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(Research Article)

Impact of sodium silicate with normal pH on mechanical strength of rice husk blend geopolymer and its performance at various percentages

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Abstract

The stabilization capability of kaolin clay powder (KCP), Ordinary Portland cement (OPC) and rice husk ash (RHA) was scrutinized using laboratory scrutiny. This was meant at assessing the effect of KCP, OPC and RHA on the stabilization of three lateritic soils for use as sub-base pavement layer materials. Three soils (Soil A, B and C) were improved with various percentages (via weight of dry soil) at 0, 2, 4, 6, 8 and 10% for all stabilizing agents and compacted via BSL (British Standard light) energy. Their impacts were assessed on the strength physiognomies such as UCS (unconfined compressive strength), OMC (optimum moisture content), and California bearing ratio (CBR), and MDD (maximum dry density tests based on ASTM (American Standard Testing Materials) codes. The result reveals that MDD improved with increase in the quantities of all the additive (SSA, KCP and geopolymer) content, while OMC for KCP reduces from 18.65% at 0% to 14.02%. Both SSA and geopolymer increase from 18.65% at 0% to 18.86% and 22.20% at 10%.Similarly, it displays highest CBR of the soil from 10.88% at 0% to 12.84%, 112.95% and 144.45% for (SSA, KCP and geopolymer, this specify that lateritic soil treated with 2% stabilizer yielded CBR values of more than 405%.

Keywords: Road Engineering; Sodium Silicate; Rice Hush Ash; Geopolymer

1. Introduction

Laterite soils as sustainable building materials are described as materials that meet the needs of the present generation without compromising the ability of future generations to meet their own needs adequately [1-3]. Though they are environmentally friendly materials, the high cost of construction projects led to a call for the incorporation of laterite in the past and recent projects [4-6]. Buildings constructed of earth materials are the most common affordable accommodation since earth materials are readily available almost anywhere on the planet [2, 7-8]. It has been found that lateritic soils are generally good construction materials and are therefore commonly used in construction [9-12]. In the tropical part of the world, as Nigeria is, lateritic soils are used as a road making material [13-15], and they constitute the sub-grade of most tropical roads, they are used as sub base and bases for low cost roads and these carry low to medium traffic [16,17]. The word 'laterites' describes no material with reasonably constant properties [18]; it can denote a different material to people living in different parts of the world [19]. In geotechnical works, a site is surveyed whether soil conditions meet the design criteria. However, most commonly, sites designated for earthworks do not reach the minimum standards [20,21], such as those with soft, highly compressible, or expansive soils lacking the desired strength for loading during construction or for their serviceability [22-24]. For this reason, such soils are enhanced through soil stabilization, wherein the mechanical properties of the soil are improved by applying materials

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that have cementitious properties or are considered to be binder materials [25-28]. But the speedy rate of industrialization and urbanization requires more quantity of cement for infrastructure construction works [29-32]. The manufacturing of cement, quite it's most vital material for concrete, cement signifies a sustainability subject that should be dealt with; which in turn known to be a substantial contributor towards the greenhouse gas emissions (GHGE) signifying about 5% of global CO_2 discharge [33-36]. The cement company needs intense energy, third (3rd) largest consumer of energy after the power as well as steel sector [37]. Roughly normal utilization of 60e75 kW h of both electrical and thermal energy is needed for generating one ton of cement [38-40]. Thus, using the readily available proximate raw materials, that release just 1 t of carbon-dioxide of energy into the climatic condition save energy beside create green environment [38, 41]. Similarly, usage of lot of locally available materials having similar chemical composition or component to cement can be used as substitute cementitious material (SCM) for instances red mud (RM)[42], slag [15], rice husk ash (RHA) [16,17], fly ash (FA)[18], metakolin for the fabrication of concrete will avert the landfill and environmental concerns [19-23].

2. Material and methods

Soil sample used in this paper was collected from three different lateritic soil borrow pit along Abuja – lokoja road in the Federal capital territory of Nigeria. It was collected at a depth below than 150mm using the disturbed sampling approach and afterward air-dried. The both cement and sodium silicate activator was purchased from the local market while rice husk was collected from a rice mill located at kwali, FCT Nigeria [24-26]. Rice husk fibre was incinerated into ash in a furnace with temperature of up to 500^{0}C for more than six (6) hours after which it was allowed to cool and absolutely grounded. Then it was sieved via 75mm sieve as prescribe BS 12 [27]. Similarly, Preliminary tests on the collected three lateritic soil sampling were done in the laboratory of the Department of Civil Engineering, Federal University of Technology, Akure, and Ondo State, Nigeria.

3. Results and discussion

3.1 Preliminary Tests results

Results of preliminary tests on the lateritic soil are shown in Table 1. It shows that the soil is classified as A-7-6 according to AASHTO classification system. This implies that it falls below the recommended standard for use for construction work and would therefore require improvement.

