ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2023.3.1.010

Dielectric Application of Agro-waste Reinforced Polymer Composites: A Review

Ishaya Iliyasu[1], Hussaini Yahaya[1] and Mbaka Stephen[1]

[1] Department of Physics with Electronics, Nuhu Bamalli Polytechnic Zaria, Kaduna State, Nigeria

Corresponding E-mail: iishaya08@nubapoly.edu.ng

Received 19-05-2023
Accepted for publication 26-06-2023
Published 26-06-2023

Abstract

Proper disposal of agricultural waste and polymers after use has long been one of the toughest environmental problems. Since it solves the majority of environmental issues, this has resulted in the development of commercial materials made from biodegradable and renewable sources, a focus of research around the globe. To make composites that are recyclable and degradable, natural fibres have been developed as reinforcing materials. Composite technology is a successful method to enhance the performance of insulating materials used in power system applications as part of the endeavour to optimize materials for industrial applications. The trend in the development of dielectric materials from agricultural waste (agro-waste) reinforced polymeric composites for use in electrical and electronic power systems is the main focus of this study. This article's objective is to provide a brief overview of the many kinds, best practices, and most often used biodegradable polymer matrix reinforcements in eco-composites for dielectric applications. Dielectric constants, dielectric loss factor, volume resistivity, and other properties of composites made with agro-waste as filler, at various frequencies and filler contents, with and without chemical modifications, have been discussed, as well as their prevails and prospects for the future.

Keywords: Composites; renewable waste (biodegradable material); dielectrics; dielectric constant.

I. INTRODUCTION

The utilization of agricultural waste and renewable materials has become more important in recent years for sustainable development and the reduction of environmental pollution. With the increase in environmental issues such as waste disposal and the depletion of natural resources, the use of natural products for industrial applications is increasing [1]-[3].

The industrial revolution has increased the demand for improvised materials that traditional materials have failed to achieve, such as high strength, low density, low cost, lightweight, etc. This has geared the focus on composite materials, which allow the use of constituents that work together to meet the tough and challenging demands of modern engineering applications, thus allowing their use in the electrical and electronics industry and related applications. [1]-[10]. The insulating material should possess the lowest possible electrical conductivity and maximum resistance to high electric fields in the same vein have long service life, low cost and ability to withstand high temperature and chemical inertness. Therefore, using insulating materials with good dielectric, thermal, electrical, mechanical, and other desirable properties has provided the emergence of composite materials with modified properties and low cost of polymer insulation [7]-[8].

A composite material reveals a substance that is unique among typical heterogeneous materials. Its current nomenclature is used to describe materials with strong fibres—continuous or Non-continuous—surrounded by a weaker matrix material. The matrix is in charge of both the load transmission to the fibres and the distribution of the fibres. Composites are materials composed of two or more components that have significantly different physical or chemical properties and remain separate and identifiable in the finished structure [9]. Most composites have a matrix of high-strength, low-stiffness fibres. The goal is usually to create a strong, stiff component, often with low density [10]. A composite material is any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is achieved [11]-[19].

Agricultural waste was used as the reinforcing material for composites to attain the objective of recyclable and biodegradable composites. [20]. The study of electrical properties of such materials like the dielectric constant (permittivity), dielectric strength, dielectric loss factor, resistance, resistivity, thermal insulating capacity, $\tan\delta$, and conductivity indicates their suitability as insulating materials for various applications [21]-[22].

As fillers, several particles have been utilised in their micro and nano sizes in polymer-based composites such as MgO, $BaTiO_3$, SiO, TiO_2, $Al_2\ O_3$, ZnO etc. but most agro-waste contains these elements and other elemental constituents that make agro-waste a better filler [23]-[34].

The objective of this article is to demonstrate a few successful ways that agricultural waste and polymers have been combined to create composites for dielectric applications. It is neither an exhaustive assessment nor a conventional choice of reinforcement in this regard; rather, it is an examination of several research accomplishments, and we recommend that the reader consult many studies on the uses of agro-waste in dielectric applications.

II. DIELECTRIC CHARACTERISATION

Dielectric characterization is the process of examining and quantifying a material's electrical characteristics in terms of its capacity to transmit and store electric charge. This involves measuring some characteristics, including polarization behaviour, loss factor, dielectric constant, and dielectric strength. These characteristics are crucial in many disciplines, including physics, electrical engineering, and materials science [35].

A. Dielectric strength

The maximum electric field an insulating material can withstand before collapsing and starting to conduct is known as the dielectric strength. It is expressed in volts per unit thickness [36]. The breakdown voltages V (kV) of the material are recorded and the dielectric strength D (kV/mm) can be obtained from (1).

$$D = \frac{V}{t} \tag{1}$$

Where t is the thickness of the material sample in millimetres [37]-[41].

B. Dielectric constant

Permittivity (ε) is known as the dielectric constant of a material, it describes the interaction of a material with an electric field.

$$k = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = \varepsilon_r' - j\varepsilon_r^* \tag{2}$$

The relative permittivity (ε_r) given by (2) is the ratio of the absolute permittivity (ε) to the permittivity of free space (ε_0). The real part of the permittivity (ε_r') is a measure of how much energy from the external electric field is stored in the material (i.e. the material's ability to store electromagnetic (EM) energy). The imaginary part $(j\varepsilon_r^*)$ is called the loss factor and is the measure of how dissipative or lossy material is to an external electric field [42].

The dielectric constant (ε_r'), is related to the capacitance as depicted in (3)

$$\varepsilon_r' = \frac{C_t}{C_0} = \frac{C_t}{\varepsilon_0 A} \tag{3}$$

Where C_t is the capacitance containing an insulator material of thickness t, Co is the capacitance of vacuum, ε_0, is the permittivity $(8.85 \times 10^{-12} F/m)$ and A, the area of the sample [29], [43]-[46].

