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Investigation Of Dielectric And Mechanical Properties Of Lignocellulosic Rice Husk Fibril For High And Medium Voltage Electrical Insulation Applications

T. Rajamanikandan
Department of EEE, Kongunadu College of Engineering and Technology, India

S. Banumathi
Department of EEE, M.Kumarasamy College of Engineering, India

B. Karthikeyan
Department of EEE, K.Ramakrishnan College of Technology, India

See next page for additional authors

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Authors

T. Rajamanikandan, S. Banumathi, B. Karthikeyan, R. Palanisamy, Mohit Bajaj, Hossam Zawbaa, and Salah Kamel

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Original Article

Investigation of dielectric and mechanical properties of Lignocellulosic Rice Husk Fibril for high and medium voltage electrical insulation applications

T. Rajamanikandan [a], *S. Banumathi* [b], *B. Karthikeyan* [c], *R. Palanisamy* [d], *Mohit Bajaj* [e], *Hossam M. Zawbaa* [f,g,h,*], *Salah Kamel* [i]

[a] *Department of EEE, Kongunadu College of Engineering and Technology, India*
[b] *Department of EEE, M.Kumarasamy College of Engineering, India*
[c] *Department of EEE, K.Ramakrishnan College of Technology, India*
[d] *Department of EEE, SRM Institute of Science and Technology, Kattankulathur, 603203, India*
[e] *Department of Electrical Engineering, Graphic Era (Deemed to Be University), Dehradun, 248002, India*
[f] *Faculty of Computers and Artificial Intelligence, Beni-Suef University, Beni-Suef, Egypt*
[g] *Technological University Dublin, Dublin, Ireland*
[h] *Applied Science Research Center, Applied Science Private University, Amman, Jordan*
[i] *Department of Electrical Engineering, Faculty of Engineering, Aswan University, 81542, Aswan, Egypt*

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ABSTRACT

The insulating material is made from rice husk and epoxy resin which are ecologically friendly and incredibly durable. When coarse Rice husk is mechanically disintegrated, fibrils are formed. By weaving together fibrillated threads, and robust biodegradables, lightweight dielectric fibers are created. Then the Composites are examined utilizing a blend of agave Rice husk fibers (10–35%) and an epoxy resin solution. The Chemical treatment of the Rice husk fibers increases the composites' mechanical strength and electrical insulating properties. The tensile strength of Rice husk in epoxy composites is increased from 37.84 MPa to 48.32 MPa. The experimental results are compared using well-known prediction models such as the rule of mixture (ROM), Halpin–Tsai, and Nielson–Chen using regression analysis with other insulting materials used in state of the art. The Nielson-Chan model predicts experimental data effectively with an average relative error of 14.64%. The proposed composite material has excellent insulating properties because of its conductivity and high dissipation factor. The composite material exhibits high stability when the frequency is in the range of 1–10 kHz than at lower frequencies.

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* Corresponding author. Technological University Dublin, Dublin, Ireland
E-mail address: hossam.zawbaa@gmail.com (H.M. Zawbaa).

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List of units, symbols, and acronyms:

ROM	Rule of Mixture
MPa	Mega Pascal
GPa	Giga Pascal
kHz	Kilo Hertz
LDPE	low Density Poly Ethylene
°C	degree Celsius
TRHF	Treated Rice Husk Fabrils
URHF	Untreated Rice Husk Fibrils
UTM	Universal Testing Machine
kJ/m^2	Kilo Joule per square meter
Vr	the percentage of volume
E	Dielectric constant
FESEM	Field Emission Scanning Electron Microscope

1. Introduction

Natural fiber composites made from recycled and biodegradable materials have become more popular as people are more concerned about global warming. Using locally available manual labor and environmentally favorable resources, low-cost natural fibers can be produced [1]. Natural fiber composites are appreciated for their low weight and inexpensive cost, as well as their high specific strength and modulus of elasticity. It is conceivable for natural fibers to spontaneously dissolve or regain their calorific value in a heating chamber when they are employed as reinforcement. This is impossible to achieve with traditional reinforcing materials like glass fibers [2]. In the reinforcing research, natural fibers such as pineapple leaves, Rice husk, flax, and jute plant fibers, as well as synthetic fibers such as nylon and polyester, were used. The natural fiber made from rice husk leaves could be a viable option for applications that require both electrical and mechanical properties in a single material [3]. The species containing cellulose content of rice husk ranges from 49 to 78%, with lignin content of 3–8%, hemi-cellulose content of 10–24%, wax content of 1–2%, and ash of 0.1–1% is rare since it has a diameter of 100–200 mm and a maximum length of 1–1.5 m, making identification difficult. It has been investigated whether de-waxing the surface, removing impurities, and lowering moisture sensitivity are all viable approaches to promote fiber-matrix adhesion [4]. Several studies have been carried out to see how chemical treatments and processing conditions alter the surface of natural fibers [5].

Polymers are widely used in the electrical and electronic sectors, such as home appliances and other auxiliary components. Because of their light weight, low cost, increased heat and mechanical resistance, and ease of fabrication, plastics are frequently utilized in electrical applications [6]. The Fiber-based polymeric materials, in addition to being good insulators, also serve as mechanical supports for field-carrying conductors allowing them to operate at higher frequencies [7]. Compound polymers are used in various applications, including the protection of wires and cables and the shielding of electromagnetic waves [8]. These high-performance composite materials are made by incorporating fiber reinforcement into polymeric matrixes and are used in a variety of devices ranging from plugs and switches to transformer components [9].

According to the study findings, the polymeric chain motion at the composite interface reduces the dielectric losses of the Rice epoxy composite as a result of the immaculate interlocking between the matrix and fibers [10]. When the temperature and frequency of the experiment are reduced, the dielectric constant of an epoxy composite made from silver-coated Rice husk will increase [11]. The dielectric properties of the Rice husk leaf-reinforced composite are determined to be frequency dependent rather than time dependent during the experiment. As the frequency of the signal decreases, the dielectric constant decreases. The chemical treatment can be used to lower the dielectric constant of an LDPE composite that has been reinforced with short Rice husk fibers [12]. Rice husk fiber is commonly employed in low-value products due to its wide diameter and the difficulty of maintaining a consistent and homogenous fiber distribution in composites. The application of rice husk fiber fibrillation is used to manage the dispersion fluctuations of rice husk fibers and overcome this constraint [13]. The electrical properties of rice husk based polymer composites produced utilizing rice husk are recently examined by researchers. Short rice husk dielectric constant, dissipation factor, and loss factor rise in direct proportion to the amount of stress applied to it [14]. By chemically removing undesirable components from the fibers, it is possible to increase the strength of fiber reinforcement. This treatment is also expected to have a favorable impact on natural fibers. It is possible to remove hemicelluloses from rice husk using a 5% alkali solution, leaving 86.27% cellulose and 4.05% lignin following the extraction process [15]. The fabrication of rice husk fibre and its mechanical and electrical characterization was analyzed with respect to tensile strength, impact strength, and flexural strength [16–18].

The study set out to determine the electrical and mechanical properties of a composite material made from chemically treated rice husk fibres for usage in high and medium voltage insulation.

The electrical properties of the composites have been thoroughly analyzed with a particular emphasis placed on the effects of several factors including fibre loading, fibre ratio, alternative fibre treatments, and a reinforcing phase on the composites' electrical characteristics. Several experiments including the dielectric loss factor, the depreciation factor, and the dielectric constant have been carried out in order to ascertain information on the loss factor and the percolation threshold of a contemporary epoxy composite. The tensile, flexural, and impact strengths of the composites are the primary areas of focus of the in-depth research conducted on the materials' mechanical properties.

