*Short Communication*

# Investigation of the Dielectric Characteristics of Banana Residue-Reinforced Epoxy Resin

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Banana (Musa acuminata) peel and leaf fiber composites were reinforced with epoxy resin. A hand layup fabrication technique was used to improve the quality of a natural fiber-based dielectric material. The electrical characteristics of the banana peel and leaf fiber-reinforced epoxy resin composites were investigated for fiber loading, fiber treatment, and hybridization with epoxy fibers. Frequency and fiber loading caused the dielectric constant to drop. The dielectric constant was improved by Alkaline, benzoyl chloride treatment and hydrophobicity was reduced by chemical adhesion. The dielectric constant of the banana leaf fiber layered epoxy composites is better than the banana peel layered fiber composites. The dielectric constant is increased due to increasing the layers of the banana leaf fiber sheets. The dielectric constant of the banana leaf layered fiber composite increased as the frequency of loading decreased. Chemical treatments used on the fiber improve the resistivity of the composite. The loss factor was minimized by chemical treatments and the use of hybrid composites. Epoxy resin was deployed to bond the banana fiber molecules together. Polymer coupled composites are likely to reduce the absorption of moisture levels through the encapsulation of the filter material by a polymer matrix. The bonding strength of banana fiber molecules is enhanced by chemical adhesives. It increases the dielectric strength of the banana fiber composite due to decreased hydrophobicity. The dielectric properties of the banana fiber composite were studied, such as dielectric constant (tan $\delta$), dissipation factor ($\varepsilon$'), and loss factor ($\varepsilon$''). The surface and bonding structure of the test sample was scanned by Field Emission Scanning Electron Microscopy (FESEM). Banana leaf fiber layered composites are suitable for electrical insulation applications in high voltage applications.

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## 1. INTRODUCTION

Plastics have become one of the most popular materials for electrical applications due to a desirable mix of attributes such as simplicity of manufacture, low cost, lightweight, and great insulation

capabilities. Plastics are only used for non-load-bearing general-purpose uses in electrical applications [1]. Fiber-reinforced plastic materials are not only good insulators, but also provide mechanical support for field carrying conductors. The electrical insulating properties of epoxy resin are well-known. However, it is extremely fragile and possesses weak mechanical qualities [2]. By incorporating fiber reinforcements into polymer matrices, high-performance composite materials with excellent mechanical properties and electrical properties are created. They can be used as terminals, connectors, plugs, switches, and printed circuit boards in industrial and household applications [3]. Natural fiber-reinforced polymer composites have garnered increasing study attention in recent years due to their potential as a substitute for synthetic fiber composites such as glass or carbon fiber composites. Natural fiber composites have several advantages over synthetic fiber composites, including ease of availability, renewability of raw materials, low cost, lightweight, high specific strength, and stiffness [4].

Natural fiber disadvantages, such as moisture absorption, low aging and weathering resistance, and hydrophilicity, which weakens the fiber/matrix contact in hydrophobic polymer matrices, can be remedied through various surface modifications. Numerous researchers have developed high-performance natural fiber composites through the use of mercerization, silanes, isocyanates, acetylation, and grafting. The development of hybrid composites using natural fibers and synthetic fibers such as glass fiber has also been shown to be a viable method of enhancing the performance of natural fiber composites [5–6]. Due to the significance of composite materials in electrical applications, it is critical to research their electrical properties such as dielectric constant, volume resistivity, and loss factor. We examined the electrical characteristics of polythiophene polystyrene composites. Enhancement of the performance of conductive composites, extremely high aspect ratio flakes are recommended, and these particles perform best when their orientation is unpredictable inside the composite [7].

The dielectric properties of mineral-filled epoxy composites incorporating a variety of dielectric fillers were investigated. The results demonstrated that the dielectric constants increased when the dielectric filler was added and as the filler's dielectric constant increased. A significant rise in the dielectric constant and decrease in the loss factor along the fiber direction relative to the transverse direction due to the increased crystallinity along the fiber direction [8]. Increasing orientation and interfacial polarization observed an increase in the dielectric constant of the composite with fiber loading. The effect of banana fiber orientation on the electrical characteristics of banana fiber reinforced epoxy composites [9]. The electrical characteristics of banana fiber-reinforced low-density polyethylene composites were compared to those of carbon black and glass fiber-filled low-density polyethylene. The influence of surface treatments on the electrical characteristics of low-density polyethylene composites reinforced with short banana fibers by the influence of alkaline and benzoyl chloride treatments is shown in Figure 1 [10-11]. Epoxy resin is used to increase the bonding strength between the banana fibers via molecular coupling of the carboxyl group. Lignocellulosic fibers interact with a mechanism of polymer couplings shown in Figure 3 (m) [12-16].
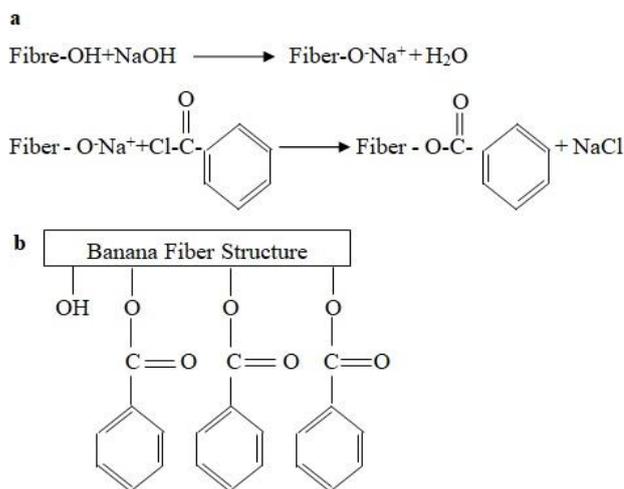
**Figure 1**. Reaction mechanism of the banana fiber (a) benzoyl chloride and (b) hypothetical banana fiber interface structure [12-16].

