2-4]. These fibers, especially natural fibers, are abundantly available, and bamboo fibers are one of them which can be harvested within 3-4 years [5]. While comparing these fibers, the advantages of using natural fibers are enormous. Examples are their naturally large quantity, low cost, low density, biodegradability, renewability, and recycle-ability [5-11]. Experimentally, it is evident that bamboo fiber can replace wood in an improved way [12]. Bamboo is a perennial plant having woody culms and underground rhizomes as its significant parts. Usually, bamboo trees differ from other woody trees because they lack vascular cambium and apical meristem cells. Therefore, it is regarded as a glass-to-void and woody stem. Many surface treatments given to

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bamboo fibers have been reported in the literature [13-23]. Bamboo is a monocotyledonous plant without secondary growth, differentiating it from other woody dicotyledonous plants with secondary growth [24]. Its growth rate should be up to 1 m per day with a height of more than 100 feet (30 m). It does not require replanting, the addition of fertilizer, pesticides, or an expert to monitor its growth. Bamboo is one of the world's existing sustainable resources. Its culm comprises the straight and void woody material found above the ground level that holds its stem, fruits, leaves, seeds, flowers, and branches. It has alternate nodes and inter-node stems with cylindrical forms, and the internode cells are axially oriented to hollow cavities inside the stem. The plant cells are framed horizontally by a divider called the diaphragm in the node between two adjacent internodes. The diaphragm serves as a transportation channel for water and nutrients. The culms' diameter and the wall thickness enlarge from top to bottom, while the inter-node length enlarges from bottom to middle and then decreases up to the top [25]. The underground portion of bamboo is called a rhizome. Rhizomes absorb and transfer water and nutrients to facilitate the plant's growth.

A rhizome is classified into patchy-morph and lepto-morph according to their branching pattern. Rhizome clumps that are short, thick, and curved that bear apical buds and culms in tropical regions are viewed as patchy-morph/sympodial rhizomes or clumping bamboo. However, the lepto-morph rhizome extends long in the soil and bears buds and roots from specific nodes and internodes. They are circulated in temperate areas, known as mono-pod-dial rhizomes or running rhizomes. Compared to the aggregate/clumsy nature of the patchy-morph rhizomes, the habitat seems like a scattered state [26]. Bamboo is a potential eco-friendly plant that has many applications in different fields. The features are abundant in nature, sustainability, high production rate, cheap, easy growth, quick maturity, nonhazardous nature, and good strength. It has been used successfully in the craft, construction, energy, and paper industries. Due to the possibility of making bamboo-based bio-composite products, researchers are now paying more attention to this fiber [27].

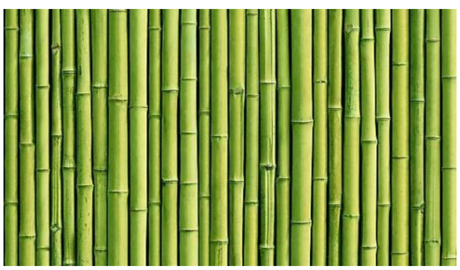

**Figure 1**. Bamboo Plant

**Figure 2**.Cross-Section of Bamboo Plant

## 2. Experimental: Materials and Methods

### 2.1. Fiber

The fibers were obtained from Avu (Owerri, Imo state), which were cut carefully, and the culms were cut into smaller sizes for easy extraction, after which they were placed on a clean, smooth and hard surface. The bark of the culms was removed, and the individual fibers were picked and pulled. The experiment continued till the fibers in the culms were exhausted. Bamboo fibers were then dried under the sun before they were chopped to obtain a fiber length of approximately 6 mm.

**Bio resin (natural honey)**: Locally made honey was processed by the indigenous people of Enugu state. The following steps were taken to produce natural honey.

Beekeepers at Enugu for this research work harvested the honey by collecting the honeycomb frame scraped off the wax cap bees make to seal off honey in each cell. Once the caps are removed, the frames are placed in an extractor, a locally made centrifuge that spins the frames, forcing honey out of the comb. After the honey is extracted, it is strained to remove any remaining wax and other particles. After straining, it is then put in bottles ready for distribution.

### 2.2. Reagents Used

Analytical-grade chemicals include sodium hydroxide, potassium permanganate, and acetone.

