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Electrical Insulative Properties of Some Agro-Waste Materials: Palm Kernel Shell Dust and Wood Saw Dust Hybrid Composite

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Abstract: Due to the need to enhance the dielectric properties of agro – based polymer composites, this work explored the possibility of harnessing the property advantages of a hybrid composite; thus, the investigation of the electrical insulating properties of some agro-waste materials: palm kernel shell dust and wood sawdust as reinforcements using 40% epoxy resin as the binder to form a hybrid composite. Electrical insulative properties tested and analyzed are: dielectric constant, resistivity, moisture content and water absorption capacity. Their moisture content decreased from 5.0% to 1.0% as the ratio of palm kernel shell dust was progressively increased from 50:50 to 90:10. There was a low range of water absorption capacities of the sample materials varying from 1.67% for 90:10 percentage ratio to 6.67% for 50:50 percentage ratio. Their moisture contents and their water absorption capacities were found to be relatively low, thereby increasing their usefulness as electrical insulators for indoor and outdoor applications. As the ratio of palm kernel shell dust increased and sawdust decreased, the surface resistivity and volume resistivity also increased; typically, the surface resistivity at 2500 V for 50:50 percentage ratio is 9.6 x 10^8 Ωmm while that of 70:30 and 80:20 percentage ratio at the same voltage is 9.96 x 10^8 Ωmm and 10.56 x 10^8 Ωmm respectively. There was a corresponding increase in the dielectric constant of the materials from 3.4 to 5.2 as the p.k.s. dust ratio increased from 50:50 to 90:10. The measured dielectric constants were reasonably high compared to the standard values. However, their best performance will be limited to low voltage applications.

1. Introduction

The research and development of new materials with the global need for reduced weight, low cost, quality, and high performance are on the increase in industries. This demand for new materials with higher specification and environmental and economic advantages birthed the idea of combining different agricultural byproducts generally referred to as agro-waste materials (palm kernel shell/saw dust) to form a hybrid bio-composite (Tri-Dung, 2020; Bouknana *et al.*, 2014; Errami *et al.*, 2013). A number of research areas are being actively pursued to fully explore the advantages of the efficient composites (Lvye *et al.*, 2021) like hybrid composites. These agro-waste materials have littered the rural and urban areas of the country thereby constituting a serious threat to environmental health of the nation and marring the beauty of the landscape of the nation.

Dielectrics find usage in electrical components intended to support or separate electrical conductors without passing current through themselves (Grigalunas, 2019). Due to high technological demand in the electrical and electronic industry, there is the need to replace the high resistive excellent processibility polymers previously in use which suffer from low stiffness and strength; thus, sophisticated substrate and high-tension insulator materials with enhanced properties becomes indispensable. Adding different bio-particles as reinforcements to a polymer helps to enhance efficient dielectric properties by the integration of the advantages of the properties of polymer resin and the bio-particles (Maiti *et al*, 2022). The applications of these materials are so varied that a choice must be made after consideration of the necessary properties including the strength of the insulators as well as the special circumstance of installation. The novelty of this work is to further exploit the properties of some agro-waste materials: palm kernel shell dust and wood saw dust so as to complement their existing areas of application as well as determine new areas of application such as their use as electrical insulation materials.

(Osarenmwinda and Nwachukwu, 2011), had earlier determined the electrical insulating properties of these agro-waste materials by increasing the sawdust composition and decreasing the palm kernel dust composition using urea formaldehyde as their test binder. Exposure to formaldehyde in concentrations greater than 0.1 parts per million (ppm) can cause nasal and throat congestions, burning eyes, or headaches as well as increasing the risk of developing cancer (Anonymous, 2022). Hence there is urgent need to develop dielectric materials using eco-friendly resin. This work therefore, tends to improve on the work of these researchers (Osarenmwinda and Nwachukwu, 2011), by increasing the composition of palm kernel shell dust to that of saw-dust and using epoxy resin as the polymer matrix so as to improve the dielectric properties of palm kernel shell and wood sawdust composites. This study therefore characterized the dielectric properties of the developed composite from agro-waste (sawdust and palm kernel shell) materials.

2. Methodology

2.1 *Sourcing and preparation of materials*

Materials used in this study are: Epoxy (matrix), hacksaw, vernier caliper, digital weighing balance, scanning electron microscope, Kaise insulation tester model SK5010, Palm Kernel Shell (PKS) (which was collected from Obukpa town), wood saw dust (which was collected from Ibagwa Timber mill), all in Nsukka, Enugu State, Nigeria. See Figure 1.