C. Loss tangent

A material's dielectric loss tangent $(tan\ \delta)$ represents the quantitative dissipation of electrical energy due to various physical processes such as electrical conduction, dielectric relaxation, dielectric resonance, and loss from non-linear processes [47]. The dielectric permittivity is a complex quantity having two parts; the real and imaginary parts as seen in (2). Physically, the real part is called the dielectric constant (ε_r'), while the imaginary part is called dielectric loss $(j\varepsilon_r^*)$. To simplify their physics, we can use the dielectric constant to point out the storage of energy or the material's polarizing ability. Whereas, we can use the dielectric loss to point out the loss of energy in a material. Now, for any materials, the ratio of the imaginary to the real dielectric loss angle constant or tangent of the dielectric loss angle is commonly employed as a direct measure of the dielectric loss. It is known as the dissipation factor and is a measure of the power dissipated. The dissipation factor tan δ can be calculated from (4).

$$\tan\delta = \frac{\varepsilon_r^*}{\varepsilon_r'} \tag{4}$$

Where ε_r^* is the loss factor and ε_r' is the dielectric constant [35].

D. Resistance, resistivity and conductivity

The electric resistance of a material is measured in ohms; it's a property of the material that shows how much it resists the flow of electric current. Insulating materials are very poor conductors, offering high resistance. The insulation resistance of a material depends on its volume resistance, and thus the volume resistivity, ρ, can be calculated by using (5).

$$\rho = \frac{RA}{l} \tag{5}$$

Where ρ is the volume resistivity (Ωm), R is the volume resistance (Ω), A, is the area of cross-section and l is the length of thickness of the material sample. The electrical conductivity is calculated according to (6).

$$\sigma = \frac{1}{\rho} \tag{6}$$

The reciprocal of electrical conductivity is electrical resistivity representing a material's ability to conduct electricity [48].

E. Breakdown in Dielectrics

As a result of the application of an electric field, many processes can cause dielectrics to break down. Electrical, thermal, electromechanical, and partial discharge are breakdown mechanisms that can categorize how dielectric is lost. Depending on the time frames and situations under consideration, it might be difficult to distinguish between breakdown and degradation. Degradation is an in-service phenomenon that occurs over longer time scales while breakdown is an experimental phenomenon that occurs over shorter time scales; there is a border zone between the two of a day to a month. [49].

High-applied electric fields can cause an electrical breakdown, with avalanche and Zener breakdown being two examples of such mechanisms. Electromechanical breakdown occurs as a result of the electrodes' electrostatic attraction, which causes the insulation's width to decrease proportionally to the material's Young's modulus [50]. When the insulation's high conductivity prevents the heat generated by Joule heating from being expelled from a unit volume of the insulation quickly enough, thermal breakdown results. A partial discharge (PD) is a localized failure that results in degradation and could ultimately trigger a system failure. When there are mild electric fields, PDs develop in gas spaces within the solid insulator [49]-[58].

III. REVIEWED FINDINGS

Reference [59] investigated the mechanical and insulation properties of eggshell microparticles as fillers with epoxy polymer in producing composite polymeric insulators. TiO_2 nanoparticles/epoxy was used as a control. The tensile strength of 4% eggshell filler showed a 22.4% improvement slightly lower than that of TiO_2 nanoparticle which can be related to the size and number of dispersed eggshell particles in the polymer matrix. Eggshells as a filler also exhibit high thermal conductivity and improved heat dissipation. Also, at lower filler loadings the composite showed a higher dielectric constant and comparable loss tangent with TiO_2 nanocomposite but the electric conductance of the eggshell at high voltages was lower than that of TiO_2 nanocomposite. Up to 3% concentration, the eggshell shows a decrease in conductance giving the addition of eggshells a better advantage as a dielectric material.

Reference [60] investigated using metal oxides from the periwinkle shells as fillers for polymer composites for high-voltage applications. The micro-composite powder from the periwinkle contained about 81.8% CaO and other metal oxides. which gave the powder a thermal conductivity of 18.0Wm^{-1}k^{-1} slightly higher than TiO_2 and Si_2, which are commonly used fillers. The electrical conductivity was lower than pure CaO, which made it a better prospect if used as filler in polymers to produce polymeric insulation materials. The study also suggested that, if the agro-waste is properly processed into possible nanosized particles, it can be a better candidate for dielectric applications.

Reference [1] developed biocomposites using amine-functionalized rice husk ash (f-RHA) as filler and a carbazole core containing aromatic diamine, cardanol, and paraformaldehyde as the polymer matrix obtained from renewable agricultural wastes. The amine-functionalized rice husk ash was incorporated into the carbazole core containing a cardanol-based polybenzoxazine (PCCBz) matrix to form f-RHA/PCCBz composites. The biowaste-based composites show high thermal stability, an improved glass transition temperature (T_g), and low dielectric constants as well as low dielectric loss.

Reference [61] studied the dynamic mechanical analysis (DMA) of cenosphere addition on agro-waste rice husk (RH)/polypropylene (PP) composite and the effect of cenosphere on RH/PP composite. 20% of the rice husks, with and without cenosphere, were developed. A different concentration of cenosphere was added to the rice husk-filled polypropylene, and its dielectric behaviour (dielectric measurement capacitance, $tan\ \delta$ values and density measurement (DMA testing)) was observed. The result showed that the dielectric constant increases (attributed to an increase in the orientation polarisation of polar groups present in the RH and porosity in the cenosphere) with the loading of PP with the RH and cenosphere and is inversely proportional to the volume fraction of the RH and cenosphere. Also, the ac conductivity showed an improvement because of the incorporation of the RH in the PP matrix. DMA and comparison studies were also carried out for the PP composite and two different filler types (RH and cenosphere), which showed that all composites had storage and loss modulus values higher than those of pure PP but a lower mechanical loss factor (damping).