### 2.3. Fourier Transform Infrared Spectroscopy (FT-IR)

Fourier-transformed infrared spectroscopy (*Shimadzu, Model: IR affinity – 1; A2137470136 SI*) was used for the determination of functional groups of the fiber. FT-IT spectroscopic technique at Energy Center (UNN, Nnsuka) was used to obtain the spectrum of the fiber. FT-IR spectrophotometer collects high spectral resolution data over the spectra range.

### 2.4. Equipment

Water bath, Beakers, Electronic weighing balance, Spatula/ Stirrer, Distilled Water, Paper Tape, Gloves, Scissors, Sample foil, and Yarn Textile Testing Machine.

**2.5. Alkali Pre-Treatment of Fibers**

In this study, bamboo fibers obtained from Avu-Owerri were immersed in varied concentrations of NaOH ranging from 1.70g to 4.5g and dissolved in 500ml of distilled water at various temperatures of 30°C, 45°C, 60°C, and 90°C for5 minutes,60 minutes, 90 minutes and 120 minutes respectively. They were washed with distilled water to remove traces of NaOH.

**2.6. Permanganate Treatment of Fibers**

The immersion of potassium permanganate ($KMnO_4$) in acetone solution is the process adopted in the permanganate treatment of natural fiber. Chemical intertwining at the interface, which aids in improved adhesion to the matrix, was achieved in this treatment. The high thermal stability of natural fibers was due to cellulose-manganate formation [28]. In this study, after treating the fibers with alkali, they were washed with water, sun-dried, reweighed, and immersed in KMnO4 solutions of the following grams (0.4, 0.6, 0.8, and 10), respectively, which were thoroughly dissolved in 100 ml of acetone for 40 minutes and at 45°C. Then, the fibers were washed with distilled water to remove KMnO4 residues/traces and were air-dried for 24-48 hours and reweighed.

The Tensile strength of the bamboo fiber is obtained using the yarn textile testing machine (Fig. 3), in which the fiber is subjected to controlled tension until failure.

**Figure 3**. Yarn Textile Testing Machine

**2.7. Reinforcing the fiber (bamboo) with bio-resin (natural honey and pawpaw leaf extract)**

The bio-resin of natural honey and pawpaw extract was prepared in a weight ratio of 3:1, 30.19g of bio-resin were used to reinforce the fibers, and 2.7 gram of both treated and untreated and treated fibers at varied concentrations of $KMnO_4$ were reinforced. After that, the fibers were kept for 24h for proper absorption to take place, were dried in air for 5 days and were reweighed and preserved for further use.

**3. Results and Discussion**

**3.1. Chemical composition of Bamboo Fiber**

Table 1 indicates the chemical constituents of Bamboo fiber. From the table, the constituent contained in the cellulose was the main, with the highest fiber proportion. Hemicelluloses, lignin, aqueous extract, and pectin are the least followed it. It was observed that the percentages of hemicelluloses, lignin, aqueous extract, and pectin were drastically reduced after the chemical treatment, and the cellulose content of Bamboo fibre was improved from 60.83% to 73.90%. The improvement in the cellulose content could be that the percentage of non-cellulose reduction enhances the amount of cellulose in the fiber.

**Table 1**. Composition of Bamboo fiber at different chemical treatments.

| Compound | Untreated bamboo fiber | $KMnO_4$ treated bamboo fiber |
|---|---|---|
| Cellulose | 60.83% | 73.90% |
| Hemicellulose | 10.99% | 6.70% |
| Lignin | 9.65% | 4.60% |
| Aqueous Extract | 2.17% | 1.12% |
| Pectin | 0.26% | 0.12% |

**3.2. FT-IR Analysis**

The FT-IR results of the fibers are presented in the figures below. Every spectrum of the graph indicates different peaks in the absorbance with wave number correlation. FT-IR spectrum is a graph of infrared light absorbance on the vertical versus wavenumber (frequency) on the horizontal axis. The unit of the wave number is $cm^{-1}$. The crests and their matching intensities signify the functional groups of the fibers [29-31]. The FT-IR analysis of Untreated Bamboo fibers (Fig. 4) shows the presence of Hydrogen-bonded O-H stretch, H-C-H Asymmetric, and symmetric stretch, C-H stretch of C=O, Hydrogen-bonded O-H stretch, C≡ stretch, N=O Bend, (C-O stretch).

The FT-IR Analysis of potassium permanganate-treated bamboo fiber (Fig. 5) shows Hydrogen-bonded O-H stretch, H-C-H Asymmetric and Symmetric stretch, C-H stretch of C=O, C≡N stretch, and C=O stretch.

