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Study on Dielectric Properties of Rice Husk Ash Stabilized Soil

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ABSTRACT

This study explored the impact of organic soil stabilizing agent on the engineering behaviors of subsoil commonly used for engineering applications in Nigeria. The soil obtained from a borrow pit and air-dried under laboratory conditions (30±5°C and 81±7% relative humidity). The dried soil sample was stabilized with rice husk ash (RHA) at the rate of 2, 4, 6, 8 and 10% (by mass of the soil) and cured for 14 days under natural conditions. A J-band microwave at a frequency of 7.0 GHz was used to measure the dielectric properties, while the standard proctor compaction test was used to determine the maximum dry density "MDD" and optimal moisture content "OMC" of the soil samples. Results obtained from the study depicted that the RHA had a significant effect on both the electrical properties of the soil. It was noted from the findings that, as the quantity of RHA used in stabilizing the soil increased from 0 to 10%, MDD values declined non-linearly from 1.61-1.42 g/cm^3, while the OMC values inclined in a non-linear pattern from 14.8 - 17.1%. Similarly, the study results indicated that the soil dielectric constant and loss increased from 3.41 to 5.13 and 0.91 to 1.44 respectively, as the RHA incorporated into the soil raised by 10%. Present findings offer valuable insights into the fields of civil and electrical engineering, especially in the context of soil treatment for engineering applications.

Keywords: *Agricultural residues, Engineering properties, Environmental sustainability, Microwave frequency, Soil particles*

INTRODUCTION

Soil is a complex composite material that consists of both organic and inorganic materials, which has various engineering properties and broad applications (Akhtar *et al.*, 2013; Akpokodje and Uguru, 2019). Soil electrical properties are relevant in electrical and civil engineering jobs, as the electrical characteristics of the soil has a significant impact on the design and performance of constructed/installed structures. Some soil geotechnical properties-moisture content, soil grain size, permeability and compaction level-are critical for understanding soil behaviors and play an essential role in various applications. They provide very useful information for agricultural and electrical engineering applications (Obukoeroro and Uguru, 2021). According to Gustavo Fano (2020), soil moisture content affects the soil electrical conductivity "EC", resistivity and dielectric properties; therefore, ground water table and soil moisture content are essential parameters to be properly evaluated during the design of grounding systems and electrical wiring.

The dielectric properties of soils are usually influenced by the bulk density, textural properties, porosity and moisture content of the soil mass. Dielectric constant (ε') of soil generally decreases with increasing bulk and dry density of the soil, as soil with high maximum dry density tends to have fewer voids for air and water, which will result in a gradual reduction of the soil ε' level (Zhao and Ling, 2016). The volume of water in soil pores significantly increases the soil dielectric constant and electrical conductivity. Similarly, soils with higher fine-grains (clay) soils develop higher dielectric constant as compared to coarse-grained (sandy) soils. Fine particles usually have a higher effective contact surface area; thereby, providing more active areas for water molecules to interact with (Schoonover and Crim, 2015).

Soil dielectric properties can be systemically influenced by alteration of some crucial factors, such as: soil moisture content, temperature, compaction level, and other physicochemical properties. According to Syeda *et al.* (2020), soil dielectric properties can be seriously influenced by the mineral composition, organic matter content and salinity level of the soil. Moderate salinity has the potential of causing serious alteration in the soil electrical conductivity and dielectric properties, as it makes the soil to be more conductive; hence, increasing the EC and ε' of the soil (Patel *et al.*, 2018).

Though a number of studies had been done to appraise the dielectric properties of various soil types (Navar khele *et al.*, 2009; Kabir *et al.*, 2020; Kumar *et al.*, 2022; Muhammad *et al.*, 2022), there is still information dearth on the electrical properties of organic material stabilized soils. Therefore, the major aim of this experimental work is to investigate the impact of rice hush ash "RHA" on the electrical properties of poor quality soil. Findings obtained from this study will be useful in various engineering applications such as soil moisture sensing and geophysical investigations.

MATERIALS and METHODS

Soil collection and preparation

The virgin soil sample employed for this study was collected from an active borrow pit site (1.5-2 m depth) in Oleh community of Delta State, southern Nigeria. Borrow pit soils are commonly used for civil engineering works in Nigeria, as they are considered to be lateritic soil with applicable engineering properties

(Uguru *et al.*, 2022). The soil was dried in the laboratory under natural environmental conditions (30±5^{o}C and 81±7% relative humidity).