A study by [62], investigated the electrical properties of sisal and coir fibre-reinforced low-density polyethylene (LDPE) composites. The result showed that the dielectric constant values increase with fibre filler loading predominantly at low frequencies while a decrease in volume resistivity was observed with decreases in fiber content. The authors also found out in extension studies the effect of chemical modification on the electrical properties of sisal fibre-reinforced LDPE composites. The result showed a decrease in dielectric value with chemical modification because of the decrease in the hydrophilicity of fibres. An increase in volume resistivity was observed in the composites of chemically treated fibres [63].

Reference [64] investigated the electrical properties of vapour-grown fibre (VGCF) reinforced vinyl ester composites. Five series of VGCF/vinyl ester (VE) composites were prepared. Electrical and mechanical properties were studied as a function of fibre loading. The volume electrical properties of these composites exhibited percolation behaviour. The authors found that the electrical properties exhibited a percolation behaviour with a drop in resistivity between 2 and 3% wt. VGCF loading even at 15wt% VGCF loading composite from nitric acid-oxidized VGCF acted as good insulators.

Reference [65] developed a low-dielectric material using hollow keratin fibres and chemically modified soya bean oil; the result showed an unusually low dielectric constant. They concluded that a low-cost composite made from avian sources and plant oil has great potential in the future of dielectrics. They observed that the coefficient of thermal expansion of the composite was low enough for electronic applications and was similar to that of silicon materials.

Reference [66] investigated the dielectric properties of sisal oil palm hybrid biofiber-reinforced natural rubber biocomposites, as well as the effects of fibre loading, frequency, and chemical modification on the composites' dielectric properties and resistivity. The dielectric constant values were found to be higher for the fibre-reinforced system than the gum due to the polarization exerted by the incorporation of lignocellulosic fibres. A decrease in dielectric constant values and volume resistivity values were observed due to chemical modification due to the increase in hydrophilicity imparted by the lignocellulosic fibres. The volume resistivity decreased with fibre content, and the dissipation factor increased.

Reference [67] studied how a sisal fibre-reinforced epoxy composite's electrical characteristics were affected by sisal fibre orientation. The result showed that the dielectric constant and dielectric dissipation factor ($\tan\delta$) of the epoxy and orientation sisal fibre epoxy composite decreased with increasing frequency, while the ac conductivity increased with increasing frequency. Clear relaxation peaks for $\tan\delta$ around 169 were observed in epoxy resin, shifting to the lower temperature side with increasing frequency.

Reference [68] examine for use in microwave transmission, certain agricultural waste and observed its dielectric characteristics. In their study, rice straw, rice husk, banana leaf, and sugar cane bagasse were used as fillers with epoxy Der 331 resin at various filler percentage weights of 10%, 20%, 30%, 40%, and 50% for each waste. The overall findings showed that the dielectric constant and loss tangent increased with filler content. The banana leaves were observed to have the best results for the dielectric properties compared with other waste samples, with the highest reading for the dielectric constant at 50% filler content. At 10% filler content, all the waste samples had a loss tangent reading of less than 0.1, which is acceptable for an antenna application. The loss tangent for all samples was high when compared to other percentages, suggesting that it could be used as an alternative material for microwave absorber applications.

Reference [69] examined the electrical characteristics of agricultural waste and Novalac-based wood-polymer composites. Maleic anhydride was used as a compatibilizer for the Novalac fibre (banana, hemp, and agave) composites, and the surface and volume resistivity were studied with and without treatment with maleic anhydride. The results showed that as fibre content increased in maleic anhydride-treated and untreated fibre composites, surface resistivity decreased, while volume resistivity increased, but surface resistivity decreased dramatically from 40 to 45% of fibre. Novolac composites and the volume resistivity drastically increased from 50% to 60% of the fibre/Novolac composite. Maleic anhydride- untreated and treated banana fibre has the highest surface and volume resistivity, followed by agave fibre composite and hemp fibre composite. The treatment of maleic anhydride shows an enhancement in surface resistivity.

Reference [70] investigated the impact of filler variation on the polarizability of polymer matrix composites developed from orange peel particulates. The resin was blended with the agro-waste in various weight fractions of 10, 20, 30, 40, and 50 wt% to fabricate the composite using the hand layup method. The result revealed that the dielectric strength and constant at 40 and 20 wt% had their optimum values, and as the filler loading increased, the resistivity decreased and a more enhanced property was obtained at the 10 wt% composition. The moisture content and water absorption values were higher at 50 wt%. The dielectric properties observed were equivalent to some typically used dielectrics, making the developed orange peel particulate composites a candidate for dielectric purposes under various voltage applications.

Reference [71] studied the impact of surface treatments on the electrical characteristics of composites made of low-density polyethene and sisal fibres. Various surface treatments, such as alkali, CTDIC, stearic acid, peroxide, permanganate, and acetylation, were carried out on the sisal fibres to improve interfacial binding. The outcome demonstrates that for all composites, the dielectric constant rises gradually as fibre loading rises and falls as frequency rises. But as a result of chemical treatment, the dielectric constant values decreased; this is because the hydrophilic nature of natural fibres decreases with treatment. The volume resistivity values of treated sisal fibre/LDPE composites were found to be greater than those of raw sisal fibre/LDPE composites. The volume resistivity values of treated sisal fibre/LDPE composites depend on the concentration of $KMnO_4$ solution used for the treatment. With an increase in the concentration of potassium permanganate solution, the value of volume resistivity increases reaches a maximum and then decreases. The dielectric loss factors of treated sisal fibre-reinforced LDPE composites were found to be lower than those of untreated sisal Fiber-reinforced LDPE composites. The relaxation peak was in the same region for all composites.

