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Synthesis and Application of Rice Husk-Based Nanosilica in Lateritic Soil Improvement

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Abstract: *The study evaluated the effect of nanosilica extracted from rice husk ash using the acid wash method on some geotechnical propertities of lateritic soil treated with 0, 0.5, 1, 1.5 and 2 % by weight of nano silica content and compacted using the West African standard compactive effort. Samples were subjected to index, compaction, unconfined compressive strength and permeability tests. Tests results the showed that addition of nanosilica to lateritic soil increases liquid limit and plastic limit values but decreases the plasticity index values. Lateritic soil treated with nanosilica reduces the maximum dry density, MDD but increased the optimum moisture content, OMC.The unconfined compressive strength of the treated lateritic soil increased from 528 kN/m^2 for the natural soil to peak value of 1135 kN/m^2 at 1.5 % nanosilica content after 28 days of curing period. The coefficient of permeability decreased with increasing nanosilica content.Although, tests results showed noticeable improvement in engineering properties of the treated soil, the lateritic soil treated with extracted nanosilica can not satisfy the Nigerian General Specifications (1997) requirement of 1720 kN/m^2 for use as road base course for lightly trafficked roads. It is therefore recommended that the extracted nanosilica can not be used as a stand alone additive, it should be used with a potent soil stabilizing agent like cement or lime.*

Keywords*:* Laterite soil, nanosilica, rice husk, soil improvement.

INTRODUCTION

The continuous advancement in technology as well as the conscious effort for clean environment has necessitated the sense of beneficial reuse of materials hitherto considered as waste. Over the years, the accumulation of waste materials has been attributed mostly to agricultural, domestic and industrial undertakings. Improper handling and unsafe disposal

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practices of these waste materials often poses health concerns and threathen the fauna and flora ecosystem.

The production of rice for subsistence and commercial purposes is a common agricultural practice adopted by most household and multinational companies across virtually all the states in Nigeria for many years. The cultivation of this agricultural product has even increased due to a deliberate government policy of the immediate past administration that effectively placed a ban on the importation of rice and other staple food products into the country to boost local production to stimulate economic diversification of Nigeria away from the crude oil. The production of this crop peaked at 3.7 million tonnes in 2017 (Bello *et al*., 2017). Rice processing from the milling factory generates rice husk as by product which is usually considered as wastes products of little or no commercial value. The annual rice husk generated globally is estimated at 10^8 tons (Ronoh*et al*., 2015). The husks constitute an eyesore within the vicinity of most rice processing mills in the country as waste dumps resulting to environmental pollution. The waste material is reportedly rich in silica and consist mainly of hydrated silicon and cellulose organic matter (Riza, 2017; Ojerinde, 2020). Rice husks ash (RHA) has been utilised extensively in the construction industry as pozzolana with some promising research outcomes (Damanhuri*et al*., 2020). The silica content in RHA is in amorphous form which means it can react readily with the CaOH that is liberated during cement hardening process to form cementitious compound (Ronoh*et al*., 2015; Olumodeji*et al*., 2023). Nanoparticles (e.g., nanosilica) have found application in the field of agriculture and engineering including soil improvement.However, the availability of nano materials and the production cost must be carefully considered and evaluated. The production of nanosilica is achieved by smelting of quartz sand at elevated temperature (13000 C). The process therefore requires huge amount of energy to achieve in addition to further purification requirement (Motomura, *et al*., 2006; Shahuru*et al*., 2024). Nanoparticles production using this method results to noise and environmental pollution. Consequently, the production of nanoparticles from organic plants results to high quality,eco-friendly at low cost and lower temperature in comparism to production of same from inorganic (Motomura, *et. al*., 2006; Ghorbani, *et. al*., 2015). Several plants species (Graminae, Cyperaceae, Poaceae and Equisetaceae) are reported to have accumulated silica contents ranging from 5 – 20 % by dry unit weights. The extraction, physiology, distribution and precipitation of silica from plants such as wheat husks, rice husks, sugar beet pulps and bamboo is reported in literature (Sharifnasab and Alamooti, 2017; Shalaby*et al*., 2024). The choice of using rice husk in the current study is due to its abundance in Nigeria.

Lateritic soils are rusty-red or reddish-brown tropics and subtropical soils formed due to weathering of the parent material over an extended time and are rich in oxides and hydroxides of sesquioxides.These soils are common in Nigeria and are used extensively for construction activities.