Figure 1. Palm kernel shells: (**a**) Washed & dried palm kernel shells (**b**) ground Palm kernel shells (**c**) sieved 300µm of PKS

The PKS was washed, dried at room temperature and milled and sieved to 300µm particle size. The wood saw-dust was dried under the sun and sieved to 300µm particle size as seen in Figure 2. In the production of the composite samples of Figure 3, the Palm Kernel Shell (PKS) and the wood saw dust (WSD) were prepared at the ratio of 50wt%:50wt%, 60wt%:40wt%, 70wt%:30wt%, wt80%: wt20%, and 90wt%:10wt% by weight of total sample (see Table 1). Hand Lay – Up method was used in the composite manufacture and epoxy was used as the test binder.

Figure 2. Saw-dust: (**a**) dried Saw-dust, (**b**) sieved 300µm of Saw-dust

Figure 3: Cast samples of the composites

Table 1: Designation and composition of PKSD and WSD in each composite

S/N	DESIGNATION	COMPOSITION
1.	Sample A	Epoxy + 40 wt% of (50%PKSD + 50%WSD)
2.	Sample B	Epoxy + 40 wt% of (60%PKSD + 40%WSD)
3.	Sample C	Epoxy + 40 wt% of (70%PKSD + 30%WSD)
4.	Sample D	Epoxy + 40 wt% of (80%PKSD + 20%WSD)
5.	Sample E	Epoxy + 40 wt% of (90%PKSD + 10%WSD)

2.2 Experiments

The voltage across an air gap (V_0) and the voltage across the sample between the two parallel plate capacitors (V) were used to determine the dielectric constant. The surface resistivities were measured using Kaise insulation tester model SK5010, in which the samples were placed between the two electrodes. The resistance is expressed in Ohms and resistivity was calculated from the equation, $\rho = RA/L$ where ρ is the resistivity, R is the resistance, A is the surface area of the sample and L is the length of the materials at the points of measurement. For volume resistance, a bare lead wire was wound round the samples, connected to the guard terminals while the probe was connected to the conductor.

For the determination of the water absorption capacity, the samples were weighed to the nearest 0.01g (M_1) and immersed in water for a period of 14 days. It was subsequently removed from the water and allowed to drain by gravity before the sample was weighed again (M_2). The water absorbed was calculated as percentage weight gain using equation 1 below.

$$W_A = \left(\frac{M_2 - M_1}{M_1} \right) \times 100 \qquad \textbf{Eqn. 1}$$

To determine the moisture content, the composite samples were weighed to the nearest 0.01g (M_3), after which, they were placed in an oven at 105°C and reweighed at one hour intervals until a constant mass M_4 was obtained. The samples were kept in a desiccator to avoid the absorption of moisture from the atmosphere. The moisture content was calculated as percentage of the dry samples from equation 2 below.

$$W_C = \left(\frac{M_3 - M_4}{M_3} \right) X\ 100 \qquad \textbf{Eqn. 2}$$

3. Results and Discussion

3.1 Surface and Volume Resistivity

Figures 4 and 5 show the graphs of surface and volume resistivity against the applied voltage for various constituent compositions. These figures of both surface and volume resistivities reveal that as the ratio of palm kernel shell dust increased and saw dust decreased, there was a gradual increase in the surface resistivity and volume resistivity. The reason for this is the difference in densities of the p.k.s. dust and the sawdust. The density of p.k.s using Archimedes principle is 0.55g/cm^3 while that of sawdust is 0.36g/cm^3. Thus as the percentage of p.k.s. increases and that of sawdust decreases, the entire composite material becomes more dense thereby increasing the resistivity of the material. This is in agreement with the recommendation given by Osarenmwinda and Nwachukwu (Osarenmwinda and Nwachukwu, 2011), that the composite insulating properties will increase as the percentage ratio of palm kernel shell is increased in the samples.