Reference [72] investigated the polarizability of eggshell (Es) particulates in polyester-reinforced composites. The study centred on the development and characterization of a polymer matrix containing different volume fractions (10 to 50 wt%) of eggshell particles. The result shows that the moisture content and water absorption capacity of the Es polyester composite is minimal, thereby making the produced composites a candidate material for capacitors and a good electrical insulator. At 40 wt%, 10 wt%, and 30 wt%, the dielectric strength, dielectric constant, and resistivity of the composites had their prime values, respectively. The dielectric constants of the ES polyester composite compared with some conventional insulators are low. The small particle size of 300 μm used improved Particle-matrix interfacial bonding, thereby minimizing the presence of inter-particle pores that would have been a good site for defects.

Reference [73] proposed a model for the dielectric behaviour of PVC/rice husk composites. The dielectric constant for RH-filled PVC composite was determined at various temperatures and frequencies. A general model was based on constant modifications in Curie's temperature dependence law and the calculated dielectric constant from the theoretical model was validated with the experimental value. The results show that the dielectric constant of RH-filled PVC composts increased as the RH content temperature increased. Also, a proposed frequency and temperature-dependent model to calculate the dielectric constant of the RH-filled PVC compound matches the experimental result. The tan peaks at different frequencies are dominant in the case of 30 and 40 wt.% of RH composite.

Reference [20] studied the acoustical, dielectric, and mechanical properties of sugarcane bagasse-reinforced unsaturated polyester composites. The sugarcane bagasse was divided into two parts: treated and untreated. Sodium hydroxide was used to treat one part of the sugarcane bagasse. The result showed that treated fibre has higher strength compared with untreated fibre composites. The fibre content increased from 5 wt% to 100 wt%, and the tensile strength also increased. The treated composites have a slightly higher sound absorption coefficient than the untreated fibre composites. But for both treated and untreated composites, the sound absorption coefficient of the composites increases with frequency. The untreated fibre composites had higher dielectric values compared with the treated fibre composites, which can be associated with an increase in the pyrophoricity of the fibre after alkaline treatment. The treated fibres show lower values compared with untreated fibres composites due to a change in the polarization properties.

Reference [74] investigated the electrical insulative properties of various agricultural waste materials (coconut shell, mango endocarp, palm kernel, groundnut shell, rice husk, and corn cob used as fillers with an aqueous solution of gum Arabic). The dielectric strength, resistivity, dielectric constant, moisture content, and water absorption capacity were determined using a variable transformer tester and an insulation tester, respectively, while the water absorption and moisture content were determined gravimetrically on dry weight loss. The result showed that the values obtained for the dielectric strength of the samples were comparable to those of commercial electrical insulators, and as such, they could be used for either high- or low-voltage insulators. The resistivities were a bit low (106cm), but within the required range for an electrical insulator, and the dielectric constant is also comparable to standard. The level of water absorption and moisture, however, was higher than most commercial and insulating materials. which restricts it under certain weather conditions (high humidity), but with appropriate technology, the moisture content can be minimized.

Reference [75] studied the thermal properties of carrots fibres and epoxy composites. The carrot was used as the reinforcement for the epoxy matrix at various weight percentages of 10, 20, 30, and 40%. The resulting composites were then tested and characterized to evaluate the dielectric constant, dissipation factors, dielectric strength, and thermal conductivity. The result demonstrates that both dielectric strength and thermal conductivity are high. The result shows that the dielectric constant increases with fibre content at all frequencies. The maximum is 40% by weight. This is because of the non-polarity of epoxy and the fact that it has only instantaneous atomic and electronic polarization. However, the dielectric constant decreases with frequency for all composites, which is also due to a decrease in orientation polarization at high frequencies. The dissipation factor increased with filler loading because of the presence of polar functional groups in the composite. A decrease in dissipation factor was observed with increasing frequency, which is attributed to a decrease in orientation polarization at high frequency. The dielectric strength decreases with an increase in fibre content. This implies that the conductivity increased with the addition of fibres because of the presence of polar groups, which facilitate the flow of current between electrodes. The thermal conductivity in terms of the fine fibre had an increase at 100% and no charges for other weight percentages, and for coarse fibre composites, there is a relatively small increase in thermal conductivity values with fibre content. This is due to the presence of phonons in the material. Carrot fibre epoxy composites are electrical and thermal insulators.

Reference [38] investigated the effect of treatment on the electrical and thermal properties of banana fibre-reinforced unsaturated polyester. The result shows that the dielectric strength of the composite shows a 29.3% improvement, mainly due to mercerization, making it suitable for use as an insulator. The untreated fibre, however, shows lower dielectric strength. The dielectric constant of the treated fibre composites and the mercerization of banana fibres improved the thermal properties compared with untreated fibre composites.

Reference [76] studied the dielectric response of luffa fibre-reinforced resorcinol formaldehyde composites. The dielectric constant, dielectric loss factor, and ac conductivity of treated fibre composites, untreated fibre composites, and pure matrix were studied. The result showed that the dielectric constant and loss factor of all the samples decreased while the ac conductivity of all the samples increased with an increase in frequency. The dielectric constant, electric loss factor, and ac conductivity also increased with an increase in fibre loading. The bonding between fibre and matrix influences the conductivity of the composites.

Reference [77] investigated the use of sugar cane bagasse as an alternative material for pyramidal microwave absorber design. In their study, the waste sugar cane bagasse was collected, ground, and mixed with the resin and hardener agent. Then, pyramidal particle board samples were made for dielectric property measurements, and a comparison was made with rice husk at a frequency range of 0.01 GHz to 20.0 GHz. Using the dielectric probe measurement technique, the average dielectric constant values for sugarcane as compared with the rice husk were 1.44 and 2.03, respectively. While the average tangent loss for sugarcane bagasse and rice husk was 0.161 and 0.132, a comparison of reflection loss between the sugar cane bagasse and rice husk was also done, which showed that the sugar cane bagasse had better reflection loss performance compared to the rice husk pyramidal microwave absorber, making it a cheaper and more environmentally friendly material.