2. Material preparation

2.1. *Materials*

The Rice husk collected from Tamil Nadu Rice Research Institute (Tanjore, Tamil Nadu, India) is used in this study. The Sodium hydroxide (>98%) is purchased from Isochem

Table 1 – Summary of Literature review.

Reference	Author	Year	Material	Inference
[1]	Thyavihalli Girijappa, Y. G et al.	2019	Hemp, jute, sisal, banana, coir, and kenaf	The major applications of natural fibers and their effective use as reinforcement for polymer composite materials were discussed
[2]	Mohammed, L. et al.	2015	Coir, Sugar cane bagasse, Jute Fiber, Rice Husk, Kanaf fiber, Epoxy	Polymer matrix which ultimately enhanced physico-mechanical and thermo-chemical properties of the natural fiber reinforced polymer composites
[3]	Karimah, A et al.	2021	Flax fiber, Epoxy resin, Bamboo, Sisal Fiber utilized	Comparison of mechanical and tests was conducted and Natural fiber having good Mechanical strength
[4]	T.Rajamanikandan et al.	2021	Banana Fiber reinforced with Epoxy Resin	Lingnocellulocic fiber contains good electrical and Mechanical Strength
[5]	Nimanpure, S et al.	2021	Sisal fibril reinforced with epoxy	composite-a high strength electrical insulating material
[6]	Ngo, T. D., Kashani, et al.	2018	Natural fiber Used for additive manufacturing	Natural fiber contains better mechanical strength during additive manufacturing
[7]	Khan, I et al.	2017		
[8]	Sankaran, S et al.	2018	Metal and carbon filler reinforced flexible polymer composites	Electromagnetic interference shielding properties of metal and carbon filler reinforced flexible polymer composites
[9]	Rajak, D. K et al.	2019	Reinforcement materials like Epoxy, Si, Alumina	Alloy reinforcement materials are having good mechanical and electrical strength
[10]	Airinei, A et al.	2021	EPDM/Flax Fiber Composites	Dielectric, Thermal and Water Absorption Properties of EPDM/Flax Fiber composites are better compare to sisal fiber
[11]	Mohammed, L et al.	2015	Sisal fiber, Rice Husk, Kanaf fiber, Epoxy, Urea formaldehyde	Comparison of mechanical and electrical tests was conducted
[12]	Elloumi, I et al.	2021	Wood-Polymer Composites	Dielectric Properties of Wood-Polymer composites was studied
[13]	Li, M., Pu, Y et al.	2020	Non wood fibers	Plant-Based Natural Fiber–Reinforced Composites and Their Applications
[14]	Quiles-Carrillo, L et al.	2018	Pieces of Poly(ε-caprolactone) and Thermoplastic Starch	Ductility and Toughness Improvement of Injection-Molded Compostable materials are discussed
[15]	Mylsamy, K et al.	2021	Raw and Alkali-treated Agave americana Fiber	Investigation on Physio-chemical and Mechanical Properties of Raw and Alkali-treated Agave americana Fiber
[16]	Alaneme, K. K et al.	2021	Rice husk ash – Alumina reinforced Al–Mg–Si alloy matrix	Fabrication characteristics and mechanical behavior of rice husk ash composites are good
[17]	Kumar, S et al.	2019	Rice-husk filler, hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy composites	Synergy of rice-husk filler on physico-mechanical and tribological properties were studied
[18]	Yusoff, N. M et al.	2019	silica synthesized from rice husk	Physical and mechanical properties of flowable composite incorporated with nanohybrid silica synthesized from rice husk was studied

Fig. 1 – A graphic view of fabrication of rice husk fibril reinforced epoxy composites.

Laboratories (Kochin, Kerala, India). The epoxy resin (IN2 infusion resin and AT30 hardener, Super first Chemicals India Pvt. Ltd, (Bangalore, India) is used for infiltration. The deionized water is used as the solvent(see Table 1).

2.2. Fabrication

The rice husk fibril reinforced epoxy composites go through various stages of growth until they become finished composite material as depicted in Fig. 1. The fine fibrils in the form of pulp are obtained from rice husk fibers using the mechanical disintegration process. It takes 24 h to dry the pulp from a dried rice husk over a piece of cotton cloth stretched with a wire mesh to obtain a density of 1.16 g/cm^3 after it is placed on the cloth. It is necessary to employ a fiber separation apparatus in order to extract the fibrils from the handcrafted rice husk paper. During the manufacturing of composites, the fibrils are used as a reinforcing component. The density of this resin is varied between 1.0 and 1.5 g per cubic centimeter. A sodium hydroxide solution containing 5% weight percent sodium hydroxide is developed for the treatment of rice husk fibril. Allowing the fibrils to soak in the solution for 2 days (48 h) at room temperature, before rinsing them with water to ensure that all sodium hydroxide has been removed from the fibrils. To eliminate moisture from the fibrils, they are dried at 80° Celsius in an air-circulating oven for 24 h. Building a composite of the epoxy composites with rice husk fibril reinforcement is illustrated in Table 2. It is necessary to sandwich a cotton cloth layer between the mould and the base plate in order to make sample removal easier. The necessary amounts of epoxy and hardener are weighed and mixed in a 3:2 ratio. Fibril particles are thoroughly mixed with resin for 20 min to ensure proper dispersion of the fibrils. The raw materials are applied in a thick coating to the waxed mould surfaces, which are waxed again. In order to produce a uniform thickness, the

Table 2 – Specimen preparation mixture of rice husk fibril epoxy composite.

Composition			
Name of the Specimen	Rice husk(g)	Epoxy resin (g)	Sodium hydroxide treatment of rice husk fibril
Epoxy	Nil	100	Not Applicable
URHF15E	15	85	Untreated
URHF25E	25	75	Untreated
URHF35E	35	65	Untreated
URHF40E	40	60	Untreated
TRHF15E	15	85	Treated
TRHF25E	25	75	Treated
TRHF35E	35	65	Treated
TRHF40E	40	60	Treated