The proposed research work has created a banana fiber-reinforced epoxy composite in our laboratory. The surface treatments of the fibers were varied. We developed hybrid composites using banana peel and leaf fiber and found that they had excellent electrical properties, indicating a beneficial hybrid effect. The electrical characteristics of the banana fiber-reinforced epoxy composite are studied in this work. The influence of alkaline and benzoyl chloride treatment on dielectric constants and loss factors is being investigated. Electrical properties are also studied for banana peel and leaf hybrid fiber-reinforced composites with varied hybrid ratios and layering patterns. The dielectric characteristics of banana fiber s were investigated in this study, such as dielectric constant ($\varepsilon$'), dissipation factor (tan $\delta$), and loss factor ($\varepsilon$').

## 2. MATERIALS AND METHODS

### 2.1. Materials

The polymer matrix was procured from Bhohir Ali Ltd., Pune, India. Banana fibers were obtained from Banana farm ICAR-National Research Center for Banana, Trichy, Tamilnadu, India. The chemicals used for the modification of banana fiber were of commercial grade.

### 2.2. Methods

### 2.2. Surface treatments for fibers

Banana fibers have been utilized to make composites both naturally and chemically treated. Numerous surface treatments have been applied to Alkaline and benzoyl chloride. Banana fibers were trimmed to a length of 6 mm before treatment [12-17].

*2.2.1. Treatment with Alkaline*

The chopped fibers were immersed in a steel container containing Alkaline for 1 hour at various concentrations (2 percent and 10%). The fibers were thoroughly washed with water to eliminate any remaining Alkaline. Finally, rinse with a small amount of acetic acid water. Fibers were dried for 3 hours at 70ºC in an air oven [12-17].

*2.2.2. Treatment with benzoyl chloride*

For almost half an hour, chopped banana fibers (6 mm) were ingested in a 2% Alkaline solution and then swirled for 30 minutes with benzoyl chloride. The fibers were then washed with water in a 70°C air oven for three hours [12-17].

*2.2.3. Analysis of dielectric properties*

Dielectric properties of fine insulation composites of banana residues were evaluated by the Agilent Impedance Analyzer E4980A, acquired from Agilent. Dielectric constant determination, LCR meter, and dielectric 16451B test equipment have been used. The dielectric constant of the 60 mm and 0,5 thickness circulatory samples was determined in the frequency range 1 kHz to 2 MHz using circular samples of 60 mm and 0,5 thicknesses by employing the contacting electrodes method[18-20].

*2.3. Dielectric characterization analysis*

Two-millimeter disc-shaped samples were made and evaluated for the dielectric test. To make the sample an effective electrode, the silver paste was applied to both the top and bottom surfaces. The dielectric loss, capacitance, impedance, and phase factor were all measured in the frequency range of 100 Hz to 100 kHz using an Agilent E4980A LCR meter. It was necessary to maintain the device's scanning temperature at 150ºC while heating at a rate of 5ºC/min [21]. The dissipation factor (tan δ), the dielectric constant (ε'), and the loss factor (ε") were determined using impedance spectroscopy using the formulae (1) and (2).

$$\varepsilon' = \frac{c}{c_0} \qquad\qquad (1)$$

Where, $C_0 = \varepsilon_0$, A/d and tan δ = έ/ὲ

The conductivity of the alternating current was determined using equation (2).

$$\sigma_{ac} = \omega\varepsilon\varepsilon_0 \tan\delta \qquad\qquad (2)$$

Where, the angular frequency is equal to the dielectric permittivity of air (8.85 x 10 x 12 F/m).,
A sample area, d –thickness, and d –thickness

*2.4. Field-Emission Scanning Electron Microscopy (FESEM)*

The banana peel and leaf s' surface morphology were studied using a FESEM (NOVA 450, Japan) at a magnification of 2000x and an operating voltage of 11,000KV [22-23]. The banana fiber s

were coated with carbon tape and gold in preparation for analyzing the sample during the manufacturing process. An LEO 1455VP Field-Emission Scanning Electron Microscope was used to determine the surface morphology of the banana fiber s (FESEM).