Reference [78] investigated the dielectric characteristics of rigid polyurethane foam (PUF) composites filled with Kenaf fibre as a function of temperature and fibre content. The outcome showed that the dielectric constant and loss tangent of kenaf fibre-filled rigid PUF were positively impacted by the fibre content. The rigid, Kenaf fibre-filled PUF's loss tangent and dielectric constant were both impacted by the electric frequency. The dielectric constant and loss tangent grew together with the fibre content. The loss tangent and dielectric constant both rose from 30 to 200 with temperature. The researchers concluded that adding kenaf fibre can accelerate the dielectric constant's rate of growth as the temperature rises.

Reference [5] did a comparative study of the dielectric properties of jute/bamboo-reinforced unsaturated polypropylene hybrid composites using jute and bamboo hybrid fibres as reinforcements in both their raw and surface-modified forms. Through the use of sodium hydroxide (NaOH), these fibres' surfaces were modified. Based on the effects of fibre loading, fibre ratio, and chemical treatment of fibres, the dielectric properties of the composites were studied. The results showed that the interfacial polarization was responsible for the maximum dielectric constant values in the lower frequency range and that the dielectric constant values decreased as the frequency was increased for all hybrid composites. Increases in the number of polar groups, which resulted in high orientation polarization, caused a rise in the dielectric constant, dissipation factor, and loss factor. Additionally, chemical processing decreased the hydrophilicity of the bamboo and jute fibres. In comparison to untreated samples, each of these conditions resulted in a decrease in dielectric constant values. Overall, when compared to jute/bamboo-reinforced polypropylene hybrid composites, the jute/bamboo-reinforced unsaturated polyester hybrid composites displayed greater values of dielectric characteristics.

IV. CONCLUSION

In conclusion, this paper reviewed some of the most recent research in the field of polymer composites with agro-waste as fillers for dielectric applications. From reviewed literature, it is observed that using agro-waste as fillers for polymer composite dielectrics is a promising technique for developing dielectric insulators. The primary focus has always been on inorganic filler materials and their polymer composites. Most research efforts have been to incorporate inorganic fillers with large dielectric constants into polymer matrices with high breakdown field strengths, in the hopes of synthesizing composites with the best attributes of each component. Different matrix systems have different properties; the dielectric, mechanical, and physical strengths of these agro-based composites are sensitive to the processing methods used in the integration of carefully chosen agro-fillers into polymers to form dielectric polymer composites is emerging as a promising approach with enormous potential for dielectric applications. The growing need for high-performance dielectrics in advanced electronics and electric power systems will certainly encourage great cost-effective improvements in current dielectric materials and inevitably catalyze the emergence of novel dielectric structures and fabrication techniques. From the studies reported in this review, we conclude that significant strides have been made in the development of polymer composites and nanocomposites with great energy density using agricultural waste.

V. FUTURE FRAMEWORK

The following areas of research are, however, needed to realize wider applications of agro-waste for dielectric applications:

- To overcome the limitations of conventional composites, the concept of polymer nanocomposites has been proposed, in which the filler particles have nanometer-scale dimensions. In this study, most of the fillers used are not nanoscale, as proposed by [31].
- For the foreseeable future, the leading edge of research in this area will continue to focus on a better understanding of the chemistry and structure of the agro-waste filler interface and its influence on composite dielectric permittivity and breakdown field strength, as well as using the agro-waste filler at the nanoscale.
- The experimentally measured mechanical properties of agro-based composites frequently contradict the mixtures rule. A full explanation can only be obtained if the interface strength and failure mechanisms are known.

Further research is needed, particularly to explain "hybrid effects" in agro-polymer composites.

- Recycling, dielectric properties, and methods of agricultural-based reinforced composites are important aspects of this new material, but so far there is very little published data. Recycling is an attractive future research direction that will bring socio-economic benefits.

It is expected that these developments, coupled with recent major developments in high-performance polymers and electroactive ceramics and ongoing fundamental research on dielectric phenomena, should lead to the development of scalable, cost-effective, high-performance dielectric materials that will revolutionize energy storage devices and insulators built for harsh environments. And that the term “agro-waste” will no longer be attributed to a bad thing but an essential by-product of agriculture.

VI. ACKNOWLEDGEMENT

The study is supported by the Tertiary education trust fund (TETFund) Institutional-based Research (IBR) 2019-2022 merged intervention.

VII. DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no conflicts of financial interests or personal relationships that could have appeared to influence the study reported in this paper.

REFERENCE

[1] V. Selvaraj, K. P. Jayanthi, and M. Alagar, "Development of Biocomposites from Agro-Wastes for Low Dielectric Applications". J. of Polym. & the Env, vol. 26, no. 9, pp. 3655-3669, 2018. DOI: 10.1007/s10924-018-1211-x.

[2] V. S. Aigbodion, E. G. Okonkwo, and E. T. Akinlabi, "Eco-friendly polymer composite: state of arts, Opportunities and challenges". Sustain. Polym. Compos. NanoComposite, pp. 1233-1265, 2019.

[3] P. Prabunathan, P. Thennarasu, J. K. Song, and M. Alagar, "Achieving low dielectric, surface free energy and UV shielding green nanocomposites via reinforcing bio-silica aerogel with polybenzoxazine". New J. of Chem., vol. 41, no. 13, pp. 5313-5321, 2017.

[4] A. D. Omah, E. E. Ugwuogbo, P. O. Offor, I. Y. Suleiman, S. V. Egoigwe, and U. C. Ogbuefi, "Experimental Effect of Filler Variation on the polarizability of polymer Matrix Composites Developed from Orange Peel Particulates". J. Mater. Environ. Sci, vol. 12, no. 3, pp. 406-417, 2021.

[5] E. Jayamani, S. Hamdan, M. R. Rahman, and M. K. B. Bakri, "Comparative study of dielectric properties of hybrid natural fibre composites". Procedia Eng., vol. 97, pp. 536-544, 2014.