MATERIALS AND METHODS

Materials

Soil: Representative soil sample used for this research was obtained from a borrow pit (7°35′ N latitude and 8°35′ E longitude) at Ikpayongo in Benue State, Nigeria by disturbed sampling technique. Samples were collected at depths of 0.5 – 2 m .
***Rice husks*:** The rice husks was sourced from rice mill in Gboko, Gboko Local government of Benue state. The rice husk was used to obtained the nanosilica used for the study.
Hydrochloric acid (HCl): This was purchased from a chemical store in Makurdi.

Methods

Index properties test: Index properties such as Atterberg limits, specific gravity, natural moisture content and sieve analysis tests were conducted on the natural and nanosilica treated lateritic soil in line with procedures outlined in BS 1377 (1990) and BS 1924 (1990) for natural and treated soils respectively.

Compaction: Soil samples passing through sieve number 4 (4.75 mm aperture) were treated with 0, 0.5, 1, 1.5 and 2 % by weight of nano silica content and compacted using the West African standard compactive effort, because it is the commonly adopted energy level in the region and recommended by the Nigerian specification code.

Unconfined compressive strength: The compacted soil samples were extruded and trimmed to height to diameter ratio of 2:1 before being wax-cured for a period of seven, fourteen and twenty-eight days. After curing, the unconfined compression strength test was performed on the extruded soil samples until failure on a machine operating at controlled rate of 0.02 %/min. strain (Head, 1994). At least three specimens of each mixture wascarried out and the average value of the tested samples were considered as the unconfined compressive strength (UCS) value.

Permeabilty: The coefficient of permeability of natural and treated soil was determined using falling head permeameter method following procedures described in BS 1377-5: 1990 and Head (1994).

Nanosilica extraction from rice husk: The stabilizer used in this study is nano silica synthesized rice husk ash. The sourced rice husk (see Plate 1a) was subjected to controlled burning to produce rice husk ash. The ash was leached with Hydrochloric acid (HCl) and heated to remove impurities. The leaching process is as shown in Plate 1b. The leached ash was thoroughly rinsed with distilled water and allowed to dry. The dried ash was calcined in a muffle furnace at a temperature of 600 °C to obtained amorphous silica. After calcination, the amorphous silica was ball milled with a rotation of 250 rpm.

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Plate 1: (A) Rice husk (B) Rice husk ash (RHA) treated with HCl acid and heated to remove impurities (C) Nano silica produced after calcination of acid treated RHA (D) Mixing of Nano silica with lateritic soil

RESULTS AND DISCUSSION

Index Properties

The preliminary tests conducted on the natural soil revealed that the soil is classified as A-7-6 according to the American Association of State HighwayTransportation Officials (AASHTO) and the visual inspection of the soil showed that the colour is redish brown. The summary of these properties is shown in Table 1.The particle size distribution curves obtained dry sieve test conducted on the natural lateritic soil is shown in Figure 1

Table 1: Properties of the natural soil

Property	**Quantity**
Percentage passing No. 200 sieve	37.8
Natural moisture content (%)	7.3
Liquid limit (%)	34
Plastic limit (%)	18
Plasticity index (%)	16
Linear shrinkage (%)	7.6
Specific gravity	2.67
AASHTO classification	A-2-6
USCS (kN/m^2)	528
Maximum dry density, MDD (Mg/m^3)	1.88
Optimum moisture content, OMC (%)	10