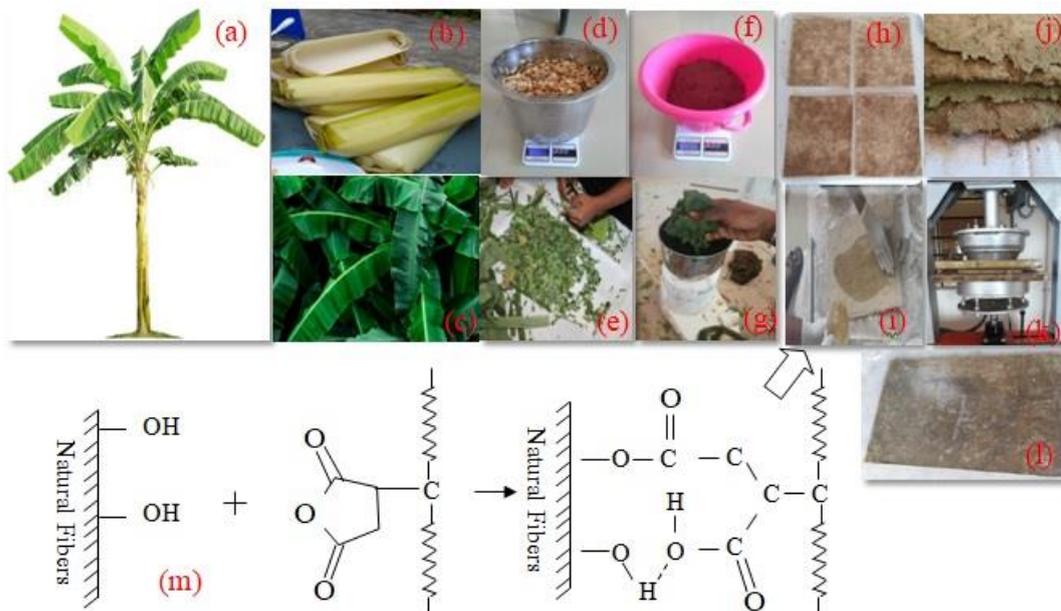## 2.5. Fabrication of banana residue fiber composite specimens



**Figure 2.** Fabrication process of banana leaf fiber composite, a) Banana Tree, b) Banana Peel, c) Banana Leaves, d) Chopped banana peel, e) Chopped banana leaves, f) Banana Peel pulp, g) Banana leaf pulp, h) Banana peel and leaf fiber sheet, i) Epoxy resin coating, j) Layers of banana fiber sheet, k) Hydraulic compression, l) Banana fiber composite, m) Ligno-cellulosic fibers interact through a polymer coupling mechanism [12-16].
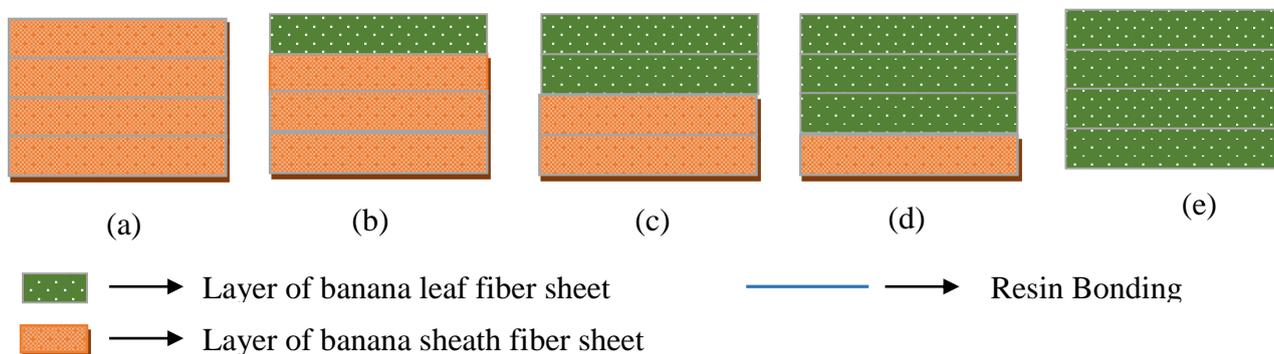


**Figure 3.** Banana peel and leaf layer placement for fabrication of composite, a) four layers of banana peel fiber sheets - Peel, Peel, Peel and peel (PPPP), b) Three layers of banana peel fiber sheets and one layer of banana leaf fiber sheet – Peel, Peel, Peel and Leaf (PPPL), c) Two layers of banana peel fiber sheets and two layers of banana leaf fiber sheet – Peel, Peel, Leaf and Leaf (PPLL), d) One layers of banana peel fiber sheets and three layers of banana leaf fiber sheet – Peel, Leaf, Leaf and Leaf (PLLL), d) Four layers of banana leaf fiber sheet – Leaf, Leaf, Leaf and Leaf (LLLL).