[6] N. M. Mehta and P. H. Parsania, "Fabrication and evaluation of some mechanical and electrical properties of jute-biomass based hybrid composites". J. of App. Polym. Sci., vol. 100, no. 3, pp. 1754-1758, 2006.

[7] W. Zhou, D. Yu, C. Min, Y. Fu, and X. Guo, "Thermal, dielectric, and mechanical properties of SiC particles filled linear low-density polyethylene composites". J. of App. Polym. Sci., vol. 112, no. 3, pp. 1695-1703, 2010.

[8] H. B. Bhuvaneswari and N. Reddy, "A review on dielectric properties of biofiber-based composites". Adv. Composites and Hybrid Mat., vol. 1, no. 4, pp. 635-648, 2018.

[9] W. D. Callister, "Materials Science and Engineering". 4th Ed., Wiley Publishing, pp. 511-531, 1997.

[10] V. S. Aigbodion, C. U. Atuanya, S. O. Obiorah, L. A. Isah, S. I. Neife, and A. D. Omah, "Effect of particle size on the fatigue behaviour of Al-Cu-Mg/Bean Pod Ash Particulate composite," Trans Indian Inst Met (2015), vol. 68, no. 3, pp. 495-499, 2015.

[11] V. S. Aigbodion, S. B. Hassan, and C. U. Atuanya, "Kinetics of isothermal degradation studies by thermo gravimetric data: Effect of orange peels ash on thermal properties of high-density polyethylene (HDPE)". J. Mater. Environ. Sci., vol. 3, no. 6, pp. 1027-1036, 2012.

[12] T. W. Clyne, "Comprehensive metal matrix composite," in Comprehensive Composite Materials, 4th ed., Eds. Elsevier, pp. 101-105, 2001.

[13] D. Gay and S. V. Hoa, Composite Materials: Design and Applications. CRC Press, 2007.

[14] A. Francis, "Progress in polymer-derived functional silicon-based ceramic composites for biomedical and engineering applications". Mater. Res. Exp., vol. 5, no. 6, pp. 062003, 2018.

[15] R. R. Nagavally, "Composite materials-history, types, fabrication techniques, advantages, and applications". Int. J. Mech. Prod. Eng. vol. 5, no. 9, pp. 82-87, 2017.

[16] O. V. Tereshchenko, F. J. K. Buesink, and F. B. J. Leferink, "An overview of the techniques for measuring the dielectric properties of materials". 2011 XXXth URSI General Assembly and Scientific Symposium, pp. 1-4, Aug. 2011.

[17] J. O. Borode, "Introduction to Composite Materials," Lecture note, Department of Metallurgical and Materials Engineering, Federal University Technology Akure, Ondo State, 2003.

[18] V. V. Valery and V. M. Evgeny, "Mechanics of Composite Materials," Elsevier, Science Ltd, The Boulevard, Langford Lane, Kidlington, Oxford OX5 IGB, UK, pp. 1-27, 2001.

[19] ACM, "Retrieved August 3, 2011, from advanced composite Materials: http://www.ac-m.com/", 2011.

[20] E. Jayamani and M. K. Bin Bakri, "Preliminary study on the acoustical, dielectric and mechanical

properties of sugarcane bagasse reinforced unsaturated polyester composites". Mat. Sci. Forum, vol. 890, pp. 12-15, 2017.

[21] J. K. Nelson, J. C. Fothergill, L. A. Dissado, and W. Peasgood, "Towards an understanding of nanometric dielectrics". Annual Report Conference on Electrical Insulation and Dielectric Phenomena, pp. 295-298, 2002.

[22] C. Parida, S. K. Dash, C. Pradhan, and S. C. Das, "Dielectric response of luffa fibre-reinforced resorcinol formaldehyde composites". Amer. J. Mater. Sci., vol. 5, no. 1, pp. 1-8, 2015.

[23] A. Atiqah, M. N. M. Ansari, and R. A. Ilyas, "Dielectric properties of kenaf fibre reinforced polymer composites: A short review". Presented at the International Conference on Advanced Materials for Better Future, Surabaya, Indonesia, 2019.

[24] M. Hussaini and K. Sabah, "Fabrication and tribological behaviour of MnO_2/Epoxy nanocomposites". Presented at the 7th International Conference on Nanostructures, Kish Island, Iran, 2022.

[25] M. S. Gaur, K. R. Rajesh, S. Rohan, and R. K. Tiwarai, "Investigation of structural and thermal properties of Graphene oxide reinforced Epoxy Nanocomposites". ECS J. of Sol. St. Sci. & Tech., vol. 11, no. 4, pp. 041007, 2022.

[26] G. Iyer, R. S. Gorur, and R. Richet, "Dielectric properties of Epoxy based Nanocomposites for high voltage Insulation". IEEE Trans. on Dielect. & Elect. Insulation, vol. 18, no. 3, pp. 659-666, 2011.

[27] Z. Romana and G. Nadimi, "Pre-processing of BaTiO3 Nanofillers in improving Dielectric response of Epoxy Nanocomposites at higher filler concentrations". IEEE Conf. on Elect. Insulation & Dielect. Phenomenon (CEIDP), pp. 447-480, 2017.

[28] M. Kurimoto, H. Okubo, K. Kato, M. Hanai, Y. Hoshina, M. Takei, and N. Hayakawa, "Dielectric properties of epoxy/alumina nanocomposite influenced by control of micrometric agglomerates". IEEE Trans. Dielectr. Electr. Insul. vol. 17, no. 3, pp. 662-670, 2010.

[29] A. A. Abdelmalik, A. Sadiq, and U. Sadiq, "Low Dielectric Loss Epoxy Polymer Composite from Periwinkle Shell Microparticles". J. Phys. Sci., vol. 31, no. 1, 2020.