The FT-IR results of untreated bamboo fiber reinforced with bio-resin (natural honey and pawpaw extract) (Fig. 6) show the presence of Hydrogen-bonded O-H stretch, C≡C stretch, N=H bend, (C-O stretch) and C=H bend. The FT-IR results of permanganate-reinforced bamboo fiber show hydrogen-bonded O-H stretch, C-H stretch of C=O, C≡C stretch (C-O stretch), N=O stretch, and N-H bend.

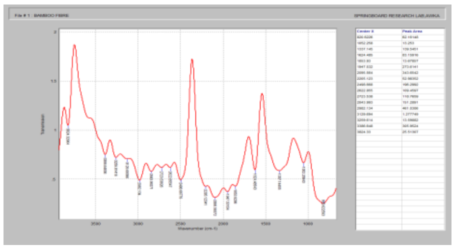

**Figure 4**. FT-IR of Untreated Bamboo Fiber

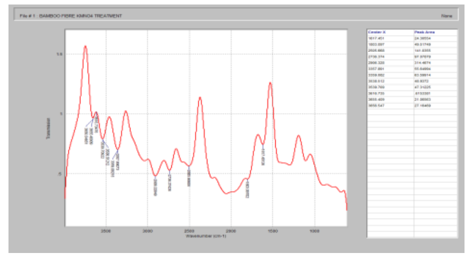

**Figure 5**. FT-IR of Potassium Permanganate Treated Bamboo Fiber

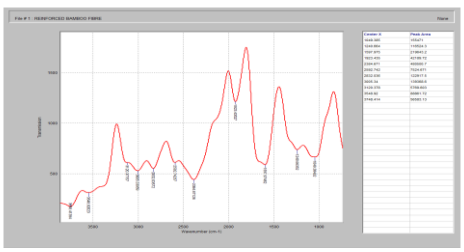

**Figure 6**. FTIR of Untreated Bamboo Fiber Reinforced with Bio Resin (Natural Honey) and Pawpaw Extract

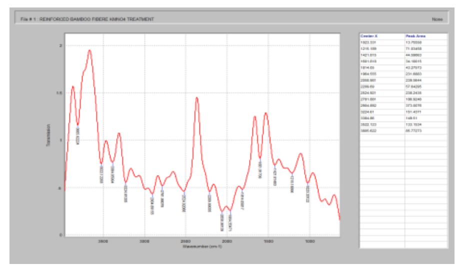

**Figure 7**. FT-IR of Potassium Permanganate Treated Bamboo Fiber Reinforced with Bio Resin (Natural Honey and Pawpaw Extract)

**Table 2**. Potassium permanganate treatment of bamboo fiber samples at varied concentrations, temperatures, and times.

| Sample | Conc. $KMnO_4$/100ml (grams of acetone) | Time (mins) | Temperature (° c) | Initial weight of fibers, $M_o$ (grams) | Final weight of fibers, $M_1$ (grams) | Weight loss (grams) |
|---|---|---|---|---|---|---|
| Sample (1.3g) | 0.40 | 40 | 45 | 1.30 | 1.37 | -0.07 |
| | 0.60 | 40 | 45 | 1.30 | 1.30 | 0.00 |
| | 0.80 | 40 | 45 | 1.30 | 1.24 | 0.06 |
| | 1.0 | 40 | 45 | 1.30 | 1.13 | 0.17 |
| Sample (2.1g) | 0.40 | 40 | 45 | 2.10 | 2.20 | -0.10 |
| | 0.60 | 40 | 45 | 2.10 | 1.98 | 0.12 |
| | 0.80 | 40 | 45 | 2.10 | 1.97 | 0.13 |
| | 1.00 | 40 | 45 | 2.10 | 1.88 | 0.22 |
| Sample (2.7g) | 0.40 | 40 | 45 | 2.70 | 2.63 | 0.07 |
| | 0.60 | 40 | 45 | 2.70 | 2.61 | 0.09 |
| | 0.80 | 40 | 45 | 2.70 | 2.43 | 0.27 |
| | 1.0 | 40 | 45 | 2.70 | 2.36 | 0.34 |
| Sample (3.2g) | 0.40 | 40 | 45 | 3.20 | 3.32 | -0.12 |
| | 0.60 | 40 | 45 | 3.20 | 3.01 | 0.19 |
| | 0.80 | 40 | 45 | 3.20 | 2.94 | 0.26 |
| | 1.00 | 40 | 45 | 3.20 | 2.84 | 0.36 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sample (3.6g) | 0.40 | 40 | 45 | 3.60 | 3.70 | -0.10 |
| | 0.60 | 40 | 45 | 3.60 | 3.26 | 0.34 |
| | 0.80 | 40 | 45 | 3.60 | 3.23 | 0.37 |
| | 1.00 | 40 | 45 | 3.60 | 3.19 | 0.41 |