The chopped banana residue was made by chopping banana leaves and peels into little bits, which were referred to as chopped banana residue. To prepare the pulp, 200ml of water was mixed with 1 kg of banana leaves and peel. For 50 minutes at 120°C, banana peel and leaf fiber were cooked in sodium hydroxide solution. Separately, the banana peel and leaf fiber pulp were made. When the viscosity or lignin ingredient was removed, the banana fiber pulp was rinsed with distilled water. This was followed by four hours of drying at 150ºC in a hot air oven. The silver foil was covered with a thin layer of pulp. Eight banana leaf and peel sheets were required to manufacture a single insulation . The dried peel and leaf fiber sheets were covered with epoxy resin on both the top and bottom surfaces. We put up eight resin-coated fiber sheets. On top and bottom of the resin-coated banana peel, as well as on the leaf fiber sheets, plywood was laid. Banana fiber sheets were compressed using a hydraulic pressing machine to increase their hardness and density. After 3 hours, the banana leaf fiber composites were removed using the compression hydraulic system, which provided 4 tones of force. It took 24 hours for the composite to heal. Figure 1 illustrates the method of fabrication. Layer placement for fabrication of banana peel and leaf fiber  composite was shown in Figure 3. Different weight percentages of the banana peel and leaf layers with epoxy resin were presented in Table 1 [15].

**Table 1.** Different weight percentages of the banana peel and leaf layers with epoxy resin [15].

| S.No. | Type of Matrix | Specimen Reference Name | Banana Peel (%wt) | Banana Leaf (%wt) | Epoxy Resin (%wt) |
|-------|----------------|-------------------------|-------------------|-------------------|-------------------|
| 1. | Epoxy | PPPP | 90 | 0 | 10 |
| 2. | Epoxy | PPPL | 70 | 15 | 15 |
| 3. | Epoxy | PPLL | 40 | 40 | 20 |
| 4. | Epoxy | PLLL | 15 | 60 | 25 |
| 5. | Epoxy | LLLL | 0 | 70 | 30 |

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of chemical treatment

Banana peel and leaf fiber composites were treated with an alkaline solution. The bonding strength and hydrophobicity of banana fibers were higher than the non-treated fiber composites because the alkaline treatment eliminates some lignin, wax, and oils that cover the outer surface of the cell wall of the fiber. As a result of Alkaline treatment, the following reaction takes place.

Fiber —OH + Alkaline $\rightarrow$ Fiber + $ONa^+$ + $H_2O$
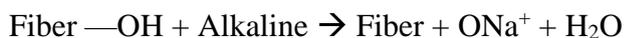
The effect of Alkaline on fiber is a swelling response, which relaxes cellulose's inherent crystalline structure. The inter-fibrillar area is probably less thick and less stiff when hemicellulose is removed and so makes the fibrils more able to reorder themselves [18].

The increase in the percentage of the alkaline-treated fibers crystallinity index is due to the elimination of cementing material that results in better cellulose chains being packaged. The cellulose fiber treatment with Alkaline leads to the swelling and dissolution process. The fiber surface shows a

higher degree of fibrillation due to hemicellulose and lignin removal. 10% of alkaline treatment showed greater fibrillations than 2% of the FESEM microphotographed alkaline treated fiber (Fig. 6a and b). The thermal conductivity and diffusivity of the composite have increased correspondingly by 9% and 10%, as alkaline levels are increased from 2% to 10%. FESEM of the tensile fractures surface of the composites were analyzed to gain additional insight into the nature of fiber/matrix adhesion in the composite. The traction tests were conducted following ASTM D 638- 76 [12].

Figure 8 a-c shows the FESEM observing of untreated banana fiber composites, treated with alkaline and benzoylated fracture surface. The tensile rupture can be seen as accompanied by the deposition of the fibers leaving hollows in the unaltered composites (figure 8a) indicating a slight adherence from the fibers to the matrix. However, a significant improvement in fiber/matrix adhesion is found for alkaline treated and benzoylated composites (Figs. 8 b and c), as demonstrated by the lack of troughs and fiber deposition. Fiber breakage rather than pull is the fracture surface of the treated composites, meaning there is improved interface strength. This creates an interface between the banana fiber and epoxy matrix, forming a bridge and acting like a compatibilizer that links two incompatible polymers [4].