Rice husk ash (RHA)

The RHA which was produced with a muffle furnace was obtained from the farm structure laboratory of the Department of Agricultural Engineering, Delta State University of Science and Technology, Ozoro, Nigeria. The rice husk ash was sieved with a 150 µm gauge sieve to obtain a homogenous particle size.

Preparation of the stabilized soil samples

The soil was stabilized by using different RHA contents in accordance to the stabilization plans shown in Table 1. After the addition of the required amount of RHA, the modified soil samples were cured for a period of 14 days in ambient environmental conditions (30±5^{o}C and 81±7% RH). During the curing period, the stabilized soil samples will experience both physical and chemical changes/reactions, leading to the desired stabilization effects - desired engineering properties (Barman and Dash, 2022).

Table 1. *Stabilization plan of the soil samples.*

Sample code	RHA quantity (% mass of the soil)
Control	0
Treatment 1	2
Treatment 2	4
Treatment 3	6
Treatment 4	8
Treatment 5	10

Laboratory analyses

Physical properties

Particle size distribution

The sieve analysis test of the virgin (control) soil sample was done by applying the wet method according to ASTM D6913-04 (2017) recommended procedures. The coefficient of uniformity (Cu) for the soil was determined using Equation 1, as outlined in the sieve analysis plot by Uguru *et al.* (2022).

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

Where: D_{60} and D_{10} correspond to the points where 60% and 10%, respectively, of the grains are finer in the sieve analysis.

Compaction test

The standard proctor compaction test was done on the soil samples in accordance with ASTMD698-12 (2021) approved guidelines. The procedure involved mixing the soil with water and subsequently placing it into a mold with a predetermined weight. The compaction process ensued with 75 blows from a rammer, administered in three layers at a rate of 25 blows for each layer within the mold. The optimal moisture content (OMC) for each soil sample was obtained by plotting the maximum dry density (MDD) values against the corresponding moisture content values.

Electrical properties

Dielectric constant and loss

The dielectric constant and dielectric loss (ε") of all the soil samples were determined in accordance with ASTM D150 (2018) approved guidelines, by using the microwave frequency of 7.0 GHz as described by Syeda *et al.* (2020), under laboratory temperature of 30±5°C, During the testing procedure, the microwave signal is directed to the soil sample and the soil's electrical properties were measured accordingly. The dielectric constant (ε′) of each soil sample was calculated through Equations 2.

$$\text{Dielectric constant} = \frac{C_a}{C_v} \tag{2}$$

Where: C_a : Soil sample capacitance, C_v : Free air capacitance.

Data analysis

The one-way analysis of variance (ANOVA) was used to analysis the influence of the RHA on the soil electrical properties.

RESULTS AND DISCUSSION

Physical properties

Soil particle size distribution

The results obtained from the particle size grading (sieve analysis) of the soil used as control, are presented in Figure 1. Figure 1 revealed that the soil had fine content of 21.2%, Coefficient of Uniformity (Cu) of 4.40 and Coefficient of Curvature (Cc) of 0.909. Soil particle sizes and their distribution pattern are fundamental soil attributes that affect its soil moisture content and electrical properties (Hu *et al.*, 2011; Uguru *et al.*, 2022). Fine grained soils tend to have lower density and compaction degree, but higher dielectric properties when compared to their coarse particle size counterpart soils (Chen *et al.*, 2018). The higher dielectric properties of fine-grained soils could be linked to their higher potential to retain more water, and this property can have implications for various applications. The higher dielectric constant of fine-grained soils, indicative of higher water content, can influence the propagation of electromagnetic waves and affect the interpretation of subsurface features (Owenier *et al.*, 2017).