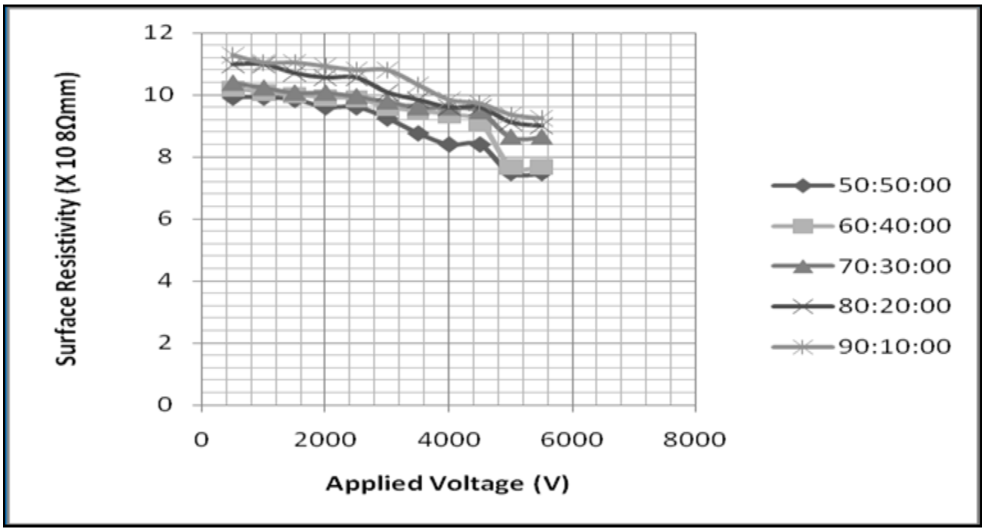

Figure 4: Graph of Surface resistivity against voltage applied

It was also observed from Figure 5, that as voltage is increased gradually, the volume resistivity was stable but as the voltage is increased further, the volume resistivity began to decrease gradually. But for surface resistivity it was not so, the resistivity changed as the voltage was changed. This is because there is faster flow of electrons at the surface than inside the volume of the lattice where the atoms are densely packed together (Yung *et al*, 2007). The resistivities of the samples were a little bit low when compared with the conventional insulation materials, but they still met the requirement of 10^8 Ohm.mm which is the minimum resistivity for an electrical insulator.

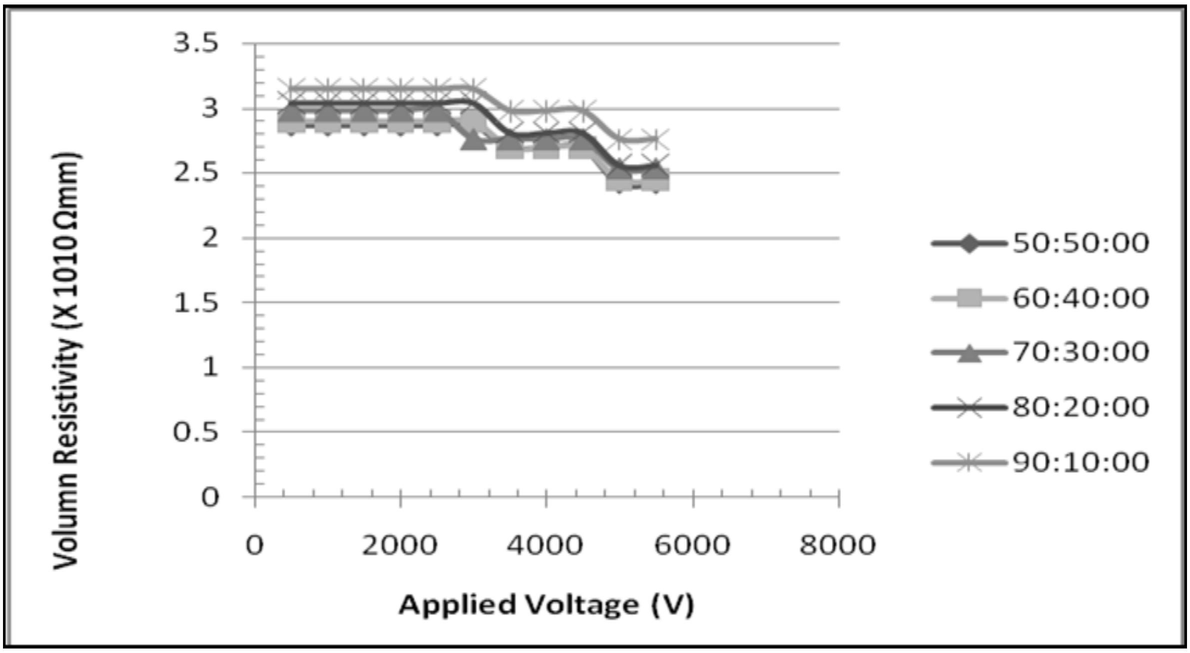

Figure 5: Graph of volume resistivity against voltage applied

3.2. Dielectric Constant

Figure 6 shows that the measured dielectric constants were not too high compared to the standard values. The dielectric constant of the composites increased with the proportion of p.k.s particles added. This was because each extra wt% addition of p.k.s. led to increase in the number of dipoles per unit volume, which means increase in the number of polarized dipoles that orients due to the effect of the electric field, thus, increased dielectric constant.