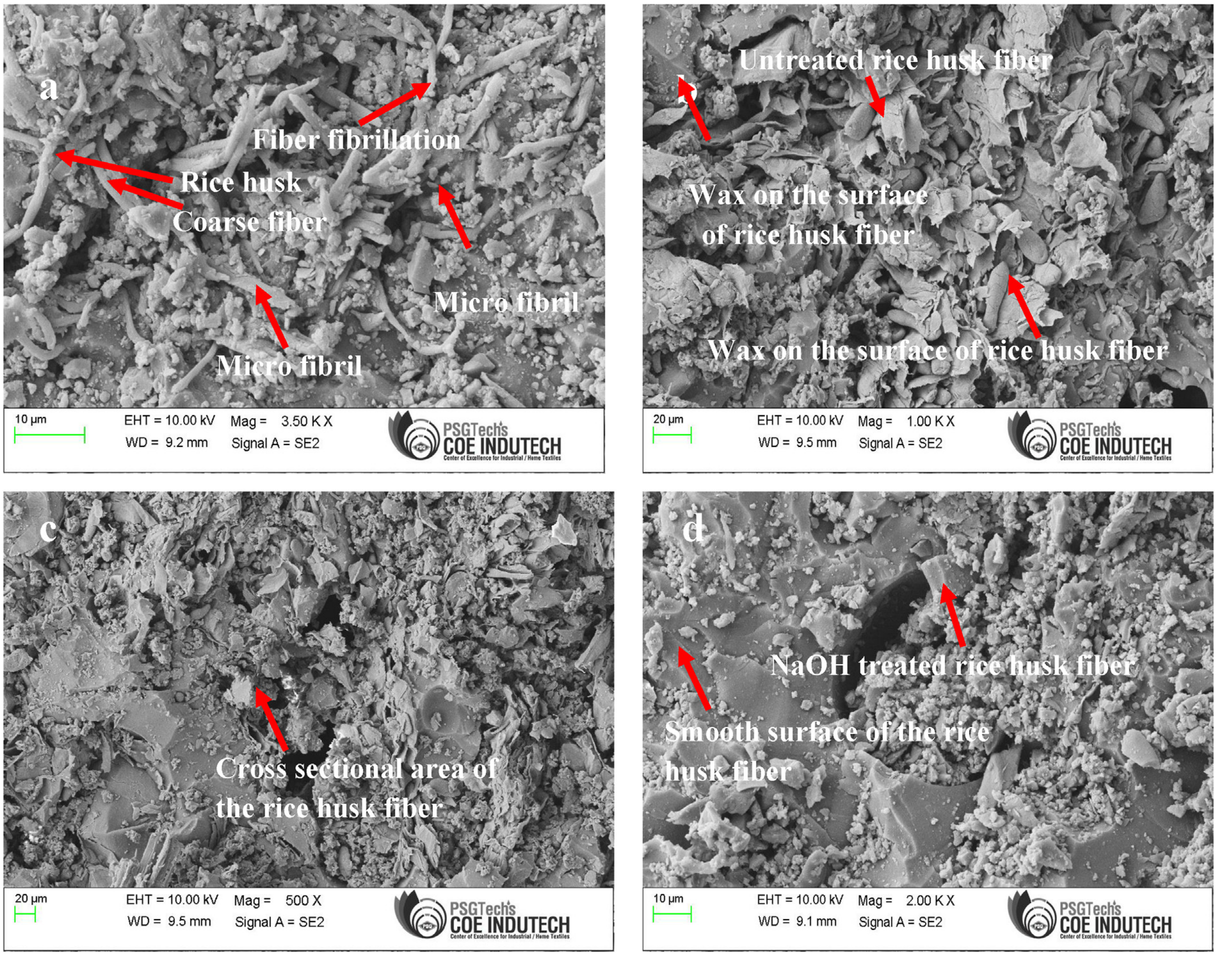

Fig. 2 – FESEM surface morphology (a) Coarse rice husk fiber, (b) Untreated Rice husk fibrils, (c) Cross-section area of rice husk fibril, and (d) Sodium hydroxide-treated Rice husk fibril.

mould is squeezed by the top punch plate which is designed to rise 3 mm above the base plate, and placed between the plates of a hydraulic press operating at room temperature with uniform pressure to reach the desired thickness. The epoxy has been cured within 6–7 h, allowing the composite plate to be withdrawn from the mould without damaging it. The plates are post-cured for 5 h at 120 °C in an air circulation oven with a fan blowing on them.

2.3. *Characterization*

A Field Emission Scanning Electron Microscope (FESEM) model SUPRA 55 VP-4132 and a model NOVA NANOFESEM 430, both made by FEI in the United States are used to analyze the morphology of the fractured surfaces of various composites.

Prior to the inspection, all specimens are coated with a 10 nm gold coating to protect them from damage. The specimen mounting to the microscope holder is accomplished with the help of conduction carbon adhesive tape and 2 kV–10 kV is observed during the experiment. It is discovered that different composites exhibit distinct modes of fracture.

2.4. *Mechanical characterization*

Tensile testing on composites is carried out in accordance with ASTM D 3039 standards. In terms of size, the specimen is 120 mm × 15 mm × 3 mm in proportions. The trials are carried out with an Instron UTM model 8801 with a 100 kN capacity. The cross-head is moved 2 μm in a matter of seconds. Typical ASTM D 790–30 flexural tests are performed at room temperature in a Tinius Olsen UTM H25KT with a 25-kN cross head speed of 10 mm per second and in a Tinius Olsen UTM H25KT with a 10-mm per second 25-kN cross head speed Each one was 70 mm long, 15 mm broad, and 3 mm thick. They are made out of aluminum and plastic [6]. The span is 50 mm, and the span-to-thickness ratio is greater than 16 times. With the same equipment, these tests are carried out on rice husk coarse fiber, untreated rice huskfibril, and rice huskfibril that have been treated with Sodium hydroxide. When performing the impact test in accordance with standard: ASTM D 256–05 at room temperature, a Ceast Izod pendulum impact tester is utilized [8]. Its dimensions are about 60 mm × 12.75 mm x 3 mm, and it is featured a 2.54-mm notch in the centre of it.

