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RESEARCH ARTICLE

Improving Soil Dielectric Properties for Electronic Component Manufacturing: A Study on Ash and Repurposed Printer Toner

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ABSTRACT

The study aimed to repurpose both organic ash and inorganic waste materials to improve the electrical properties of soil for electronic applications. Eight soil samples were treated with a mixture of yam peels ash (YPA) and spent computer printer toner (SCT) at various quantities. Following a curing period of 28 days, their electrical characteristics were assessed in line with ASTM guidelines. From the results, there is a strong indication that the two blending agents had significant impact of the soil dielectric constant (ε'), dielectric loss (ε''), and relaxation time values ($p \leq 0.05$). It was noted that with an increase in the quantity of YPA from 0 to 20% and at 5% SCT, the soil's ε', ε'' and τ values ranged from 3.8 to 8.72, 0.84 to 3.19, and 3.91 to 6.47, respectively. Likewise, as the YPA content increased from 0 to 20%, in conjunction with a 10% SCT quantity, the soil samples exhibited varying values for ε', ε'', and τ, ranging from 3.8 to 9.21, 0.84 to 3.22, and 3.91 to 6.18, respectively. This study findings revealed that yam peel and SCT (a toxic compound), can be effectively recycled to manufacture high-quality electronic components. This offers a sustainable approach to waste management while simultaneously promoting environmental sustainability. The observed enhancement in the dielectric behaviors of the fortified soil holds significant advantages for the electronic industry, particularly in the production of capacitors and diodes.

Keywords: *Soil Dielectric Properties; Electronic Component Manufacturing; Repurposed Printer Toner*

Introduction

Soil contains numerous elements and minerals which are fundamental raw materials used for the production of electrical and electronic components (Kumari and Mohan, 2021). Some of the essential elements and compounds found in soil, which are useful in the electrical and electronic sectors include: silicon, copper, neodymium, cerium, mica, lanthanum, iron, and graphite (Aide and Aide, 2012; Sanematsu and Watanabe, 2016). These essential materials are used to manufacture basic electrical and electronic components, such as: hard drives, capacitors, heating elements, inductors, electric motors, diodes, batteries and integrated circuits. Soil plays crucial and complex roles in the computer and electrical industries, as it acts as a natural reservoir and conductor, which provides a suitable route for save dissipation of excessive electrical charges (Xue *et al*., 2019).

The grounding (earthing) system, acts as an avenue for transmitting and dispersing excess charge electrons; hence, safeguarding sensitive electronic equipment (Chevalier et al., 2012; Uguru and Obukoeroro, 2020). The potentiality of using any soil for production of engineering components is dependent on its level of contamination, mechanical and electrical properties. The electrical behavior of soil can significantly influence its suitability for electrical and electronic components production, as well as its applications in electrical insulation, conductivity, or electromagnetic environments (Al-Obaidy *et al*., 2019). Soil electrical properties such as electric conductivity (EC), dielectric constant (ε'), electrical resistivity, and dielectric loss (ε'') play crucial roles in determining its performance in electrical and electronic devices (Gustavo Fano, 2020).

Soil electrical properties can be enhanced through proper incorporation of inorganic or organic improvement (admixtures) materials. Incorporating soil with appropriate materials with high electrical conductivity and water retention levels, tend to boost the mobility of charged electrons within the soil (Friedman, 2005; Pozdnyakov *et al*., 2006). Koul and Taak (2018) stated that the existence of biomaterials with high water absorption and withholding degree assist immensely in maintaining the moisture level within the soil, which further supports electrons mobility in the soil mass. Some materials used to improve soil electrical and mechanical properties include: carbon black, lime, bio-ashes rich in carbon carbonates, biochar and organic matters with high waste absorption tendency. Organic materials play a crucial role in improving soil structure, facilitating microbial activity, and enhancing moisture retention, all of which can have significant effects on the electrical and geotechnical properties of soil (Akpokodje and Uguru, 2019; Urra *et al*., 2019; Amoah-Antwi *et al.,* 2020). Though there is ample information available regarding the blending of soil and other composites with inorganic carbon-based compounds to enhance their electrical properties (Ezquerra *et al*., 2001; Chakraborty *et al*., 2014; Das *et al*., 2021), a review of related literature yielded no information on the hybridization of recovered materials. Therefore, the goal of this research is the improvement of the soil dielectric properties, by treating it with yam peels ash and recovered spent computer printer toner.