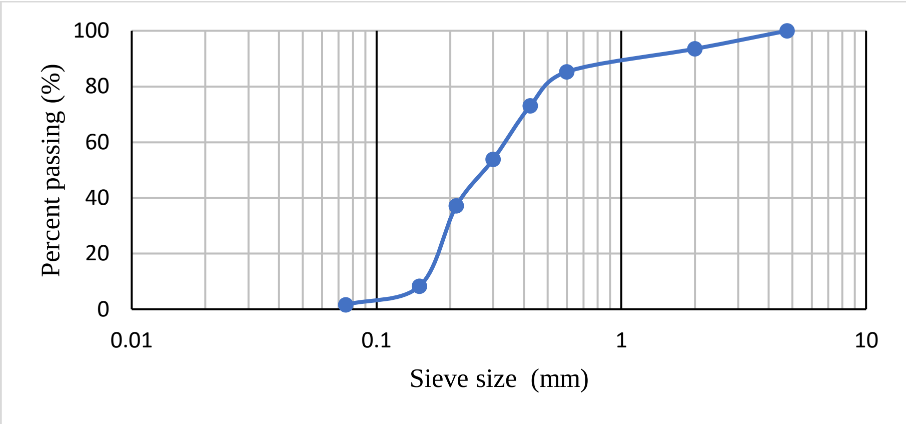

Figure 1: Particle size distribution cureve for the natural soil

Effect of Nanosilicaon Specific Gravity Treated Lateritic Soil

The effect of nanosilica on the specific gravity of soil-nanosilica mixtures is shown in Figure 2. The results obtained show a decrease in the specific gravity values with increasing percentage of the nanosilica content. The value of specific gravity of the soil decreased from 2.67 for the natural soil to the lowest value of 2.57 at 2% nanosilica content. The decrease in the specific gravity of the soil – nanosilica blend could be attributed to the lower specific gravity of nanosilica (nanosilica 2.19) replacing the soil with a higher specific gravity of 2.67.The trend is consistent with those recorded by Kalhor *et al*., 2021 as well as Shalaby*et al*., 2024.

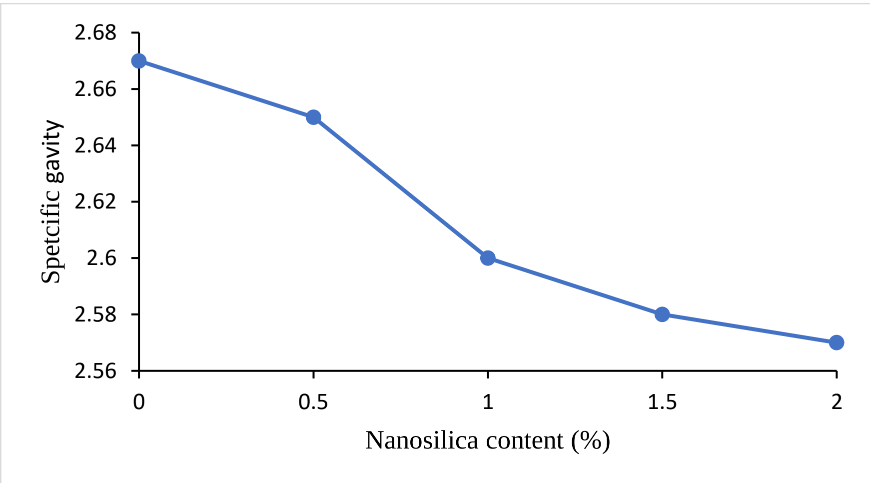

Figure 2: Variation of specific gravity of lateritic soil with nanosilica content.

Effect of Nanosilica on Atterberg Limits of Treated Lateritic Soil

The result showing the varying effect of nanosilica content on the liquid limit (LL), plastic limit (PL)and plasticity index (PI) of the treated lateritic soil is presented in Figure3. The results showed a general increase in the LL and PL values as the naniosilica content increases. The LL and PL increased from 34 and 18 % to peak values of 40 and 30 % at 2 % nanosilica content respectively. However, the observed increment in LLand PL values after treatment resulted in a general decrease in the PI values (Figure 3). The resultant decrease in PI values recorded connotes soil improvement (Azunna*et al*., 2020; Shalaby*et al*., 2024).The increase in LL and PL may be traced to the high specific surface area of nanoparticles owing to its fine nature (Pashabavandpouri and Jahangiri, 2015; Iswarya and Satheeskumar, 2018).

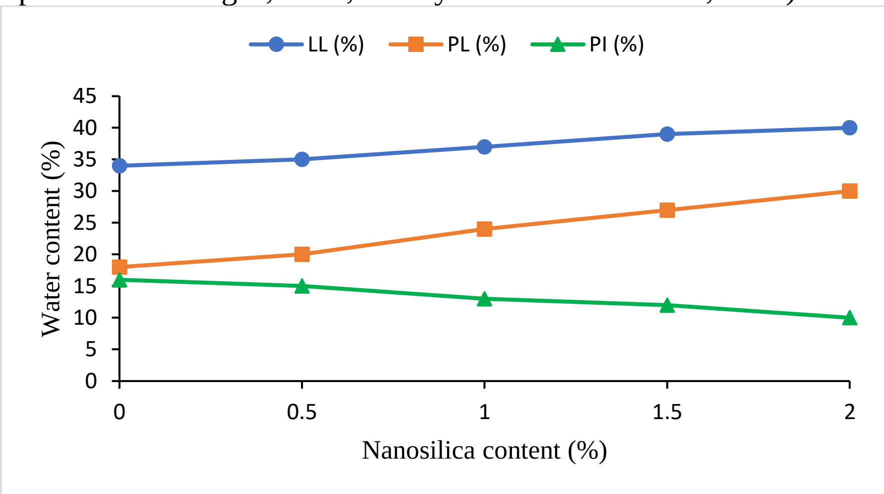

Figure 3: Variation of Atterrberg limits (liquid limit, LL, plastic limit, PL and plasticity index, PI) of treated lateritic soil with nanosilica content