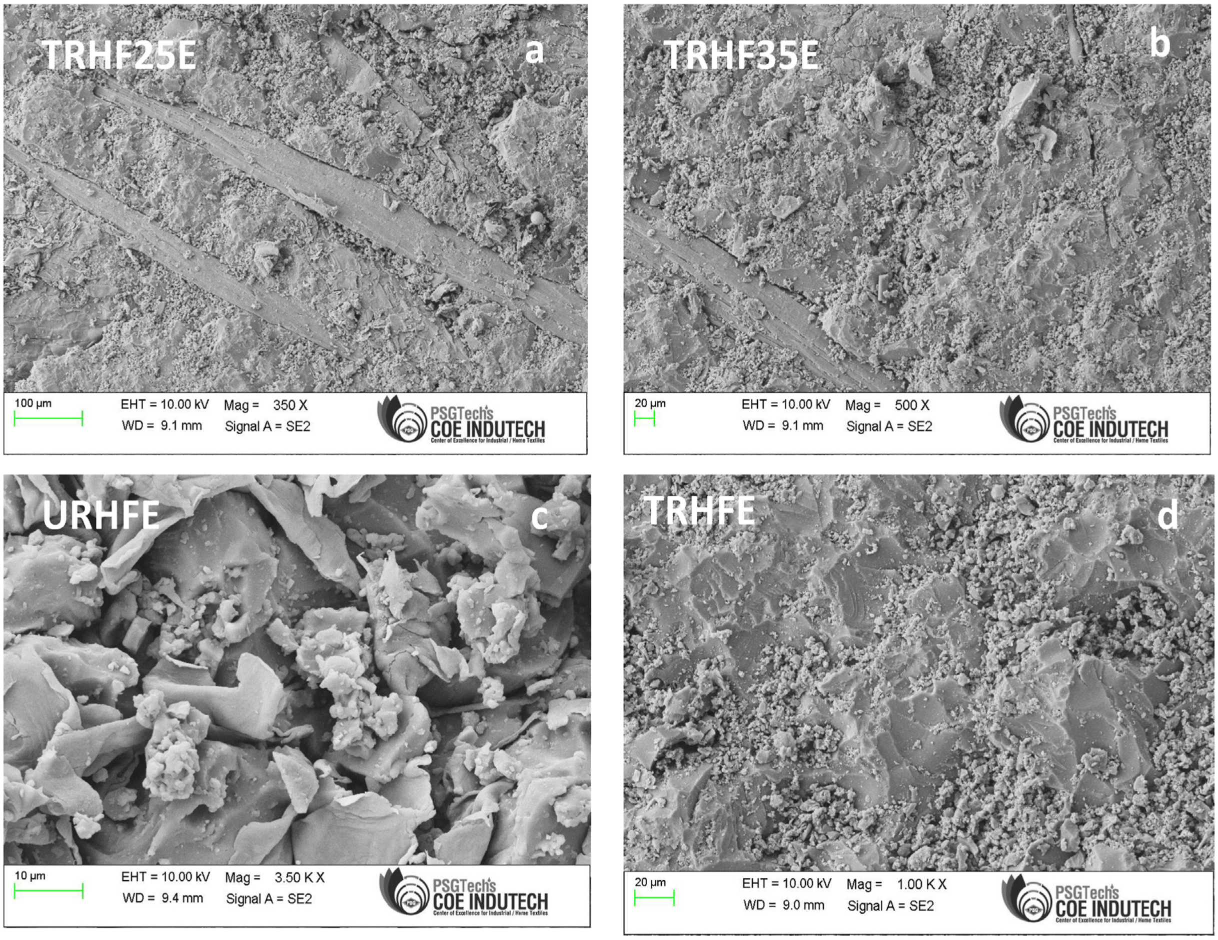

Fig. 3 – FESEMsurface morphology (a) 20 wt% fibrils, (b) 30 wt% fibrils, (c) URHFE composite, and (d) TRHFE composite.

3. Results and discussion

3.1. *Mechanical property analysis*

Fig. 2a shows coarse rice husk fibers that are bundled together with bundles of macro and micro fibrils. The coarse rice husk fiber with a diameter of 80 mm–150 mm is used in the research. The process of turning fiber into a fibril was already discussed in the context of material preparation. Fig. 2b shows rice husk fibrils that have not been treated. Fibrils are rectangular in shape and have a thin waxy coating on the surface of their bodies. In the fibril of Rice husk leaf, the breadth ranges between 5 and 20 mm. The area of a rice husk fibrils cross section after it has been fractured is depicted in Fig. 2c and d shows the fracto-graph of a rice husk fibril that has been treated with sodium hydroxide. When compared to untreated Rice husk fibril, the surface of Sodium hydroxide treated Rice husk fibril is smoother with less trace of wax and a more uniform cross section indicating that it has been treated with Sodium hydroxide.

The tensile fractured samples are used in the FESEM analysis, which is carried out on them. Fig. 3a depicts composite containing 20% fibrils, whereas Fig. 3b depicts composite containing 30% fibrils. Fibers and epoxy matrix may be seen in these fracto-graphs indicating their presence. The Fibrils are distinguished by their diameter, length, and straightness. Because of the inclusion of rice husk fibrils in the composite, the epoxy fracture pattern is brittle, whereas the brittle fracture pattern of the epoxy is ductile. The fractured surfaces of untreated and alkali-treated TRHFE composites are depicted in Fig. 3c and d, respectively. After the rice husk fibril has been partially linked with epoxy, as shown in Fig. 3c. The addition of Sodium hydroxide to rice husk fiber composites (Fig. 3d) resulted in increased adhesion between the natural fiber and epoxy matrix, showing a strong bond between the fiber and epoxy matrix between two materials. After the Sodium hydroxide therapy, the fibrillation becomes more severe. As a result of the increased surface area, fibril and epoxy are able to stick to it more effectively. FESEM tests have shown that treated fibrils and epoxy have better adhesion than untreated fibrils and epoxy, according to the results. The apparent absence of matrix material attaching to the untreated fibril serves to highlight the poor fibril matrix adhesion of the untreated fibril.

Treatment of fibrils with mechanical interlocking and friction may result in increased tensile strength in the long run. In these micrographs, alkali-treated fibrils are seen to form a tight link with one another. In order to identify the

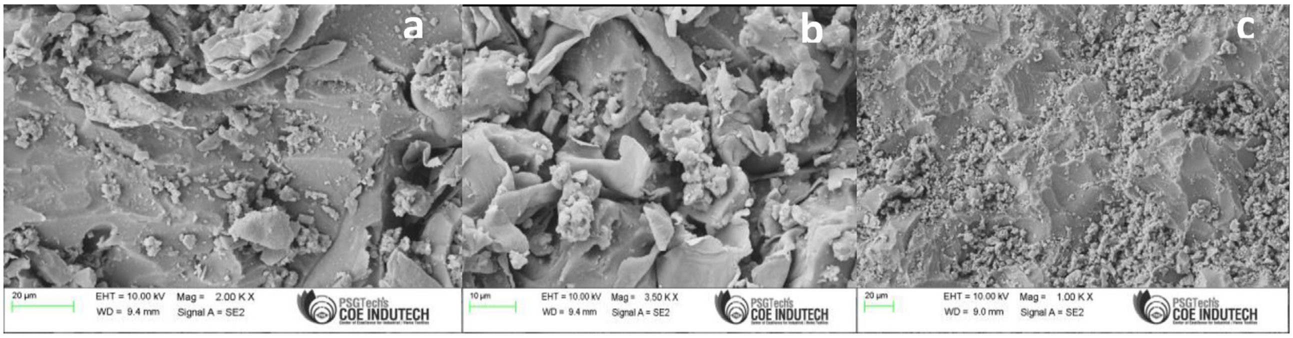

Fig. 4 – FESEMsurface morphology (a) Epoxy, (b) URHFE composite, and (c) TRHFE composite.

morphologies of flexural fracture surfaces of clean epoxy, untreated rice husk fibril epoxy (URHFE), and TRHFE composites, FESEM is used to examine their flexural fracture surfaces. On the right-hand side of Fig. 4a, the shattered surface of the epoxy sample is shown. The typical surface morphology of a brittle epoxy polymer can be seen in this image. Fig. 4b shows a FESEM micrograph of the broken surface of the URHFE composites, which is obtained using a scanning electron microscope. In this particular instance, a rough surface is visible as a result of fibril pullout and insufficient bonding between the fibril and the matrix. The FESEM micrograph of TRHFE composites is depicted in Fig. 4c. The fact that alkali treatment can produce fibrillation in the fibril means that it binds to the epoxy matrix more effectively under these conditions. As a result, the effective surface area of the fibril increases. Fibril dispersion is more uniform in alkali-treated fibrils than in untreated fibrils.

The fibrillation of coarse rice husk fiber into fine fibrils has greatly enhanced the tensile strength of the rice husk fiber, as shown in Table 3. The tensile strength of a fiber is determined by the degree of fineness of the fiber. As the fineness of the fiber is lowered, the strength of the fiber increases. The coarse granular fibers are fibrillated into fibrils resulting in a reduction in cross-sectional defects and an increase in tensile strength. The most prevalent source of faults in cells is the presence of voids in the weak bonding component of the cells. Comparing the tensile strength of rice husk fibrils that have not been treated with treated with sodium hydroxide, the tensile strength of the Sodium hydroxide-treated fibrils is much higher. The removal of lignin and/or hemi-cellulose from the fibrils as a result of treatment with Sodium hydroxide leads to an increase in the tensile strength of the fibrils.

The fibrils have the ability to reorganize themselves in the direction of tensile deformation. The reorganization of the

Table 3 – Improved tensile strength.