### 3.2. Dielectric properties of banana residue fiber insulation composites

Dielectric parameters such as dielectric constant ($\varepsilon'$), dissipation factor (tan $\delta$), and dielectric loss ($\varepsilon''$) should be present in electrical insulating materials. The dielectric characteristics of most materials are temperature dependant. The temperature-dependent dielectric constant ($\varepsilon'$) for various banana leaf fibril weights at various frequencies is shown in Figure 3. It was determined that banana fiber loading improved the dielectric constant ($\varepsilon'$). Similarly, the dielectric constant increased as the banana leaf fiber loading was increased in both PPPP and LLLL composites. The tests suggested that adding layers to the banana leaf increased its dielectric constant. The multilayer insulating composite constructed entirely of pure banana leaf fibers has a lower dielectric constant than the pure banana peel. The conductivity of the banana peel fiber insulation composite was raised as a result of the peel fiber composite absorbing water from the ambient. Natural fibers exhibit varying degrees of hydrophobicity depending on the amount of lignocellulosic fiber-resin bonding. In comparison to banana peel fiber, banana leaf fibers contain a larger percentage of lignocellulosic fiber and are securely bound with epoxy resin. Agilent E4980A LCR meter was used to determine the dielectric properties. Natural fiber composites with varied polarization matrices and interfacial polarization have been generated as a result of banana fiber bonding [24]. By increasing the number of banana leaf layers in banana peel fiber insulation composites, polarization was increased, although pure banana leaf fiber insulation composites exhibited high polarization (4 layers of the banana leaf). As the frequency increases, the dielectric constant decreases correspondingly.

As a result, the dielectric constant ($\varepsilon'$) dropped with increasing frequency, as shown in the graph below. According to Figure 4, at frequencies of 1 kHz and temperatures of 20$^{o}$C to 120$^{o}$C, the dielectric constants of PPPP and PPLL are 11.21, 10.32, 12.46. 14.56 and 16.68, respectively. When exposed to high frequencies in varying temperatures, the chemically-treated banana leaf fiber composites had higher sensitivity than banana peel fiber composites. When banana leaf fiber sheet layers were increased, both

interfacial and orientation polarization increased. In the low-frequency region, banana leaf fiber composites performed better than peel fiber composites, as measured by dielectric constant (ε') at 1 kHz. The dielectric constant of banana leaf fiber composites was increased by using alkaline treatment. Polarization orientation decreased due to hydrophobicity of porous moisture zone in treated composites, and it may induce a decrease in the dielectric constant (ε') in treated fibril fibers. All treated banana leaf composites showed a decrease in polar groups, which may lessen orientation polarization.
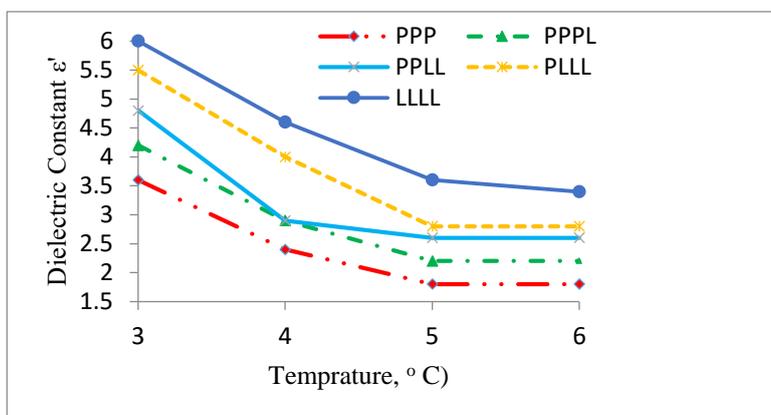