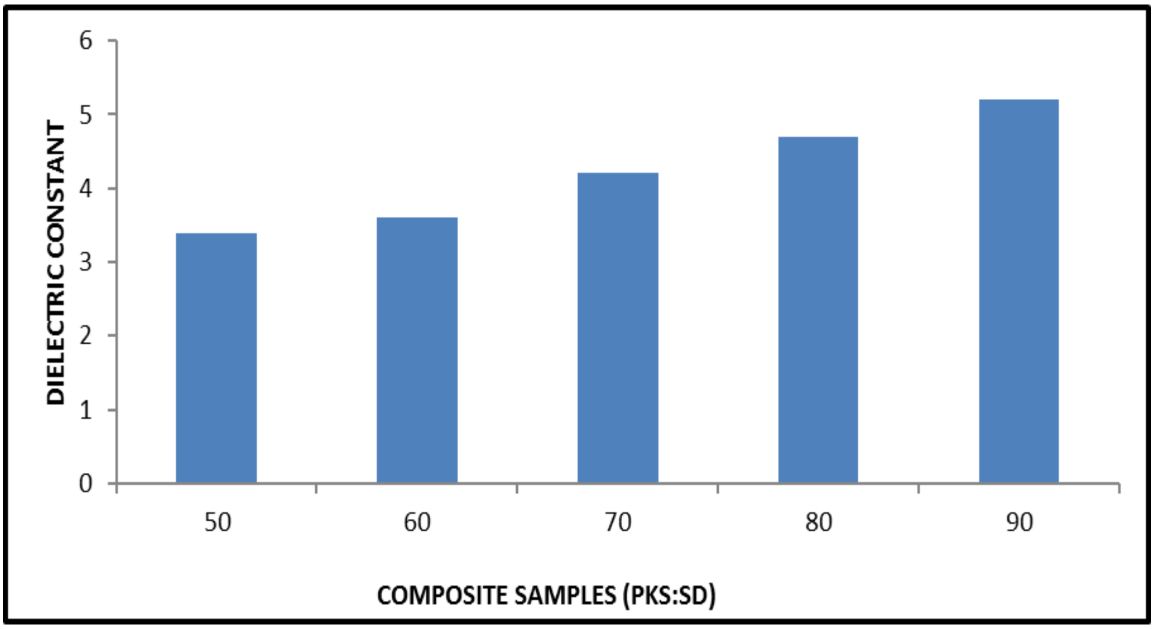

Figure 6: Dielectric constant at different composite compositions

3.3Moisture Content

The values for moisture content as seen in Figure 7 decreased as the ratio of palm kernel dust increased. It varied from 1.0% for 90:10 percentage ratio to 5.0% for 50:50 percentage ratio. This is also attributed to the density of the p.k.s. which is higher than that of sawdust. Epoxy resin absorbs high degree of moisture (Kim *et al*, 2005) which is due to the ability of the water molecules to penetrate through the epoxy network either in form of free water which will fill the micro-cavities of the network structure in the composites or strong interactions which occur between the water molecules and polar group of epoxy resin (Han and Dzarl, 2003). But fiber reinforcement in epoxy matrix however helps to reduce the penetration of water in epoxy matrix (Omah *et al*, 2016). Thus as the more dense p.k.s dust is increased it absorbs the moisture in the matrix better than the sawdust which has lower density, as a result reducing the overall moisture content of the material. The reduction in the moisture content of the composite sample led to an increase in both surface resistivity and volume resistivity. Low values of dielectric constant are best for high frequency or power applications to minimize electric power losses (Rady *et al*, 2023).