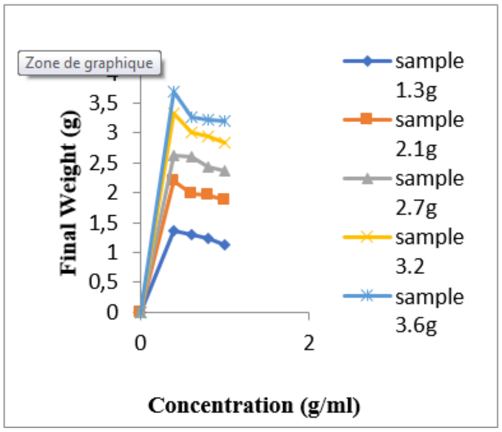


**Figure 8**. Permanganate treated sample fibers at varied concentrations

### 3.3. Tensile strength

The Tensile Strength of untreated bamboo fiber was measured as 4N. There was an increase in the tensile strength of the fibers after treatment with $KMnO_4$. These increments in the tensile strength were $KMnO_4$ concentration and fiber grams dependent. We observed a sharp increase in the tensile strength of 12.5N to 27.5N fiber sample 1.3g from 0.4g of $KMnO_4$ to 0.6g of $KMnO_4$ and further decrease to 25N and 15N, respectively, when 0.8g and 1.0g of $KMnO_4$ were incorporated into the fiber. Fiber samples of 2.1g also show a similar trend. There was an increase in the tensile strength of the fiber of 8.5N, 21N, and 40N when 0.4g, 0.6g, and 0.8g of $KMnO_4$, respectively, were incorporated into the fiber, but a sharp decrease in tensile strength of 30N was observed when 1.0g of $KMnO_4$ was incorporated to the fiber. For the fiber sample of 3.6g, we observed a sharp increase in the tensile strength of 5N, 10N, 18N, and 20N, respectively, when 0.4g, 0.6g, 0.8g, and 1.0g of $KMnO_4$, respectively were incorporated into the fiber. This is evidence to prove that the tensile strength of $KMnO_4$ is $KMnO_4$ concentration and fiber weight concentrations. We should also note that the quantity of acetone used to dissolve the $KMnO_4$ was constant, i.e., 100ml was used for each gram of $KMnO_4$ in this work. Therefore, the untreated fiber has the lowest tensile strength of 4N. This also proved that $KMnO_4$ enhances the strength of the fiber [32-35]. Finally, we conclude that incorporation of $KMnO_4$ improves the strength of the fibers up to 0.6g of $KMnO_4$ for fiber samples 1.3g and 2.1g, respectively, and reduces when further increments were made, but for fiber sample 3.6g, we observed a sharp increase in the tensile strength throughout.

**Table 3**. Tensile strength of potassium permanganate untreated and treated bamboo fibers with different concentrations.

| Conc. of $KmNO_4$ (g/L) | Sample 1.3g Weight of fiber | Force at break (N) | Sample 2.1g Weight of fiber (g) | Force at break (N) | Sample 3.6g Weight of fiber (g) | Force at break (N) |
|---|---|---|---|---|---|---|
| **Untreated** | 1.30 | 4 | 2.10 | 4 | 3.60 | 4 |
| **0.4** | 1.30 | 12.5 | 2.10 | 8.5 | 3.60 | 5 |
| **0.6** | 1.30 | 27.5 | 2.10 | 21 | 3.60 | 10 |
| **0.8** | 1.30 | 25 | 2.10 | 40 | 3.60 | 18 |
| **1.0** | 1.30 | 15 | 2.10 | 30 | 3.60 | 20 |