Type of fiber	Tensile strength (Mpa)
Course Rice husk fiber	380–580 MPa
Rice husk fiber	590–810 MPa
Sodium Hydroxide Rice husk fiber	780–880 Mpa

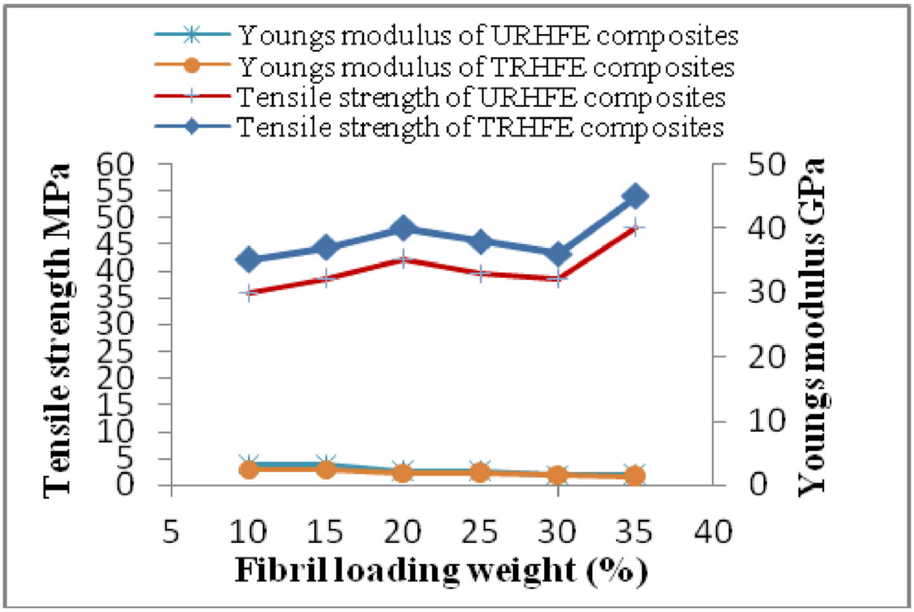

Fig. 5 – The tensile strength and modulus of URHFE and TRHFE composites.

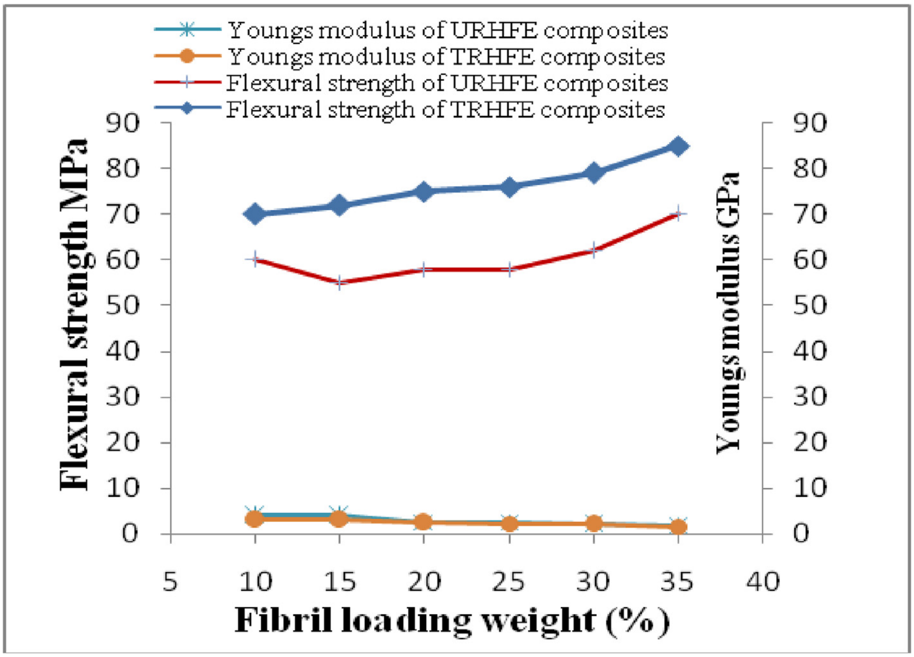

Fig. 6 – The flexural strength and modulus of URHFE and TRHFE composites.

fibrils that occurs throughout the stretching process leads to an enhancement in their ability to withstand stress. The elimination of lignin increases the tensile strength of the fibril by filling in microvoids in the intermediate lamella of the fibril. The change in tensile strength and modulus of URHFE and TRHFE composites as a function of rice husk fibril loading is depicted in Fig. 5. They are incorporating Rice husk fiber into composites resulted in enhanced tensile and modulus strength. The increase in tensile strength of Rice husk fibrils as the amount of loading increases demonstrates the effectiveness of fibril reinforcing. Both the tensile strength and the modulus of alkali-treated rice husk fibril composites are significantly greater than those of the corresponding values for untreated rice husk fibril composites.

The modulus of the URHF35E and TRHF35E specimens are 2.76 GPa and 3.30 GPa, respectively. When the TRHF35E composite is compared with the URHF35E composite, the modulus of the TRHF35E composite is increased by 19.76%. The removal of hemicelluloses from rice husk fibers with Sodium hydroxide has resulted in a rise in cellulose concentration which increases fiber strength. When alkali-treated rice husk fibril composites are employed in epoxy, their tensile strength is increased by 17.89% when 10% fibril loading is applied. Fig. 6 shows a comparison of the flexural strength and modulus of TRHFE and

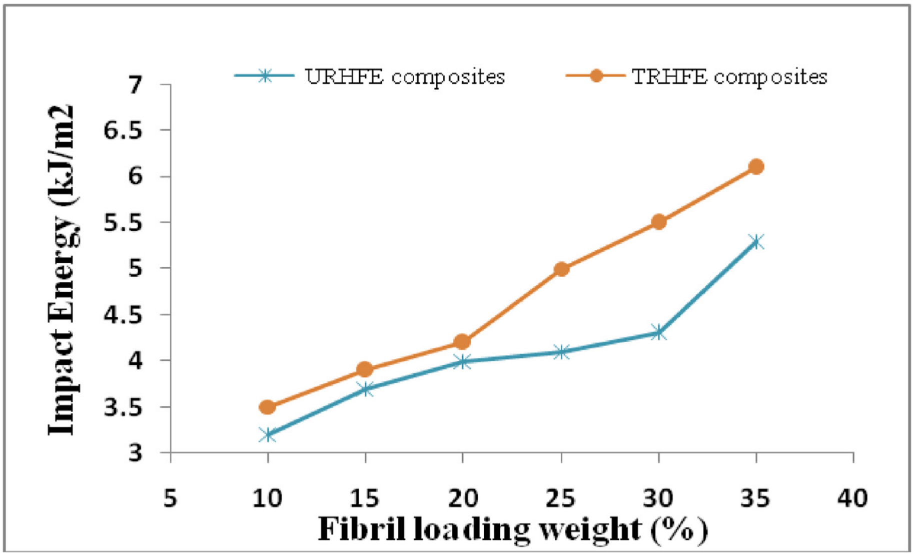

Fig. 7 – The impact strength of epoxy, URHFE, and TRHFE.