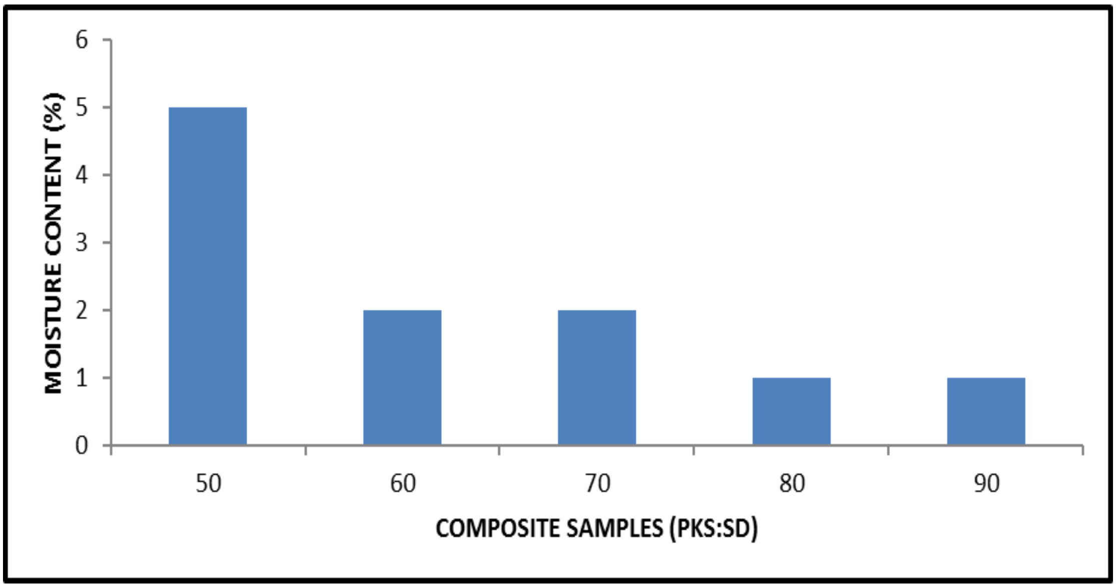

Figure 7: Moisture content at different composite compositions.

3.4 Water Absorption Capacity

The amount of water absorbed by the material in service will affect the service life of the material and even reduce the resistivity of the materials; thus, absorbed water reduces the insulation resistance (Pakkala, 2014). Figure 8 shows a low range of water absorption capacities of the sample materials varying from 1.67% for 90:10 percentage ratio to 6.67% for 50:50 percentage ratio. The p.k.s. dust which has higher density fills the micro-cavities of the network structure in the composites than the sawdust thereby reducing the water absorption capacity of the produced dielectric composites (Omah *et al*, 2016, Chow, 2007). Thus materials with higher ratio of p.k.s which have low water absorption capacities would perform more efficiently in a high humidity environment than those with high water absorption capacity. Conversely, a sample with lower ratio of p.k.s. having a high water absorption capacity would perform more efficiently in a low humidity (dry) environment than in a wet one (Inegbenebor and Adeniji, 2007). This shows that the samples produced in this work will have a long life service whether it is used in high humidity area or not.

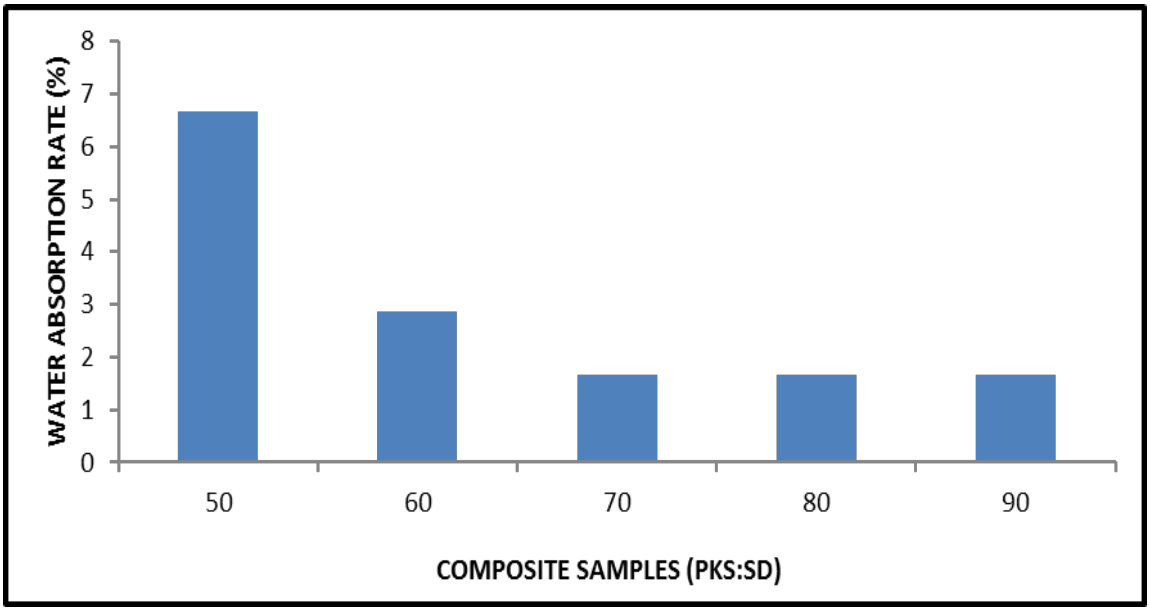

Figure 8: Water absorption capacity at different composite compositions.

3.5 Microstructural Analysis on PKS:SD Hybrid Composites.

The SEM/EDS of the hybrid composites were shown in Figures 9 – 13. Particle-matrix interface played an important role in composite properties. A strong particle-matrix interfacial bond was critical for high dielectric properties of composites.