**Figure 4.** Dielectric constant of various banana residue fiber insulation composites

*3.3. Dissipation factor of banana residue fiber insulation composites*

Once the voltage is supplied to a conductor, a portion of the energy wasted is lost in the insulator. Heat will be generated as a result of the insulator's energy loss. Because the insulator's measuring dissipation factor is the most critical component to consider [24]. The polar component of the banana fiber insulating material was discovered to be an important factor in determining the material's dissipation factor. It is calculated by dividing the tangent of the dielectric loss angle (tan δ) by the dissipation factor. The dissipation factor values for various banana fiber insulation composites are shown in Figure 5. The dissipation factors of the specimens decreased as the frequency of the specimens increases. In the laboratory, the pure banana peel fiber insulation (EPOXY) specimen produced the lowest and highest values for pure banana leaf fiber insulation, respectively (LLLL). The dissipation factor reduces as the number of banana peel fiber layers increases. The results indicated that banana peel fibers included less lignocellulosic fiber and had a lower bonding density than banana leaf fiber specimens. As the temperature increased from 30 to 150ºC, the dissipation factors of PPPP and PPPL composites were observed to be 1.2302 and 0.8848, respectively. Increase the temperature from 20 to 120ºC in the same way for 1 kHz, the dissipation factors (tan δ) were 0.4432, 0.4272, and 0.0085 correspondingly for PPLL, PLLL, and LLLL at 120ºC.
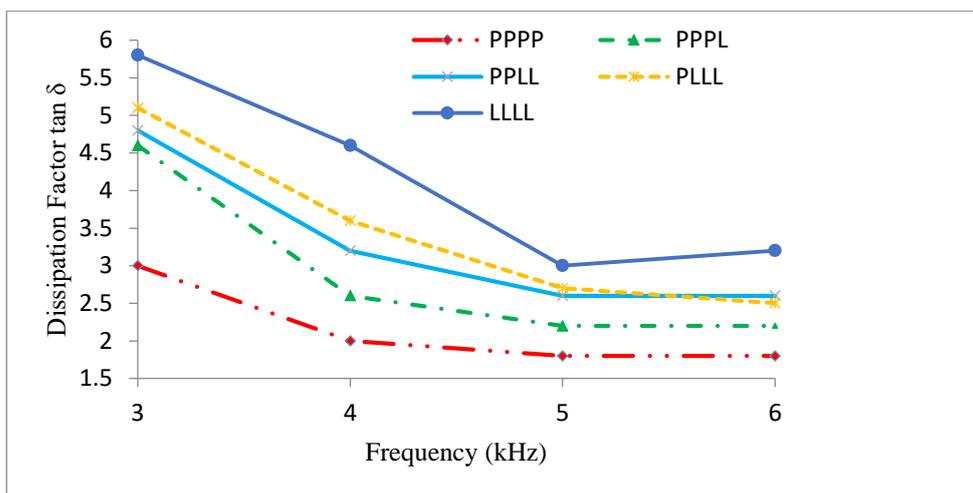
**Figure 5.** Dissipation factors of various banana residue fiber s

## 3.4. Loss factor

According to Fig.6, the loss factor ($\varepsilon''$) study demonstrated that the loss factors had been reduced, increasing in event frequency. As a result, a specimen that comprises a large number of banana leaf layers at a certain frequency has a high loss factor. Due to the vast number of banana leaf layers, the dissipation factor was high in lower frequency regions and low in higher frequency regions. Because leaf fibers are polarized, the loss factor in lower frequency zones is proportional to the number of leaf fibers present. However, it did not exist at higher frequencies. As a result, the polarization of banana leaf fiber layers increases [24].
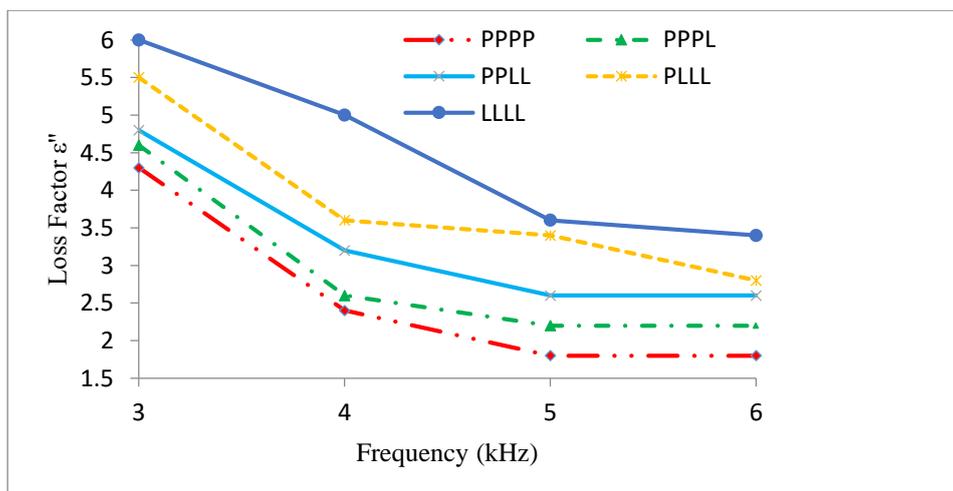


**Figure 6.** Loss factors of various banana residue fiber

With a frequency of 1 kHz to 10 kHz, Figure 6 displays the dielectric loss ($\varepsilon''$) of the banana peel and leaf fiber composites at different temperatures and varied banana leaf fiber loadings. Peel and leaf composite dielectric losses ($\varepsilon''$) increase as the temperature rises and decreases with an increase in frequency. With an increase in banana fiber loading in composite peels and leaves, dielectric loss ($\varepsilon''$)

*Int. J. Electrochem. Sci.,* 16 **(2021)** Article Number: 21124

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rose. Fig. 6 shows the dielectric loss of PPPP and PPPL at 1 kHz, 20°C. Additionally, at 120°C and 1-10 kHz, the dielectric loss of PPLL, PLLL, and LLLL composites was reported to be 12.254, 26.245, and 29.256 correspondingly.