Effect of Nanosilica on Compation Characteristic of Treated Soil

The variation of maximun dry density (MDD) and optimum moisture content (OMC) of lateritic soil – nanosilica blend is shown in Figure4. It was observed that the MDD decreses with increasing nanosilica content.OMC on the other hand, increased with increasing amount of nanosilica in the soil matrix. OMC value of 10 % recorded for the natural soil increased to highest value of 14 % when treated with 2 % nanosilica content (Figure 4). Similarly, the MDD value of 1.88 Mg/m^3 recorded for the natural soil decreased to 1.83, 1.78 and 1.81 Mg/m^3 at 1, 1.5 and 2 % nanosilica contents respectively. The observed increasing trend in OMC after treatment may be due to hydrophilic nature of nanoparticles occasioned by its large specific surface area resulting to high water absorption capacity of the nanosilica treated soil (Kalhor et al., 2019; 2021).The decrease in MDD could be as a result of the light weight of nanosilica replacing heavier soil particle in the compacted soil matrix. The observed trend is consistent with those reported by Iswarya and Satheeskumar, 2018 as well as Nair and Tara, 2020.

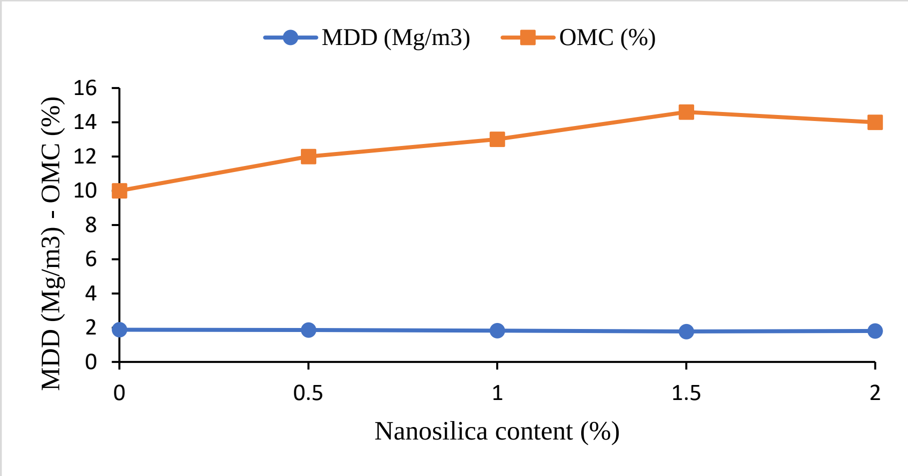

Figure4: Variation of maximum dry density, MDD and optimum moisture content, OMC of lateritic soil – nanosilica mixtures.

Effect of Nanosilica on Unconfined Compressive Strength of Treated Soil

The results of the variation of UCS of lateritic soil – nanosilica mixture is shown in Figure5 for 7,14 and 28 days curing.. Generally, the UCS of soil – nanosilicamixtures increased with higher nanosilica content. Also, the UCS values increased with increase in the curing time (Figure 5).

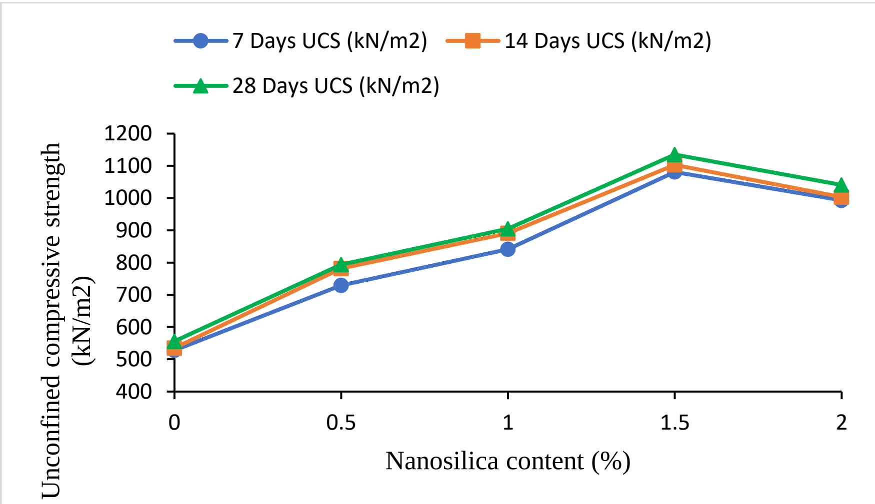

Figure 5: Variation of unconfined comressive strength with varying nanosilica content