Materials and Methods

Materials

Soil Sampling

The soil specimen was obtained from a currently operational borrow pit and subsequently air-dried in the laboratory for three weeks, maintaining a temperature of 30±6^{o}C.

Yam Peel Ash (YPA)

The yam peel ash was obtained through burning of dried yam tuber peels in the open air. Subsequently, the ash derived from the burning underwent sieving procedure using a 150 µm sieve to obtain fine particulates used as the admixture.

Spent Computer Printer Toner (SCT)

This is the discarded toner cartridges from computer printers. It contains significant amount of carbon powder.

Methods

Treatment of the Soil Samples

The soil was stabilized with YPA and SCT in the dosage presented in Table 1, and cured for 28 days at a temperature of 31±6°C.

Table 1: Soil Treatment Plans

Code	PPA (% mass of the soil)	SCT
Control	0	0
SAM 1	5	5
SAM 2	10	5
SAM 3	15	5
SAM 4	20	5
SAM 5	5	10
SAM 6	10	10
SAM 7	15	10
SAM 8	20	10

Laboratory Analyses

Electrical Properties

The stabilized soil specimens electrical properties (dielectric constant "ε′" and dielectric loss "ε′′") were determined in accordance with standard procedures outlined by ASTM D150 (2018), by employing a unique microwave frequency of 9.0 GHz at laboratory temperature of (30±3°C).

Relaxation Time

The relaxation time (τ) of the nine soil samples from the experimental plan was determined by employing the formula presented in Equation 1.

$$\tau = \frac{\varepsilon''}{\omega\varepsilon'} \qquad 1$$

Where $\omega = 2\pi f$

Statistical Analysis

The impact of amendment agents (YPA and SCT) on both the geotechnical and electrical properties of the soil was assessed utilizing one-way analysis of variance (ANOVA).

Results and Discussion

Dielectric Constant

The ANOVA results of the impact of the admixtures on the soil dielectric constant are presented in Table 2. It was noted that the combination of the YPA and SCT had significant effect on the ε′ of the soil specimens ($p \leq 0.05$). The average ε′ values are depicted in the graph provided in Figure 1. It was noted that the ε′ values exhibited a non-linear increasing pattern of from 3.8 to 9.21, as the YPA content uniformly rose from 0 to 20, regardless of the quantity of SCT included in the admixture formulation. The observed increase in the soil's ε′ following the application of YPA and SCT may be attributed to the notable presence of calcium oxide (CaO) in the YPA included in the formulation (Khater *et al*., 2019). Similarly, Brady and Weil (1999) stated that the presence organic matter facilitates the cation exchange and water retention ability of soils; hence, leading to improve and more uniform electrical properties. Furthermore, Obukoeroro and Uguru (2021) and Chaudhari (2015) affirmed that $CaCO_3$ have the potential of increasing the ε′ of different materials including soils, by influencing the distribution and mobility of water and charged electrons within the soil.

Table 2: One-way ANOVA results of the influence of admixtures of soil ε′

	Sum of Squares	df	Mean Square	F	p-value
Between Groups	65.916	8	8.240	2990.14	1.69E-26*
Within Groups	0.050	18	0.003		
Total	65.97	26			