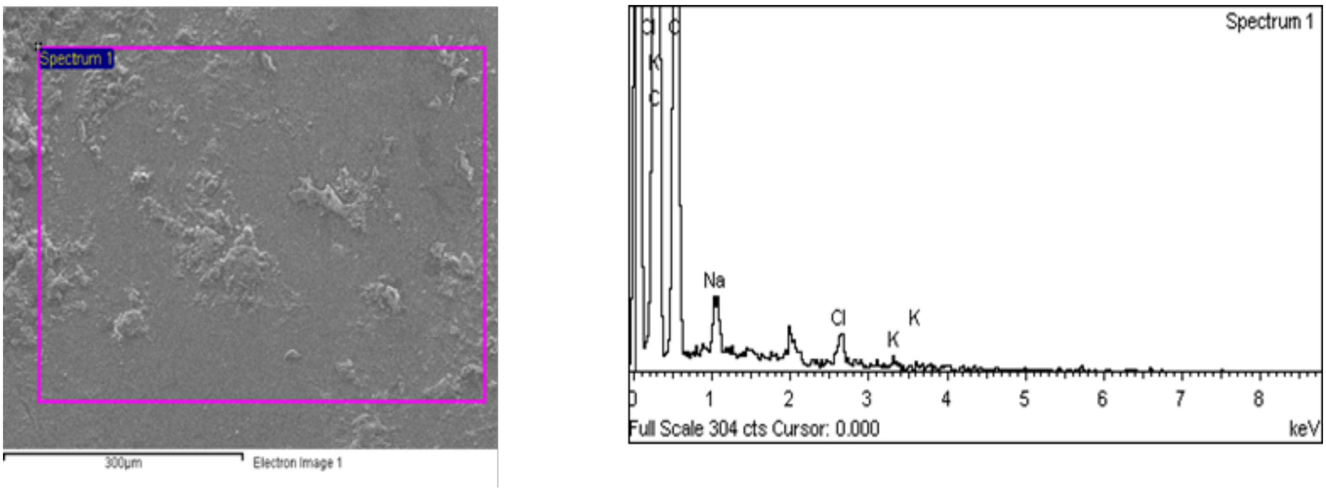

Figure 9: Photomicrograph of PKS:SD (50:50) as revealed by SEM/EDS

Table 2: Chemical analysis of PKS:SD (50:50)

Element	Weight%	Atomic%
C	65.13	72.09
O	32.09	26.67
Na	1.04	0.60
Cl	1.26	0.47
K	0.48	0.16
Totals	100.00	

The SEM micrographs of the composites showed the apparent difference in the morphologies of composites. There was a good particle-matrix interface and a good uniform grain structure; but as palm kernel shell was increased there was a change in the grain structure thus, maximum dielectric properties. These results suggest that good particle-matrix interface and good grain structure were important factors in determining the optimal dielectric properties of the hybrid composites. The SEM micrographs showed that there was great convergence of particles, high homogeneity and high stable distribution in all directions at higher wt% composition of PKS, but at lower wt% composition of PKS, the composites suffered from weaknesses in the dispersal and the homogeneity of the fillers in the matrix.