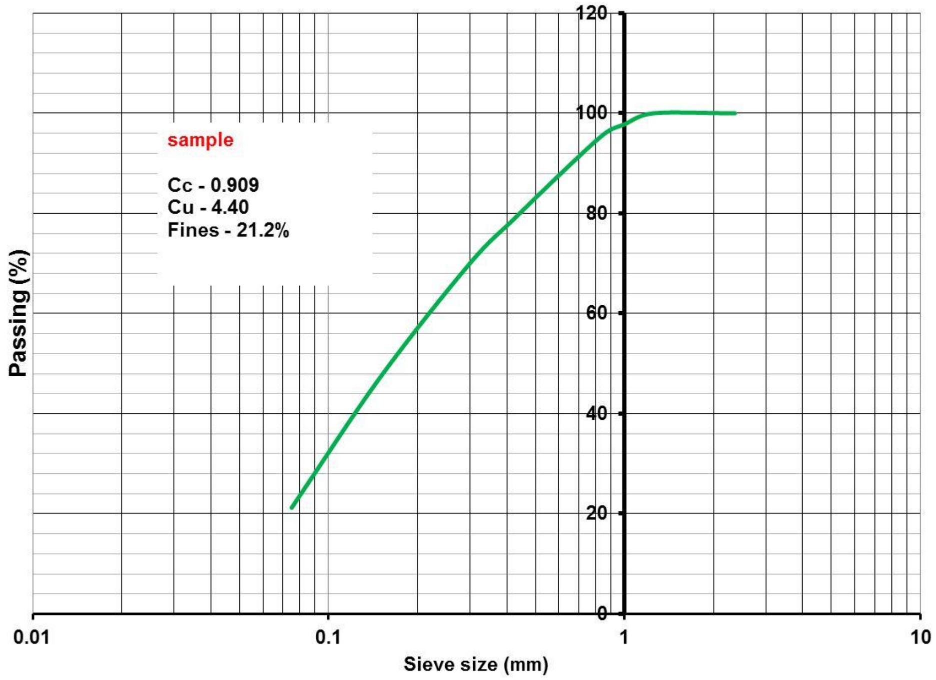

Figure 1. *A plot of the natural/virgin soil sieve analysis.*

Proctor compaction

The mean results of the stabilized soil samples MDD and OMC parameters are presented in Table 2. It was reliably observed from the findings that, when the RHA volume increased from 0 to 10%, their respective MDD value decreased from 1.61 to 1.42 g/cm^3, and their OMC values increased from 14.8 to 17.1% respectively. This is an indication that RHA relatively decreased the density of all treated soil samples (Treatments 1 to 5), and consequently increased the available water content of the same soil. Similar results were obtained by Ewa *et al.* (2018) when a lateritic soil OMC increased from 18.3-21.63%, as the RHA increased from 0 to 20%. Pushpakumara and Mendis (2022) during their experimental studies into the suitability of green materials in stabilizing poor quality soils reported that, the addition of RHA to different soil samples relatively increased their OMC values. The increment observed in a soil sample OMC after stabilization can be linked to the high absorption rate of RHA; hence increasing the soil water holding capacity. RHA being a pozzolanic material has the capacity to increase the binding properties of the soil; hence resulting in an improved water retaining capability of the soil (Okafor and Okonkwo, 2009).

The difference in the OMC and MDD values obtained from this research when compared to other authors findings can be related to the chemical compositions of the different soil samples and RHA used for the experiment. According to Rajeev *et al.* (2022), pre-harvest and post-harvest management of crops significantly affects their engineering properties and chemical compositions. The higher OMC values of the stabilized fine-grained soil are attributed to their ability to retain more water, and this property can have implications for various civil and electrical engineering applications. The soil moisture content significantly affects its resistivity and dielectric properties. Higher optimal moisture content can lead to higher soil moisture content, potentially influencing the resistivity and dielectric constant of the soil. These attributes have serious implications in the design, development and performance of electrical earthing systems, which are critical for the safety and reliability of electrical installations (Uguru and Obukoeroro, 2020).

Table 2. *The MDD and OMC results of the various soil samples.*

	MDD (g/cm^3)*	OMC (%)*
Control	1.61±0.09	14.8±0.13
Treatment 1	1.57±0.02	15.3±0.29
Treatment 2	1.54±0.04	15.9±0.55
Treatment 3	1.49±0.03	16.2±0.21
Treatment 4	1.45±0.04	16.7±0.42
Treatment 5	1.42±0.06	17.1±0.44

* n= 3; ± Standard deviation

Electrical properties

The results of the one-value ANOVA presented in Table 3 revealed that RHA had significant effect on the dielectric constant and dielectric loss of the soil samples ($P \leq 0.05$). This is an indication that the RHA can significantly altered the electrical behaviors of the soil samples.