* = significant at P ≤0.05

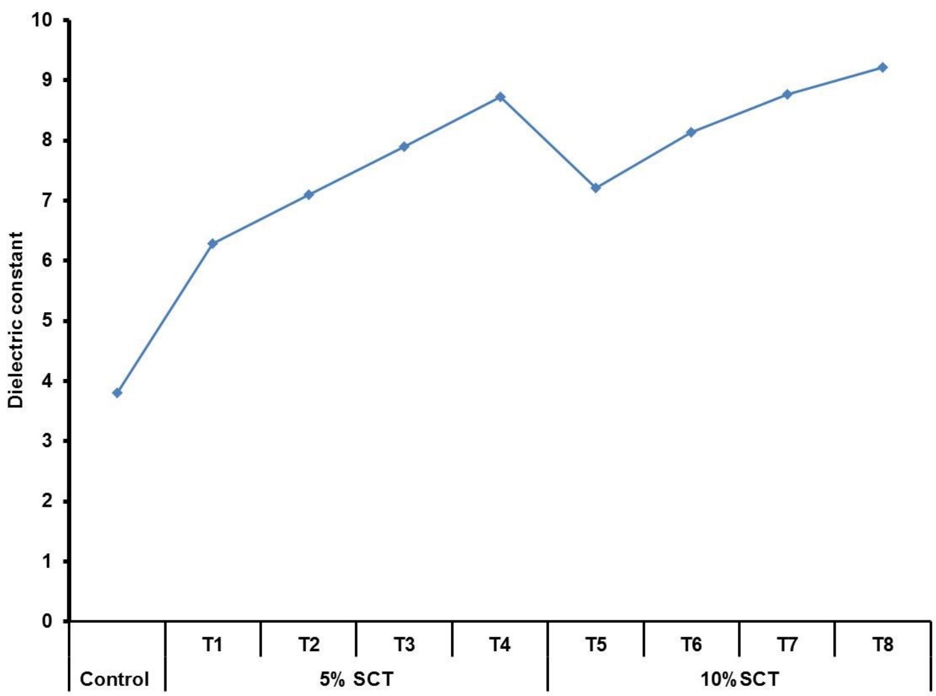

Figure 1: The specimens' dielectric constant

Dielectric Loss

Table 3 displays the results of the ANOVA regarding the influence of the admixtures on the soil ε′′. The statistical outcomes revealed that the mixture of the YPA and SCT exhibited significant influence on the ε′′ level of the soil ($p \leq 0.05$). Figure 2 shows the mean ε′′ values, and the results depicted that the control, T1, T2, T3, T3, T4, T5, T6, T7 and T8 specimens' ε′′ value was 0 0.84, 1.78, 2.22, 2.97, 3.19, 1.91, 2.36, 2.95 and 3.22, respectively. This is evident that the recycled materials have substantial effect on the soil ε′′. Furthermore, the findings indicated that organic ash with significant amount of CaO tends to enhance the soil ε′′, which is advantageous in capacitors production. Capacitors require materials with high ε′′ values to facilitate the dissipation of the excess energy; hence, averting voltage breakdown within the unit (Wang *et al*., 2021). The results of this research had indicated that the mixture of YPA and SCT can be used to produce capacitor for high-voltage applications. According to Mayoux (2000), capacitors intended for circuit systems prone to high voltage should possess high dielectric loss characteristics. This is to mitigate the risk of electrical breakdown in scenarios where the dielectric material insulating characteristics collapse under the influence of high electric field stress.

Table 3: The ANOVA of the impact of YPA and SCT of soil dielectric loss

	Sum of Squares	Df	Mean Square	F	p-value
Between Groups	15.043	8	1.880	757.750	3.81E-21*
Within Groups	0.045	18	0.002		
Total	15.087	26			