The UCS value of 528 kN/m^2 recorded for the natural soil increased to peak values of 1081, 1103 and 1135 kN/m^2 at 1.5 % nanosilica content for 7, 14 and 28 days of curing respectively. The observed increment in the strength values may be due to chemical reaction between the nanosilica and the soil particles leading to enhanced cohesion and the bonding ability of the resultant soil matrix. Also, the filing of voids in the compacted soil by the nanosilica particles may be responsible for the increased strength (Iswarya and Satheeskumar, 2018; Zeiba et al., 2018). It is pertinent to note however, that the peak UCS value 1135 kN/m^2 recorded after 28 days curing period fall short of the 1720 kN/m^2 recommended by the Nigerian General Specifications (1997) for use as road base course for lightly trafficked roads.

Effect of Nanosilica on Coefficient of Permeability of Treated Lateritic Soil

The effect of nanosilica on the coefficient of permeability (k) was investigated and the results shows that the permeability characteristics of the compacted treated lateritic soil decreased with increase innanosilica content. The coefficient of permeability value of 9.84 x 10^{-9} recorded for the natural soil decreased to 9.97 x 10^{-9}, 9.13 x 10^{-9} and 8.54 x 10^{-9} m/s when treated with 1, 1.5 and 2 % nanosilica contents respectively. The reduction in permeability coefficient may be traced to filling of voids within the soil matrix by the nanoparticles thereby preventing the free flow of water molecules within the voids. Furthermore, the enhanced chemical bonding between the nanosilica particles and the soil matrix results to improved molecular bonding of the resulting soil matrix leading to little or no flow pathways with the soil matrix leading to low coefficient of permeaility of the nanosilica treated lateritic soil (Zeiba*et al*., 2018).

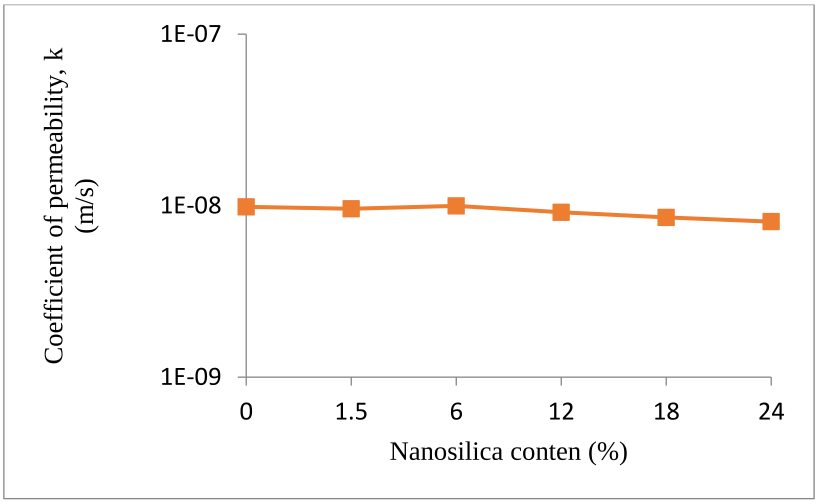

Figure6: Variation of coefficien of permeability with varying nanosilica content

CONCLUSION

The study investigated the effect of nanosilica extracted from rice husk ash on some geotechnical propertities of lateritic soil. On the basis of the tests results the following conclusions were drawn:

1. Blending of nanosilica to lateritic soil increases LL and PL values but decreases the PI values.
2. Lateritic soil treated with nanosilica reduces the maximum dry density, MDD but increased the optimum moisture content, OMC.

3. The unconfined compressive strength of the treated lateritic soil increased from 528 kN/m^2 for the natural soil to peak value of 1135 kN/m^2 at 1.5 % nanosilica content after 28 days of curing period.
4. The coefficient of permeability decreased with increasing nanosilica content.

Although, there is significant improvement in geotechnical properties of the treated soil, the lateritic soil treated with extracted nanosilica can not satisfy the Nigerian General Specifications (1997) requirement of 1720 kN/m^2 for use as road base course for lightly trafficked roads.

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