[30] S. Larguech, A. Triki, M. Ramachandran, and A. Kallel, "Dielectric properties of jute fibres reinforced poly (lactic acid)/poly (butylene succinate) blend matrix". J. Polym. Environ. vol. 29, no. 4, pp. 1240-1256, 2021.

[31] S. Santannu and T. M. Joy, "Influence of filler loading on dielectric properties of ZnO nanocomposites". IEEE Trans. on Dielect. & Elect. Insulation, vol. 16, no. 2, pp. 531-542. 2009.

[32] S. K. Karuppannan, M. J. H. Dowlath, G. D. Raiyan, S. Rajadesign, and K. D. Arunachalan, "Application of Poultry Industry waste in producing value-added products- A review concepts of advance zero waste tools". Concepts of Advanced zero waste tools, pp. 91-121, 2021.

[33] P. Vlamidir, L. Rynno, H. Irina, P. Alex, and V. Sergey, "Introduction to Nanomaterials and Technology". Tartu University Press, 2007.

[34] C. Buzea, I. P. Blandino, and R. Kevin, "Nanomaterials and Nanoparticles: Sources and Toxicity," Biointerphases, vol. 2, no. 4, 2007. MR17-MR71.

[35] G. Subodh, V. Deepu, P. Mohanan, and M. T. Sebastian, "Dielectric response of high permittivity polymer ceramic composite with low loss tangent". App. Phy. Lett, vol. 95, no. 6, p. 062903, 2009.

[36] J. G. Speight, "Monomers, polymers, and plastics," Handbook of Industrial Hydrocarbon Processes, pp. 597-649, 2020.

[37] C. A. Harper, "Modern Plastic Handbook," Mc Graw Hill Co., New York, 2000.

[38] R. A. Nassif, "Effect of chemical treatment on some electrical and thermal properties for unsaturated polyester composites using banana fibres". Matrix, vol. 1, pp. 7, 2010.

[39] L. Berger, "Dielectric strength of insulating materials". Carbon, vol. 1, no. 2006, pp. 2, 2006.

[40] J. W. Swanson and F. C. Dall, "On the dielectric strength of synthetic electrical insulating materials". IEEE International Conference on Electrical Insulation, pp. 196-200, Jun. 1976.

[41] Z. G. Datsios, P. N. Mikropoulos, P. K. Samaras, and T. E. Tsovilis, "Experimental arrangement for investigating the surface dielectric strength of insulating materials". IEEE International Conference on High Voltage Engineering and Application (ICHVE), pp. 1-4, Sep. 2020.

[42] F. H. Wee, P. J. Soh, A. H. M. Suhaizal, H. Nornikman, and A. A. M. Ezanuddin, "Free space measurement technique on dielectric properties of agricultural residues at microwave frequencies". SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), pp. 183-187, 2009.

[43] E. J. Murphy and S. O. Morgan, "The dielectric properties of insulating materials". The Bell Sys. Tech. J., vol. 16, no. 4, pp. 493-512, 1937.

[44] X. Y. Zhao and H. J. Liu, "Review of polymer materials with low dielectric constant". Polym. Int., vol. 59, no. 5, pp. 597-606, 2010.

[45] L. Berger, "Dielectric strength of insulating materials," Carbon, vol. 1, no. 2006, pp. 2, 2006.

[46] P. A. Kohl, "Low–dielectric constant insulators for future integrated circuits and packages," Annual Review of Chemical and Biomolecular Engineering, vol. 2, pp. 379-401, 2011.

[47] M. T. Sebastian, M. A. S. Silva, A. S. B. Sombra, H. Jantunen, and R. Ubic, "Measurement of microwave dielectric properties and factors affecting them". Microwave Mat. & App., pp. 1-51, 2017.

[48] G. George, K. Joseph, E. R. Nagarajan, E. T. Jose, and K. C. George, "Dielectric behaviour of PP/jute yarn commingled composites: Effect of fibre