Table 3. *The ANOVA results of the impact of RHA of soil samples.*

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	48.084	2	24.0422	5.0104	0.0215*	3.682
Within Groups	71.976	15	4.798			
Total	120.060	17				

* = Significant at 95% confidence level

Dielectric constant

The results of the influence of the stabilizing therapies on the soil samples dielectric constant behavior are presented in Figure 2. Figure 2 obviously revealed that the soil ε' values increased non-linearly as the quantity of the soil stabilizing materials increased evenly from 2 to 10%. The ε' values for the soil samples amended with 0, 2, 4, 6, 8 and 10% RHA were 3.41, 3.95, 4.18, 4.33, 4.72 and 5.13, respectively. The findings clearly given by this study are signal that the correlation between the volume of RHA used in stabilizing the soil, and the dielectric constant is not a simple linear correlation. The rapid increment of dielectric constant levels in the soil containing with higher percentages of RHA depicted that, changes in the electrical characteristics of the soil can be duly linked to the addition of this material (RHA) to the soil. These observations are similar to previous reports of Chaudhari (2015), which stated that organic materials have a strong potential to improve (increase) the dielectric constant of poor soil samples. Similarly, Muhammad *et al.* (2022) stated that the incorporation of decaying agricultural materials into the soil considerably enhances most of its electrical properties, as reflected in the dielectric constant values. The increase in dielectric constant is an important indicator of changes in the soil electrical characteristics. Remarkably, higher dielectric constants have considerable impact on the soil water retention, nutrient availability, and other factors relevant to plant growth (Zhang *et al.*, 2021).

Additionally, the outcomes of the experimental revealed that soil OMC values increases as the ash content incorporated into the soil increase from 0 to 10%. This increase in moisture content corresponded to an elevation in the dielectric constant value of the soil.

Alteration in the soil moisture level and organic matter content can lead to indicative of variations in the soil dielectric constant values (Park *et al.*, 2019).

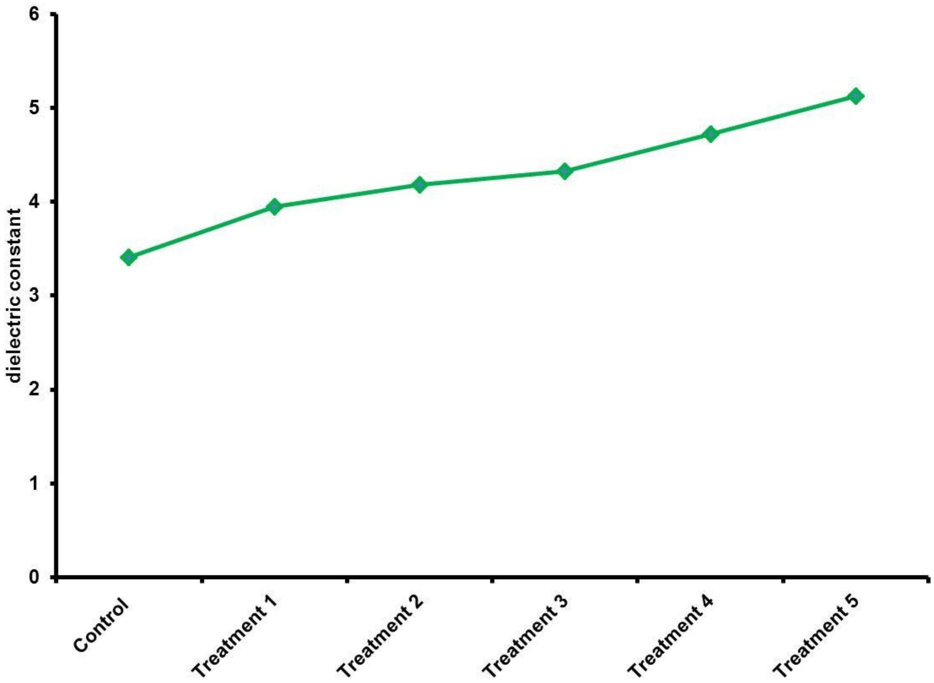

Figure 2. *The dielectric constant of the soil samples.*

Dielectric Loss

Figure 3 shows the plot of the Dielectric Loss values of the stabilized soil samples for engineering applications. The ε″ values for the control, Treatment 1, Treatment 2, Treatment 3, Treatment 4 and Treatment 5 soil samples were 0.91, 1.12, 1.25, 1.31, 1.36 and 1.44, respectively. This portrayed that the stabilizing agent (RHA) enhanced (increased) the **ε"** levels in the soil specimens, and the ε″ increment was in direct proportion to the quantity of the RHA added to the soil. It can be observed from the findings that the reaction (effect of the RHA on the soil properties) was a dose-dependent relationship; because, when the amount of RHA incorporated into the soil increases, the dielectric loss factor values also increase proportionally in a non-linearly pattern. These findings (results) are comparable to those previously obtained by Navar khele *et al.* (2009), where they noted that the dielectric loss of soil increased with increasing organic materials in the soil increase despite the experimental microwave frequencies.