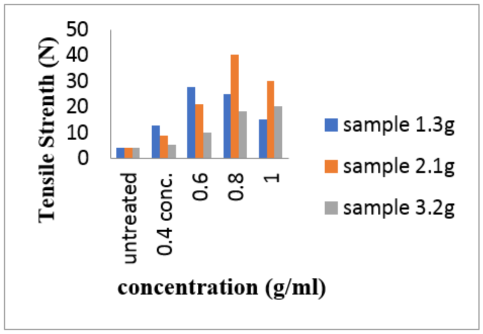


**Figure 9**. Tensile strength of permanganate treated and untreated fibers

**3.4. Tensile strength of bamboo fibers reinforced with bio-resin (natural honey and pawpaw extract)**

From the results, we observed that permanganate-reinforced samples of 2.7g with 0.4g, 0.6g, 0.8g, and 1.0g concentrations of $KMnO_4$ reinforced with 30.19g/l concentrations of bio-resin showed a decrease in the tensile strength of 22N, 21N, 20N and 17N respectively. It shows that the tensile strength of permanganate-reinforced fibers treated with $KMnO_4$ depends on the concentrations of $KMnO_4$ used for the treatment. The lesser the concentration of $KMnO_4$ used in treating the fiber at constant bio resin reinforcement, the more the tensile strength of the fiber. It means that any increase in the concentration of $KMnO_4$ should require an increase in the quantity of the bio-resin if a high tensile strength is needed. Also, we observed that the lowest tensile strength of 15N was obtained when fiber was not treated with $KMnO_4$. It means that $KMnO_4$ contributes a lot to the strength of the fiber.

**Table 4**. Tensile strength of untreated fiber at different concentrations and weight of permanganate.

| Conc. Of $KMnO_4$ (G/L) | Conc. of bio-resin | Weight after permanganate | Weight after reinforcement | Weight gain (grams) | Tensile Strength (N) |
|---|---|---|---|---|---|
| **Untreated** | 30.19 | 2.70 | 4.20 | 1.50 | 15 |
| **0.4** | 30.19 | 2.63 | 4.64 | 2.01 | 22 |
| **0.6** | 30.19 | 2.58 | 4.62 | 2.04 | 21 |
| **0.8** | 30.19 | 2.43 | 4.59 | 2.16 | 20 |
| **1.0** | 30.19 | 2.36 | 4.67 | 2.31 | 17 |

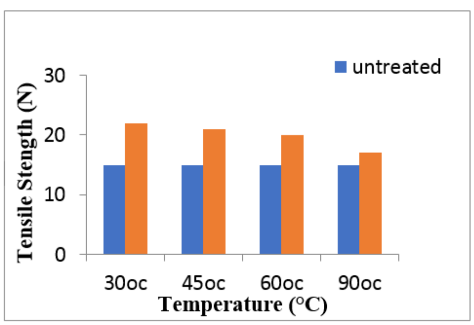


**Figure 10**.Tensile strength of reinforced fibers untreated, treated at different concentrations

## 4. Conclusion

The effects of permanganate treatment on the properties of bamboo fibre and its reinforcement with bio-resin (natural honey and pawpaw extract) were analyzed using yarn textile testing and Fourier transform infrared spectroscopy. Permanganate treatment improved the mechanical properties of the fiber and reinforced fibers with an increase in the concentration of $KMnO_4$. From the results, it was evident that the untreated fiber has the lowest tensile strength of 4N. There was an increase in the fiber's tensile strength after being treated with $KMnO_4$. We also observed that the increments were $KMnO_4$ concentration and fiber grams dependent. We noted a sharp increase in the tensile strength of 12.5N to 27.5N fiber sample 1.3g from 0.4g of $KMnO_4$ to 0.6g of

$KMnO_4$ and further decrease to 25N and 15N, respectively, when 0.8g and 1.0g of $KMnO_4$ were incorporated into the fiber. The fiber samples 2.1g, and 3.6g followed a similar trend. It thereby proved that $KMnO_4$ enhances the strength of fiber while the untreated fiber has the lowest tensile strength of 4N. Also, we observed that permanganate reinforced samples of 2.7g with 0.4g, 0.6g, 0.8g, and 1.0g concentrations of $KMnO_4$ reinforced with 30.19g/l concentrations of bio-resin showed a decrease in the tensile strength of 22N, 21N, 20N and 17N respectively. It shows that the tensile strength of permanganate reinforced fibers treated with $KMnO_4$ depends on the concentrations of $KMnO_4$ used.

In general, chemical treatment has improved the mechanical properties of bamboo fiber and reinforced bamboo fiber with bio-resin.

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