content, chemical treatments, temperature and moisture". Composites Part A: App. Sci. & Manufacturing, vol. 47, pp. 12-21, 2013.
[49] L. A. Dissado and J. C. Fothergill, "Electrical degradation and breakdown in polymers". Inst. of Eng. & Tech. (IET), 1992. DOI: 10.1049/PBED009E. ISBN: 9780863411960. E-ISBN: 9781849193634.
[50] C. A. Harper, "Handbook of Wiring Cabling, and Interconnecting for Electronic". McGraw-Hill, New York, 1972.
[51] R. G. Geyer, "Dielectric characterization and reference materials". IEEE Trans. on Elect. Insul. vol. 27, no. 3, pp. 445-464, 1992.
[52] M. S. Venkatesh and G. S. V. Raghavan, "An overview of dielectric properties measuring techniques," Can. Biosys. Eng., vol. 47, no. 7, pp. 15-30, 2005.
[53] S. O. Nelson, "Dielectric properties measurement techniques and applications," Trans. of the ASAE, vol. 42, no. 2, pp. 523-529, 1999.
[54] S. O. Nelson, "Measurement and applications of dielectric properties of agricultural products," IEEE Trans. on Instrumentation and Measurement, vol. 41, no. 1, pp. 116-122, 1992.
[55] S. O. Nelson, "Dielectric properties of agricultural products-measurements and applications," IEEE Trans. on Elect. Insul, vol. 26, no. 5, pp. 845-869, 1991.
[56] S. O. Nelson, "Fundamentals of dielectric properties measurements and agricultural applications". J. of Microwave Power & EM Energy, vol. 44, no. 2, pp. 98-113, 2010.
[57] O. V. Tereshchenko, F. J. K. Buesink, and F. B. J. Leferink, "An overview of the techniques for measuring the dielectric properties of materials". XXXth URSI General Assembly and Scientific Symposium, pp. 1-4, Aug. 2011.
[58] J. M. Lundstrom, T. L. Smith, L. F. Rinehart, R. C. Pate, M. L. Krogh, and W. Huebner, "Measurement of the dielectric strength of titanium dioxide ceramics," Digest of Technical Papers. 12th IEEE International Pulsed Power Conference (Cat. No. 99CH36358), vol. 2, pp. 1489-1491, Jun. 1999.
[59] A. A. Abdelmalik, M. O. Ogbodo, and G. E. Momoh, "Investigating the mechanical and insulation performance of waste eggshell powder/epoxy polymer for power insulation application". SN App. Sci., vol. 1, no. 10, pp. 1-12, 2019.
[60] A. A. Abdelmalik and A. Sadiq, "Thermal and Electrical Characterization of Composite Metal Oxides Particles from Periwinkle Shell for Dielectric Application," SN App. Sci., vol. 1, no. 4, pp. 1-8, 2019.
[61] J. Sharma and N. Chand, "Dynamic mechanical analysis and dielectric studies of agro-waste rice husk/polypropylene composites with cenosphere," J. of Composite Mat., vol. 47, no. 15, pp. 1833-1842, 2013.
[62] A. Paul and S. Thomas, "Electrical properties of natural-fibre-reinforced low-density polyethylene composites: A comparison with carbon black and glass-fibre-filled low-density polyethylene composites," J. of App. Polym. Sci., vol. 63, no. 2, pp. 247-266, 1997.
[63] A. Paul, K. Joseph, and S. Thomas, "Effect of Surface Treatments on the Electrical Properties of Low-Density Polyethylene Composites Reinforced with Short Sisal Fibers". Composite Sci. & Tech., vol. 57, no. 1, pp. 67-79, 1997.
[64] J. Xu, J. P. Donohoe, and C. U. Pittman Jr, "Preparation, electrical and mechanical properties of vapour grown carbon fibre (VGCF)/vinyl ester composites". Composites Part A: App. Sci. & Manufacturing, vol. 35, no. 6, pp. 693-701, 2004.
[65] C. K. Hong and R. P. Wool, "Low dielectric constant material from hollow fibres and plant oil," J. of Nat. Fibres, vol. 1, no. 2, pp. 83-92, 2004.
[66] M. Jacob, K. T. Varughese, and S. Thomas, "Dielectric characteristics of sisal–oil palm hybrid fibre reinforced natural rubber biocomposites". J. of Mat. Sci., vol. 41, no. 17, pp. 5538-5547, 2006.
[67] N. Chand and D. Jain, "Effect of sisal fibre orientation on electrical properties of sisal fibre reinforced epoxy composites," Composites Part A: Ap. Sci. & Manufacturing, vol. 36, no. 5, pp. 594-602, 2005.
[68] N. A. Zulkifli, F. H. Wee, N. Mahrom, B. S. Yew, Y. S. Lee, S. Z. Ibrahim, and A. L. Am Phan, "Analysis of dielectric properties on agricultural waste for microwave communication application". MATEC Web of Conferences, EDP Sciences, vol. 140, p. 01013, 2017.
[69] J. B. Naik and S. Mishra, "Studies on electrical properties of wood polymer composites based on agro-waste and Novolac," Polymer-Plastics Tech. & Eng., vol. 43, no. 4, pp. 1085-1091, 2004.
[70] A. D. Omah, E. E. Ugwuogbo, P. O. Offor, I. Y. Suleiman, S. V. Egoigwe, and U. C. Ogbuefi, "Experimental Effect of Filler Variation on the polarizability of polymer Matrix Composites Developed from Orange Peel Particulates," J. Mat. Env. Sci, vol. 12, no. 3, pp. 406-417, 2021.
[71] A. Paul, K. Joseph, and S. Thomas, "Effect of surface treatments on the electrical properties of low-density polyethylene composites reinforced with short sisal fibres," Composites Sci. & Tech., vol. 57, no. 1, pp. 67-79, 1997.
[72] A. D. Omah, K. N. Idoko, S. N. Ude, V. S. Aigbodion, C. D. Mkpume, I. E. Ike-Eze, and P. O. Offor, "The Characterization of the Microstructure and Interfacial Behaviour of Egg Shell Particulate Polyester Reinforced Composites Proposed for Dielectric Applications". IEEE Trans. on Dielectrics and Elect. Insul. vol. 28, no. 3, pp. 950-958, 2021.
[73] J. Sharma and N. Chand, "Dynamic mechanical analysis and dielectric studies of agro-waste rice husk/polypropylene composites with Cenosphere,"

J. of Composite Mat., vol. 47, no. 15, pp. 1833-1842, 2013.

[74] A. O. Inegbenebor and F. A. Adeniji, "Electrical insulative properties of some agro-waste materials". West Indian J. of Eng., vol. 30, no. 1, pp. 17-26, 2007.

[75] W. A. Hussain, "Dielectric and Thermal Properties of Carrot Fibers–Epoxy Composites". Eng. & Tech. J., vol. 29, no. 16, pp. 3359-3367, 2011.

[76] C. Parida, S. K. Dash, C. Pradhan, and S. C. Das, "Dielectric response of luffa fibre—Reinforced resorcinol formaldehyde composites". American J, of Mat. Sci., vol. 5, no. 1, pp. 1-8, 2015.

[77] Z. Liyana, F. Malek, H. Nornikman, N. M. Affendi, L. Mohamed, N. Saudin, and A. A. Ali, "Investigation of sugar cane bagasse as an alternative material for pyramidal microwave absorber design". IEEE Symposium on Wireless Technology and Applications (ISWTA), pp. 66-70, IEEE, September 2012.

[78] P. Li, Y. Tao, and S. Q. Shi, "Effect of fibre content and temperature on the dielectric properties of kenaf fibre-filled rigid polyurethane foam". BioResources, vol. 9, no. 2, pp. 2681-2688, 2014.