Figure 7 illustrates the link between time (hours) and moisture absorption percentage. All banana leaf fiber composites exhibit stability after 50 hours of water absorption. The percentages of water uptake by treated PPPL, PPLL, PLLL, and LLLL were 21.892, 19.985, 18.283, and 17.846, respectively. Water absorption data demonstrate that treated banana leaf fiber composites perform much better than banana peel fiber layered composites.
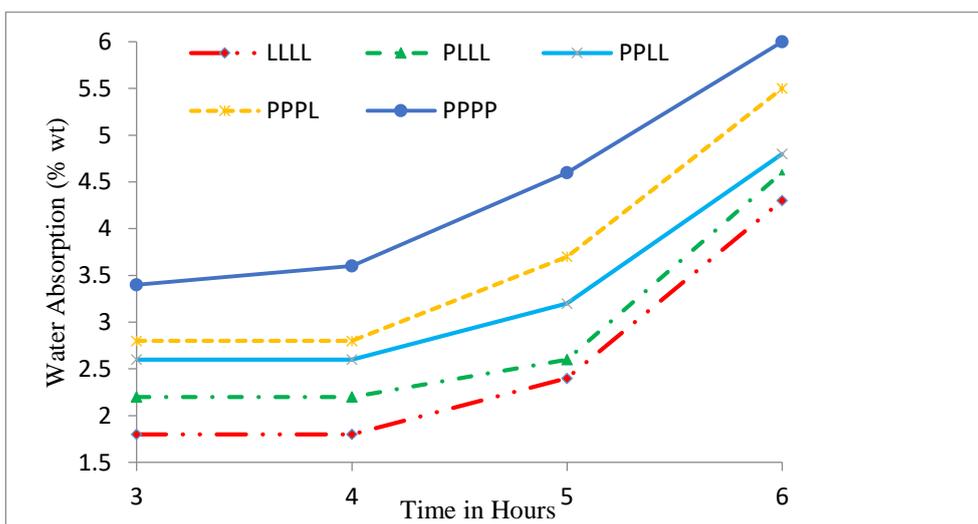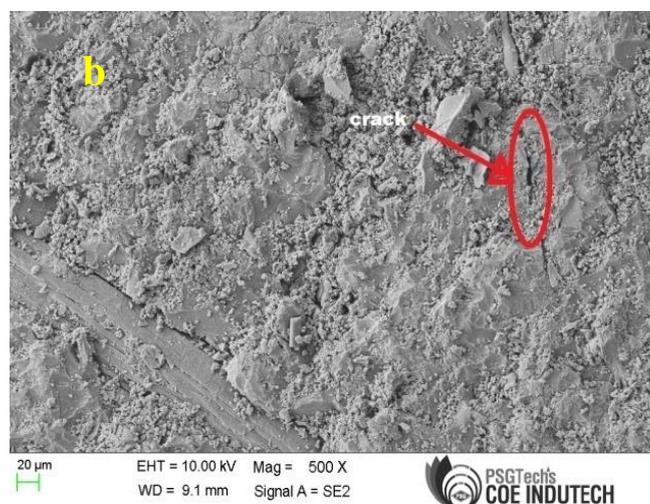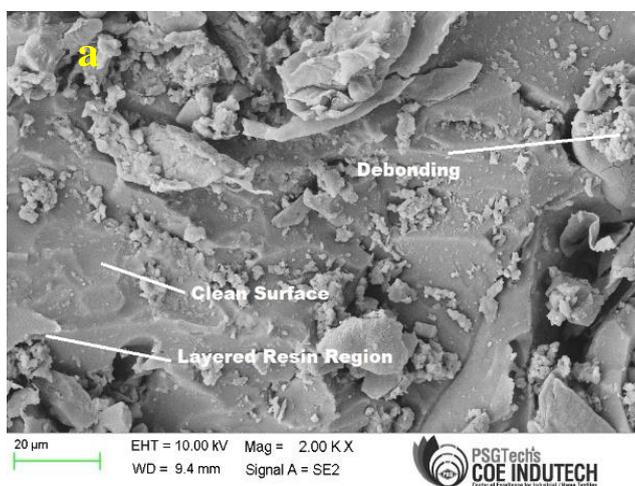