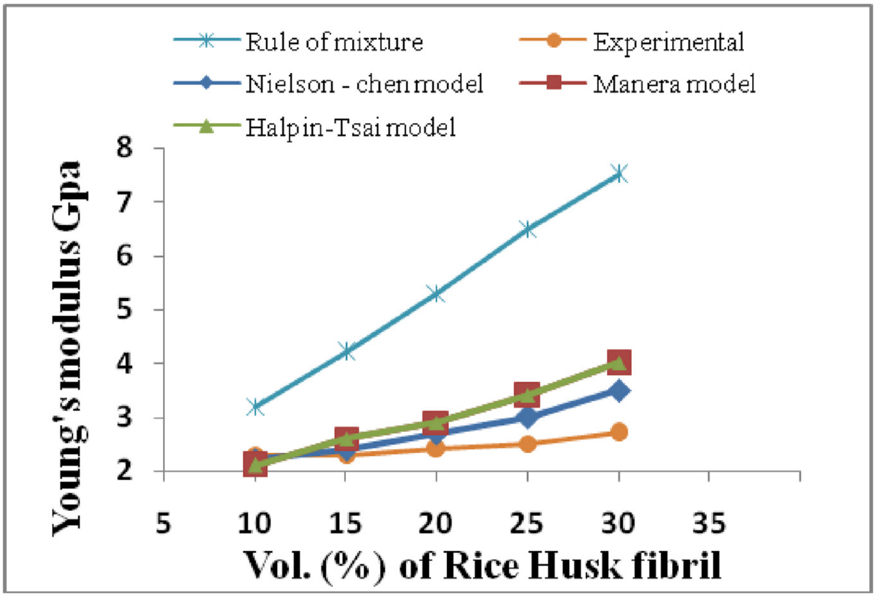

Fig. 8 – Difference between experimental vs. mechanical models.

URHFE composite flexural beams. After doing this test, it was discovered that treated fibrils in composites have a higher bending strength than untreated fibrils. The flexural strength of the URHF35E and TRHF35E specimens is 79.41 MPa and 79.41 MPa, respectively. TRHF35E composite has an 8.80% higher flexural strength than URHF35E composite as a result. The flexural strength of TRHFE composites is enhanced from 68.57 MPa to 86.40 MPa by increasing the loading of alkali-treated fibril from 10% to 35% by weight. Elastic and flexural modules both exhibited similar patterns. In this study, the flexural module of URHF35E and TRHF35E specimens are determined to be 4.21 and 5.07 GPa, respectively. This data shows that the instance of treated rice husk fibrils has improved by 20.42%. As the loading rises from 10% to 35%, the modulus of the treated fibrils increases from 2.09 GPa to 5.07 GPa. The reported increase in flexural strength and modulus in the treated composites has been attributed to the observed improvement in fibril-to-matrix adhesion. Fig. 7 shows the impact strength of the URHFE and TRHFE following surface modification. TRHFE composites have high impact strength compared toURHFE composites, according to the results.

The impact strength of the URHF35E specimen is 5.50 kJ/m^2, while the TRHF35E specimen is 6.07 kJ/m^2. As a result, the impact strength is increased by 10.25%. The impact strength of the composite is increased from 3.61 to 6.07 kJ/m^2 by increasing the amount of rice husk fibril. By removing natural and manufactured contaminants from the fibril surface, adhesive qualities and Sodium hydroxide treatment have enhanced impact strength. The impact response of fiber composites is regulated by the adhesive bond strength, fiber properties, and matrix characteristics. The natural fiber reinforced composites' elastic characteristics shall be calculated using a variety of micromechanical models. When attempting to anticipate the properties of composite material parameters such as Young's modulus (E), Poisson's ratio (v), and the volume percent of both fibers and matrix are considered, and the following models are used to predict Young's modulus in this study. The rule of mixture (ROM) predicts the composite materials' elastic properties. This equation contains Young's modulus E_1.

$$E_1 = E_F V_F + E_M V_M \tag{1}$$

$$p/p_m = \frac{1 + \xi \eta Vr}{1 - \eta Vr} \tag{2}$$

Table 4 – Comparison of the tensile, impact, and bending strengths of the different rice husk composite reinforcements.

Samples	Average Tensile Load (MPa)	Average Impact Load (MPa)	Average Flexural strength (MPa)	Reference
Rice husk ash – Alumina reinforced Al–Mg–Si alloy matrix	54.85	4.31	36.17	[16]
Rice-husk filler hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy	57.35	4.74	32.38	[17]
Silica synthesized from rice husk	50.51	5.61	38.63	[18]
Chemically treated Lignocellulosic Rice Husk Fibril with epoxy resin	56.68	4.82	38.62	[Proposed Work]

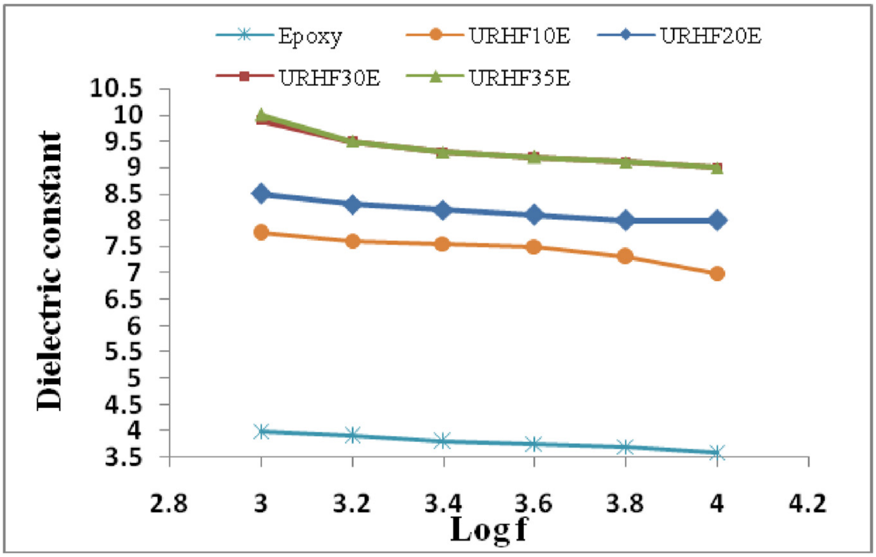

Fig. 9 – Dielectric constant of URHFE composites.

$$\eta = \frac{\left(p_r/p_m\right) - 1}{\left(p_r/p_m\right) + \xi} \tag{3}$$

The Halpin–Tsai equations are compared to the numerical solution of the micromechanics equations in order to figure out a number. Vr stands for the percentage of the volume that is added.

$$\xi = 2\,l/t + 40V_r^{10} \text{for } E_{11} \approx 2\left(l/d\right) \tag{4}$$

The significance of 40 Vr^{10} is negligible. The Nielson-Chen model goes like this: It is possible to estimate the elastic properties of fiber-reinforced composites using the Nielson-Chen model. The formal representation of the equation is as follows:

$$E_c = 3/8E_1 + 5/8E_2 \tag{5}$$

$$E_1 = E_f V_f + E_m\left(1 - V_f\right) \tag{6}$$

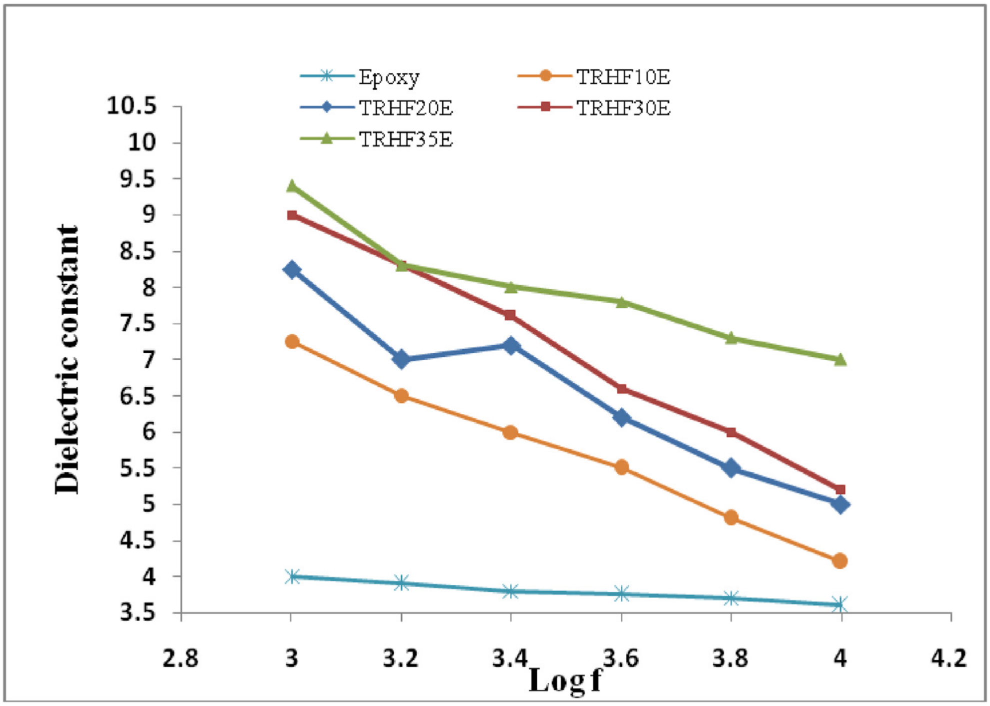

Fig. 10 – Dielectric constant of TRHFE composites.

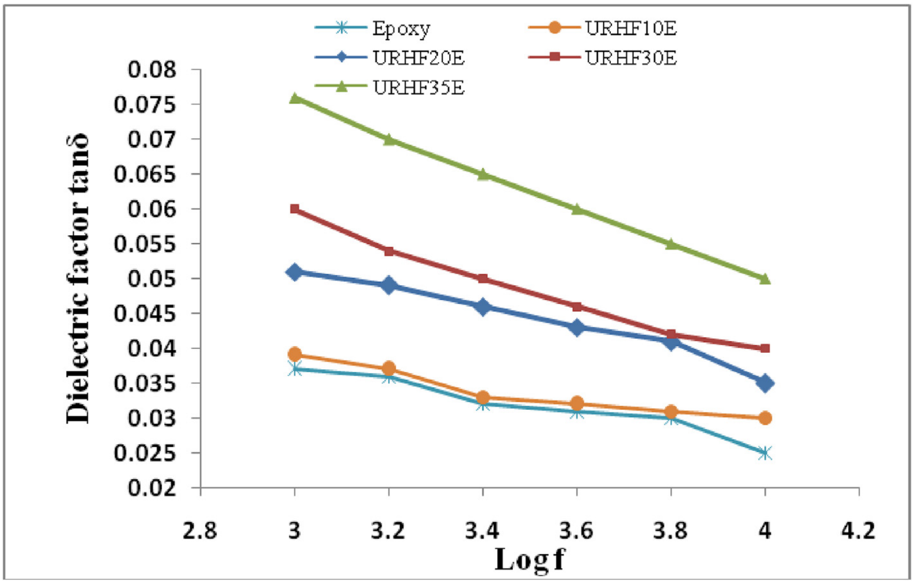

Fig. 11 – **Dissipation factor of URHFE composites.**

$$E_2 = \frac{E_f E_m}{E_f(1 - V_f) + E_m V_f} \tag{7}$$

Here, the volume percentage of fibers is represented by V_f, and the moduli of the matrix and fibers are represented by E_m and Fe, respectively. The micromechanics formulation by Puck is used in conjunction with the invariant composite characteristics by Tsai and Pagano. Puck invariant equations and approximation equations are shown below.

$$E_c = V_f\left(16/45E_f + 2E_m\right) + 8/9E_m \tag{8}$$

Matrix modulus, fiber modulus, and fiber volume fraction are all denoted by the abbreviation V_f. Average relative errors between experimentally determined values of Young's modulus of composites with variable fiber loading and those predicted by various micromechanical models are calculated and shown in Fig. 8. With an average relative inaccuracy of 46.5%, the ROM is the most inconsistent with the experimental results. Table 4 shows the comparison of tensile strength, impact strength, and flexural strength of different rise husk materials used in the literature with the proposed material.

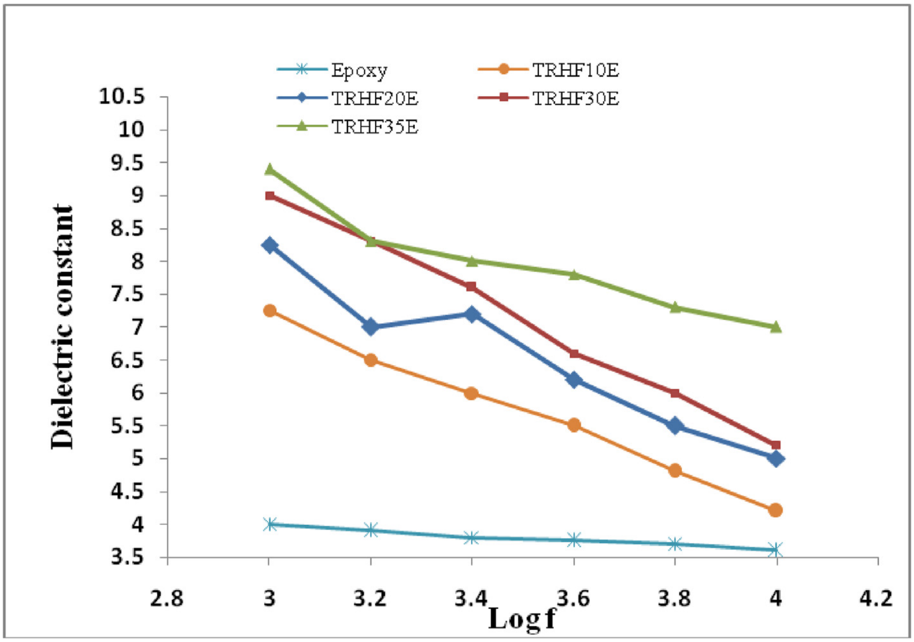

Fig. 12 – **Dissipation factor of TRHFE composites.**

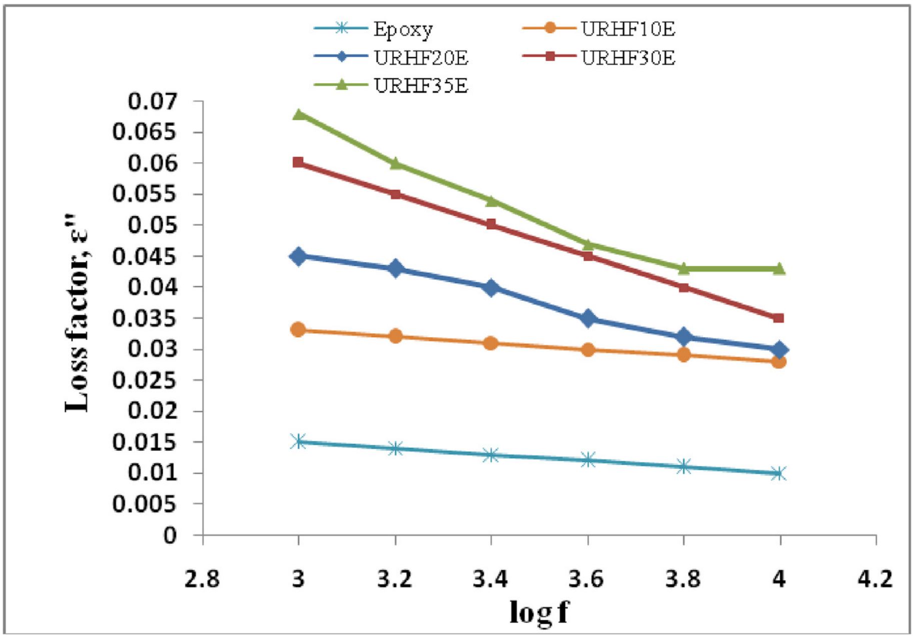

Fig. 13 – Loss factor of URHFE composites.