* = significant at P ≤0.05

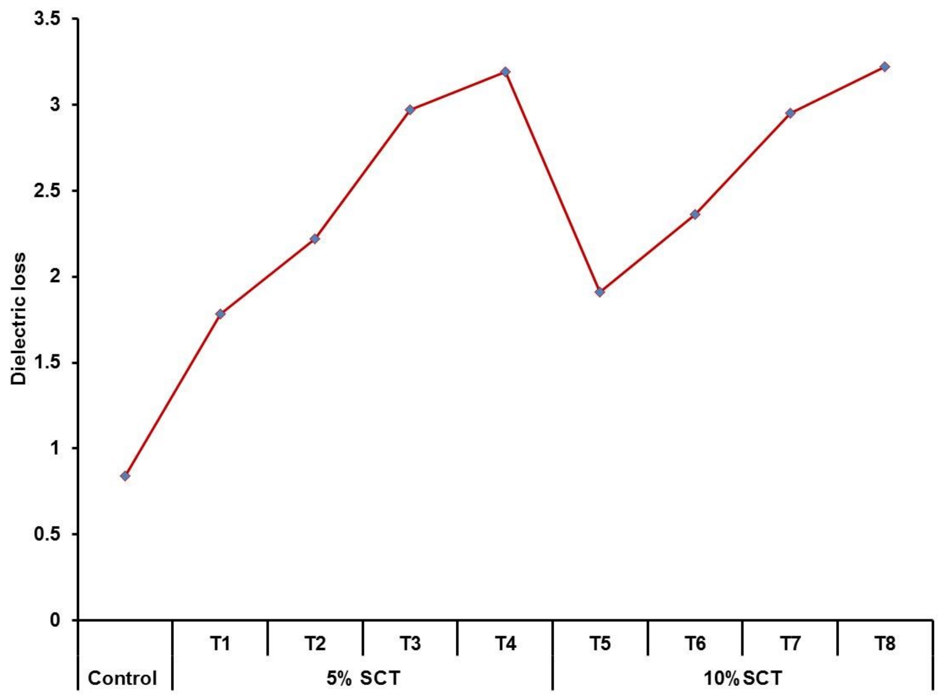

Figure 2: The ε'' of the specimens

Relaxation Time (τ)

The graphical representation in Figure 3 shows relaxation time results of the different samples. As depicted in Figure 3, the treatment agents exhibited a notable influence on the specimens' τ, with the τ values decreasing irregularly as the YPA and SCT contents in the virgin soil increased uniformly. After the curing duration, the control, and Treatments 1 – 8 samples recorded τ values of 3.91, 5.00, 5.54, 6.66, 6.47, 4.68, 5.13, 5.95 and 6.18, respectively. Electrical relaxation time is a crucial parameter that is usually considered during the design and development of electrical devices, especially – capacitors and inductors. According to Zhang et al. (2020), adequate knowledge about the relaxation time of materials is crucial for designing circuits with specific response times, in order to prevent unsolicited oscillations and optimize the performance of the device. Furthermore, Mazloom *et al*. (2016) stated that τ plays a critical role in the behavior of materials under the influence of electric and magnetic fields, making it a key parameter in the development of modern electronic and optoelectronic devices.

This research outcome is in conformity with the findings of Liu *et al*. (2013), which stated that organic materials are capable if enhancing the soil dielectric properties. The generally fluctuation recorded in the soil electric properties as the ash volume increases as recorded by the various authors could be attributed the different in chemical oxides compositions, organic matter content, particle interactions, processing and storage techniques (Ijabo *et al*., 2019). Additionally, this study had revealed that SCT which is a potentially harmful material to the ecosystems can be recycled to produce high quality capacitors for industrial applications; hence, offering a sustainable solution for waste management while also contributing to environmental sustainability.

Figure 3: The soil units' relaxation time

Conclusion

This study was undertaken to assess the influence of organic ash and recovered toner on the electrical properties of soil. Soil units were augmented with different amounts of yam peel ash (YPA) and spent computer toner (SCT), and their dielectric properties were evaluated following ASTM guidelines. The outcomes strongly suggest that the incorporation of the two admixtures had a considerable effect on both the dielectric constant and loss values of the soil. It was observed in the results that the soil ε′, ε′′, and τ exhibited uneven increments with the increasing volume of admixtures incorporated into the soil samples. The improvement noted in the dielectric properties of the fortified soil offers substantial benefits to the electronics industry, especially concerning the manufacturing of capacitors and diodes. Moreover, the study uncovered that spent printers toners which is potential harm to ecosystems, can be repurposed into high-quality capacitors for industrial use. This offers a sustainable approach to waste management while also aiding environmental sustainability efforts.

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