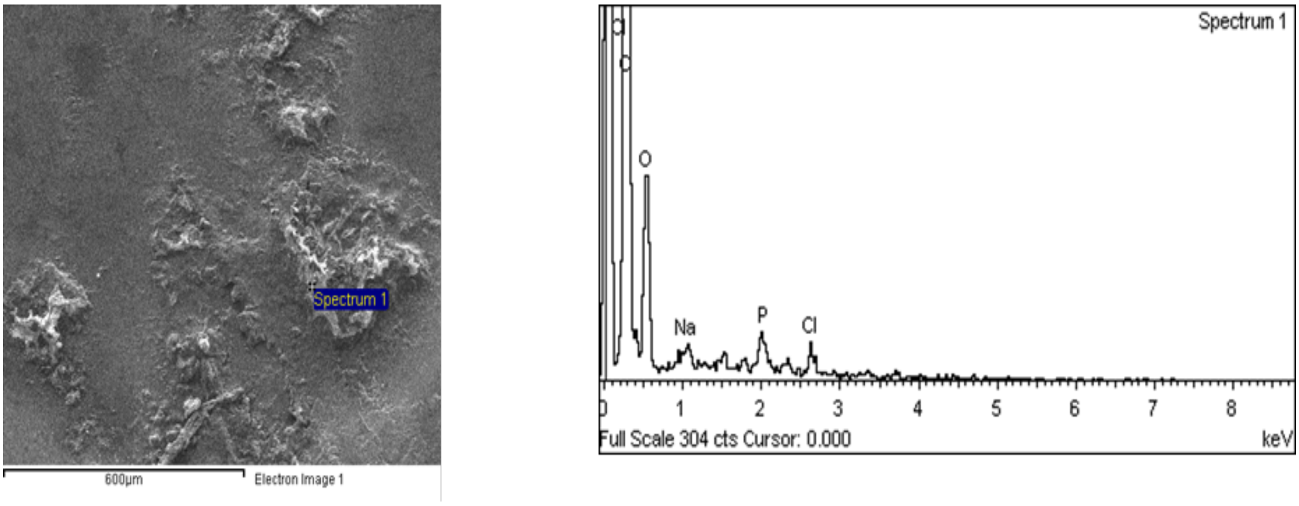

Figure 10: Photomicrograph of PKS:SD (60:40) as revealed by SEM/EDS

Table 3: Chemical analysis of PKS:SD (60:40)

Element	Weight%	Atomic%
C	70.77	77.59
O	25.07	20.63
Na	0.68	0.39
P	1.67	0.71
Cl	1.80	0.67
Totals	100.00	

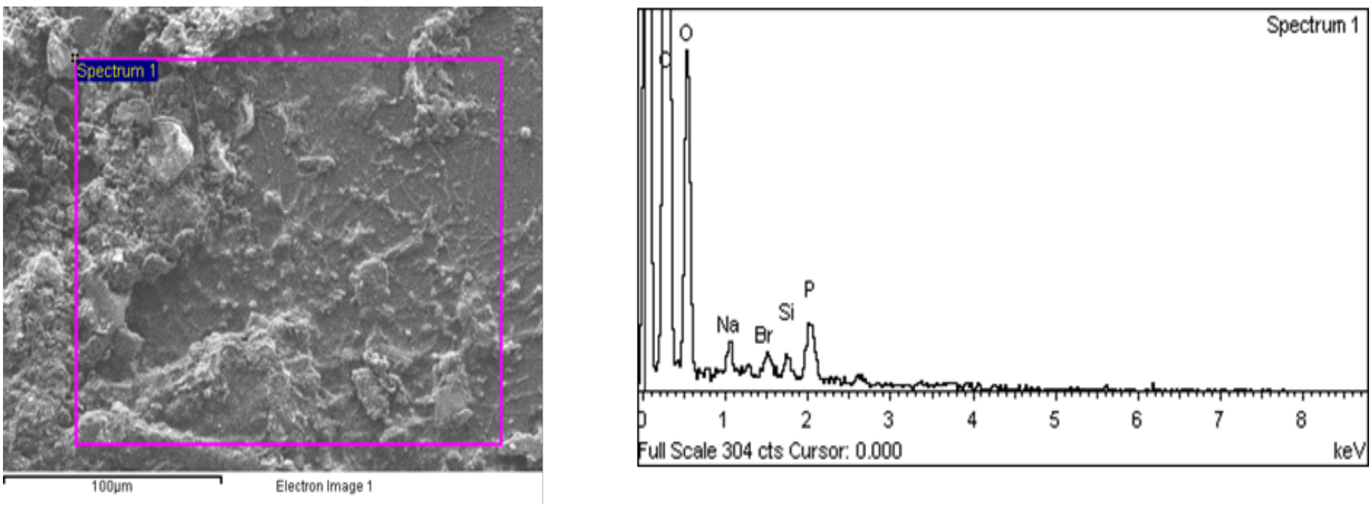

Figure 11: Photomicrograph of PKS:SD (70:30) as revealed by SEM/EDS

Table 4: Chemical analysis of PKS:SD (70:30)

Element	Weight%	Atomic%
C	68.39	75.83
O	26.61	22.15
Na	0.83	0.48
Si	0.77	0.36
P	2.33	1.00
Br	1.07	0.18
Totals	100.00	