**Figure 7.** Water absorption of various banana residue fiber
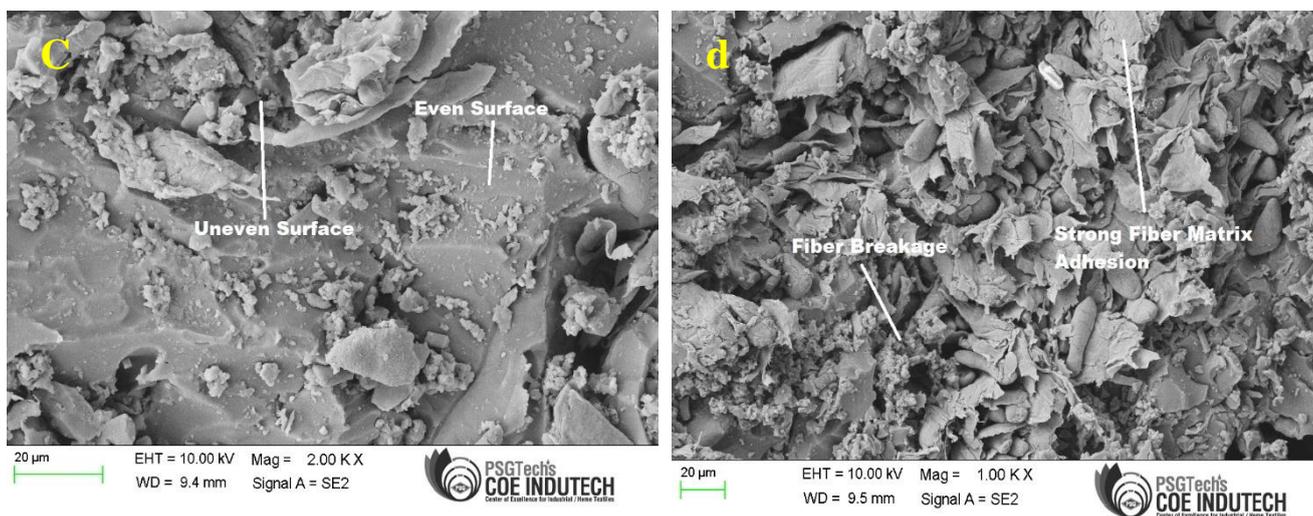
*3.5. FESEM analysis of fiber*

**Figure 8.** FESEM images of (a) PPPP combination of fiber  and (b) PPLL combination of fiber  (c) LLLP combination of fiber  and (d) LLLL combination of fiber

The FESEM SSS, PPLL, and LLLS fibers, as well as the FESEM LLLL fiber, are depicted in Figure 8. FESEM FESEM Fiber is presented on the screen. Figures 8 (a) and (b) show a clean and uniform surface of EPOXY fiber that has been processed. On close inspection, the banana bonding, surface structure, and resin adherence may all be observed clearly. The whole surface area of all cellulosic and non-cellulosic fibers is projected onto the paper. This was the primary cause of the smoothness of the surface structure. Figures 8 (c) and (d) show, on the other hand, the outward alterations that occur in the case of LLLL fibers (d). Specifically, the surface of banana fiber is observed to be rough and disrupted as a result of the deactivation of the top waxy layer and the presence of other non-cellulosic components. The absence of these adherence mixers allows chemicals to penetrate and divide tightly packed cellulose fibers. The disconnection has been increased as a result of the increased length of the banana sheet fibers. Furthermore, because banana leaf fibers are tightly related to adhesion, which results in the formation of a constructive lacuna for matrix integration, the top and bottom surface structures are efficiently bonded to one another. The banana leaf layered composites were better than the banana peel layered composites due to improved interfacial clamping between the fiber and the matrix, which was observed in the experiments.

## 4. CONCLUSION

Chemically treated banana (Musa acuminata) fibril-reinforced epoxy composites were created with varying reinforcement weight percentages, although the reinforcement weight percentages remained constant. The electrical properties of untreated and alkaline treatment composites, such as the dielectric constant, dissipation factor, and dielectric loss factor, were evaluated and compared for 1 kHz and 10 kHz frequencies. The composite's electrical insulating characteristics are particularly good at

higher frequencies. The electrical properties of both composites increased in value as the temperatures of the materials climbed. It was revealed that after alkaline treatment, LLLL banana fiber composites have a higher electrical insulating capacity than peel fiber composites. This was ascribed to the removal of hemicellulose from the banana fibril in the current investigation. Due to the homogenous dispersion of banana fibrils in composites, the glass transition temperature increases with increasing banana fibril loading. The dielectric and FESEM results indicated that the pure banana leaf fiber (LLLL) insulating composite attracted the most attention due to its superior polarization characteristics. As the banana leaf layer density increases, the quality of the polarization also improves. Thus, the polarization and dissipation coefficients (tan δ), as well as the loss coefficients, are dependent on the number of banana leaf layers utilized to form the structure. The dielectric constant of all banana residue insulating s was decreased by increasing the frequency of the electrical current. The banana peel fiber insulation s had weaker dielectric properties and had fewer lignocellulosic fibers, resulting in a high water absorption quality for the boards. Chemical adhesives strengthen the bonds between banana fiber molecules. It decreases the banana leaf hydrophobicity. Epoxy resin is used to increase the bonding strength between the banana fibers through the molecular coupling of the carboxyl group. As proved by the experiments, the banana leaf fiber s are suitable for high voltage applications due to their dielectric and FESEM properties.

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