3.2. *Electrical characterization*

The dielectric constant is a critical electrical property and is defined as the ratio of the material's permittivity to that of the surrounding vacuum. The dielectric constant E is determined to be 5C/Co for samples, where C_O and C denote the capacitance values of the air and specimens, respectively. At room temperature, the capacitance (C) of the samples is determined using a Hewlett-Packard LCR Meter model 4274 A. The distance between two electrodes with an area of 0.8854 cm^2 and a spacing of 0.8854 cm is denoted by d (cm). The quantity of heat dissipated in an insulator can be calculated using the dissipation factor, denoted by the symbol Tan D. At a given frequency, the capacitive response of a material to its resistance is represented by the ratio tan d 5E"/E′, where E″ signifies dielectric loss and E′ denotes resistance.

The average relative error for the Halpin–Tsai model was 20.142%. When 10% of the fibers are loaded, the relative error is 9.98%, raising the percentage of loaded fibers. Manera's approximation model has an average relative error of 19.164% for projecting Young's moduli. All of the models predicted that the proportion of fibrils in composites rises as the weight fraction

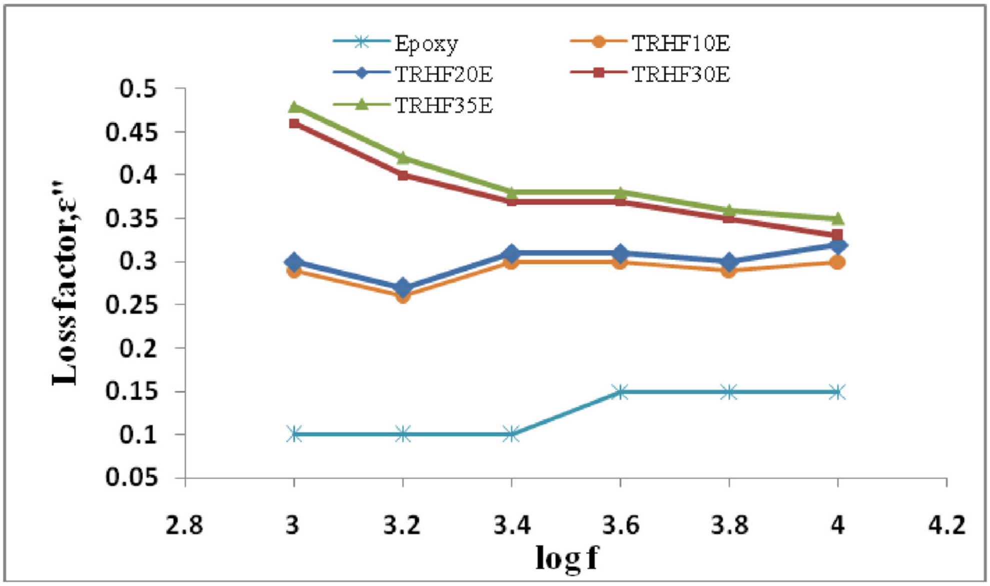

Fig. 14 – Loss factor of TRHFE composites.

of fibrils in the composites. At room temperature, Figs. 9 and 10 illustrate how samples treated with or without alkali vary their dielectric constant (E′) as a function of frequency (log f).

The dielectric constant of epoxy resin is considerably improved when rice husk fibril is added. There is a decrease in E's value as the frequency increases. Epoxy composites reinforced with rice husk fibrils have shown greater sensitivity to variations in frequency (f) than epoxy resins. Alkali-treated fibril composites age with lower dielectric constant values than untreated fibril composites, as shown in Fig. 10. The rice husk fibril epoxy composites are extremely sensitive enough to frequency variations compared to epoxy resin. The slopes of the curves shown in Fig. 10 are significantly higher than that of the slopes shown in Fig. 9. The rice husk fibers are affected by alkali treatment which led to the trend. This specimen's E′ value at 104 Hz is 7.9, while the specimen with 10% treated rice husk fibril is 4.6, which almost exactly matches the value of the pure epoxy sample. The results show conclusively that the modified fibril composite works in the higher frequency range. Low E′ values in alkali-treated composites may reflect a decrease in the polarization of molecules due to increased hydrophobicity of the treated fibril, which results in a decline in the fibril's moisture content.

The orientation polarization of the treated fibril composites is decreased as a result of a reduction in the number of polar groups in the fibers. Chemically modified fibril composites are utilized in place of their untreated counterparts to achieve a lower dielectric constant. The chemical connection between the fibril and the epoxy matrix improved interfacial adhesion between the fibril and the epoxy. As the concentration of water in the solution fall down, the dielectric constant is decreased. As the fibril moisture content decreases, the orientation polarization and the dielectric constant values decrease significantly. The effects of orientation polarization and interfacial polarization are what cause the rise to be greater at low frequencies and less at high frequencies.

For epoxy and URHFE composites at room temperature, Fig. 11 shows how to log f changes tan d. The low-frequency dissipation factor is greatly improved when rice husk fiber is added to epoxy. The value of tan d appears to rise in all samples at low frequencies due to the freedom of dipoles to move within the material. To improve the dissipation factor and orientation polarization, there should be an increase in the number of fibers in the composite. The TRHFE composites' dissipation factor and frequency follow a similar pattern. When comparing Figs. 11–12, an amazing discovery is made. A significant dissipation factor is found in samples made from alkalized rice husk fibers in the low frequency range. Figs. 13 and 14 show how E″ fluctuates depending on the frequency of the composite. The composites with more fibers have a bigger E_{00} in the low frequency range than composites with fewer fibers. The composites’ polarization rise in direct proportion to the number of fibers it contains, which increases the diversity of the composite led to this outcome (see Fig. 12).

4. Conclusion

The rice husk fibril reinforced epoxy composites in various weight fractions were developed primarily to meet the demand for electrical insulation. The mechanical and electrical properties of composites are superior when the rise husk fibril is added. There was an improvement in tensile strength of 32.64% when the weight percent of reinforcing rice husk fiber was increased from 9 to 40%. These improvements were made to not only the flexural but also the impact strengths as well, which were raised by 2.98–4.68 kJ/m^2. In trials with weight percentages varying between 9 and 40% at lower frequencies and 6.84–9.21% at higher frequencies, it was discovered that the dielectric constant fluctuated between 6.32 and 8.742%. The dissipation factor of a rice husk fibril composite comprising 36% rice husk fiber climbed to 0.068 at lower frequencies. Its impact strength was 7.25 kJ/m^2, while its tensile, flexural, and impact strengths were 52.24 MPa, 76.23 MPa, and 52.24 MPa, respectively, for the 36% weight treated epoxy composite. An increase of 0.084% in the lower frequency zone was found in treated rice husk fibril epoxy composites with a weight percentage of 38%. The mechanical and electrical properties of the rice husk fibril-epoxy adhesive connection could be improved by treating the fibril's surface. The micromechanical models can be used to forecast the properties of rice husk fibril epoxy composites.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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