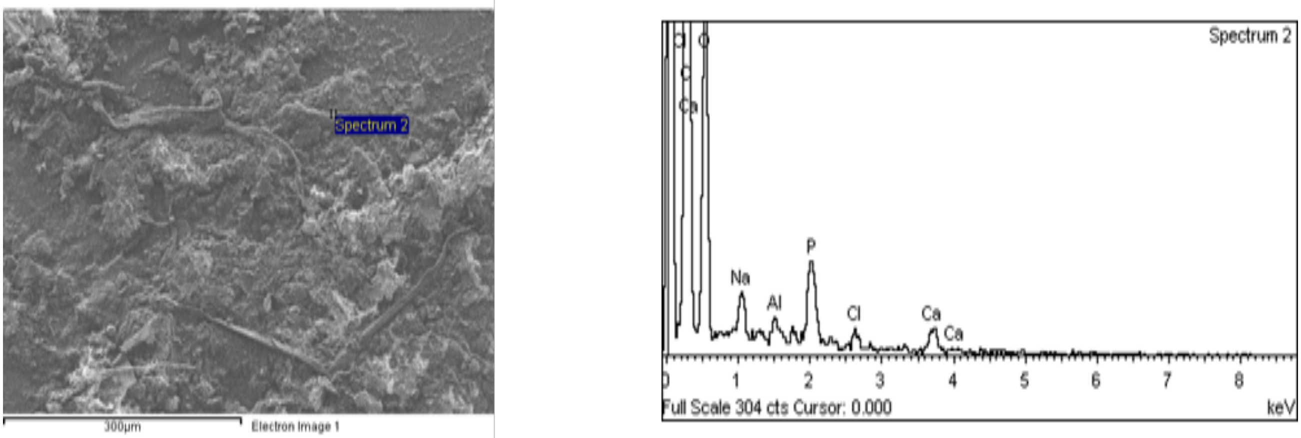

Figure 12: Photomicrograph of PKS:SD (80:20) as revealed by SEM/EDS

Table 5: Chemical analysis of PKS:SD (80:20)

Element	Weight%	Atomic%
C	61.86	70.80
O	29.75	25.56
Na	1.15	0.69
Al	0.50	0.25
P	3.42	1.52
Cl	0.98	0.38
Ca	2.34	0.80
Totals	100.00	

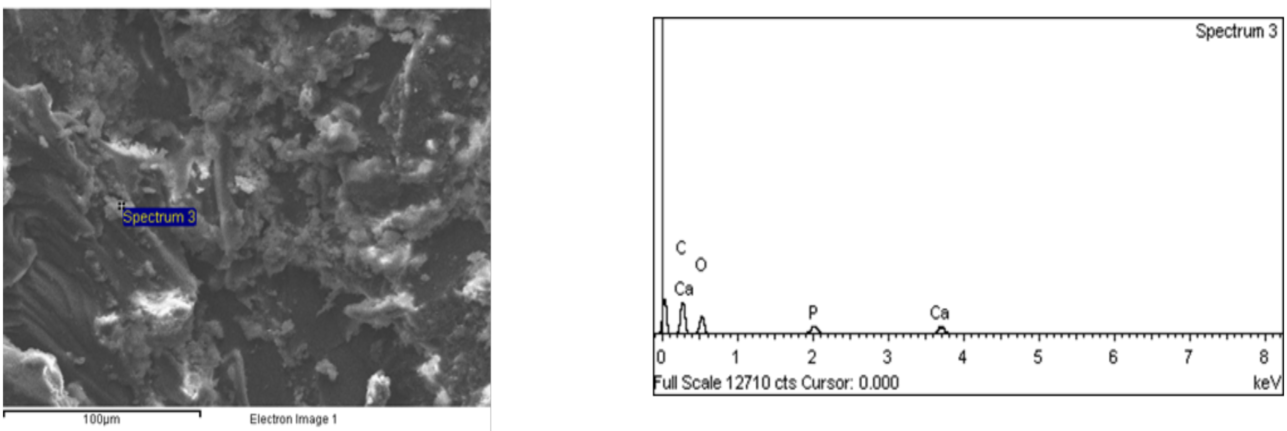

Figure 13: Photomicrograph of PKS:SD (90:10) as revealed by SEM/EDS

Table 6: Chemical analysis of PKS:SD (90:10)

Element	Weight%	Atomic%
C	49.72	60.30
O	37.85	34.46
Na	0.52	0.33
Mg	0.33	0.20
Si	0.21	0.11
P	4.32	2.03
Cl	0.22	0.09
Ca	6.83	2.48
Totals	100.00	

Conclusion

From the discussion above the following conclusions were made:

1. Eco-friendly dielectric materials using Palm kernel shell/saw dust composite bound with epoxy resin were successful produced
2. The measured properties of the materials are comparable to those of standard insulators.
3. The moisture contents and their water absorption capacities are relatively low; thereby increasing their usefulness as electrical insulators for indoor and outdoor applications; also, due to these properties their work life will be relatively high.
4. However, there resistivities are relatively low when compared with the conventional insulators, but they still met the requirement of 10^8 Ohm.mm which is the minimum resistivity for an electrical insulator. The application of the fabricated composite material may be limited i.e. they may not be used for very high voltages.

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