According to Chaudhari (2015), organic manure tends to have higher dielectric loss property when compared to inorganic materials; hence these materials (organic matter) have a higher potential of increasing the overall dielectric loss characteristic of the soil. Soil dielectric properties are highly dependent on the soil organic materials, water content and mineralogy level (Szypłowska *et al.*, 2021). Dielectric loss is more pronounced in the presence of moist environment; therefore organic materials with higher water retention ability tend to increase the dielectric loss in the soil (Kumar *et al.*, 2022).

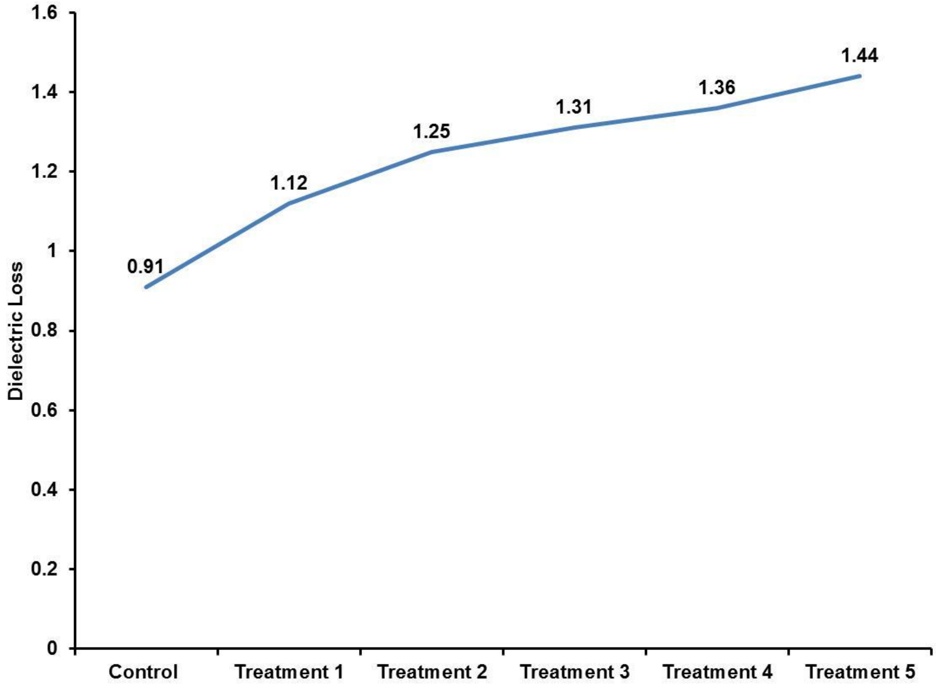

Figure 3. *The dielectric loss vales.*

CONCLUSION

The effect of rice husk ash on the dielectric properties of soil samples was duly investigated in this study. The soil was stabilized with RHA at the rate of 2, 4, 6, 8 and 10% (by the weight of the soil) and their (the stabilized soil samples) maximum dry density, optimal moisture content, dielectric constant and dielectric loss were determined in accordance with ASTM International approved guidelines. Findings obtained from this study revealed that the dielectric properties (ε′ and ε″) of the soil increased unevenly as the quantity of the RHA incorporated into the soil increased from 0 to 10%. Similarly, the results portrayed that the OMC values increased non-uniformly as the RHA content in the soil increases uniformly, while the MDD values declined as the RHA volume into the soil increase. Outcomes of this research revealed that 10% RHA yield the optimal results. The information obtained from this research has serious valuable insights in the field of electrical engineering, especially in the context of sustainable soil improvement for electrical engineering practices.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.

Ogaga Akpomedaye: Designed the research Methodology and writing of the original draft.
Friday Elohor Odoh: Data analysis and review of the original draft.
Helen Juwah: Designed the research and writing the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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