3.2 Effect of pH on geopolymer materials

Sodium silicate was mixed with the soil at 1%, 3%, 5%, 7% and 9% by dry weight of the soil according to 1 to 4% mixing ratio by dry weight of the soil given in Fig. 1. The minimum mixing ratio was limited to 1% based on the findings of Roychand [2] that smaller ratios do not bring improvement in the engineering properties of the soil. Similarly, the weight ratio of sodium silicate ranges from 1.6 to 3.2 which is inversely related to pH value as it has been presented in Fig. 3. The pH range of sodium silicate which should be between 11 and 13 also imply "low" or "high" alkalinity of a silicate solution is a relative term.

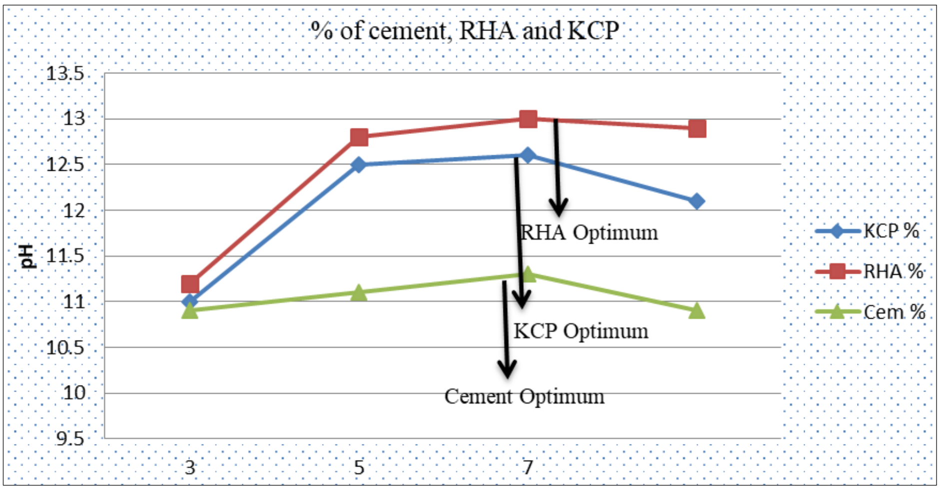


Figure 1 pH test

The weight ratio of the liquid sodium silicate used in this study is 2.2 and the pH is measured to be 12.2 which comply with the theoretical range. Fig 2 shows this relation with respect to the results obtained. This value also shows the sodium silicate used for the study slightly deviates from the neutral range and it can be considered slightly alkaline. According to Fig 3, medium to slightly lower dried strength and medium to slightly higher solubility and drying time are expected.

Table 1 Properties of three lateritic soils

Properties	**Soil samples (control)**		
	KA	**SA**	**DA**
Natural Moisture Content	6.5	7.5	5.4
Specific Gravity	2.5	2.6	2.2
Grain Size Distribution			
Coarse (%)	90.88	93.42	91.87
Fine (%)	09.12	06.58	08.13
Bulk density (KN/m^3)	14.64 – 29.76	12.23 – 22.36	14.63 – 22.76
Consistency Limit (%)			
Liquid Limit	40.45	41.25	37.00
Plastic Limit	17.09	24.59	12.00
Plasticity Index	23.36	16.66	25.00
Compaction Test			
Maximum Dry Density (KN/m^2)	18.65	17.80	15.19
Optimum Moisture Content (%)	9.15	9.89	9.67
California Bearing Ratio (%)	9.88	8.46	7.42
Unconfined compressive strength(N/mm^2)	107.45	105.54	106.95
Triaxial test			
Cohesion (KN/m2)	19	18	19
Angle of internal friction Θ^0	23	22	23
Soil Classification	A-2-7	A-2-7	A-2-4
Colour	Reddish brown		Brown
Soil Type	Silty or clayey gravel and sand		

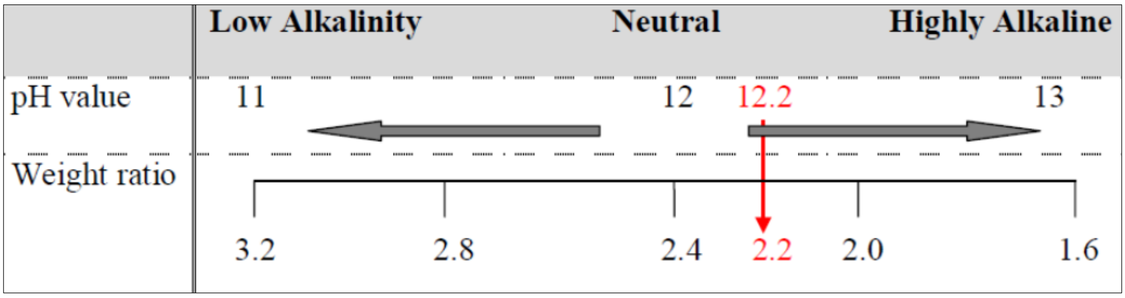


Figure 2 pH and weight ratio of sodium silicate used

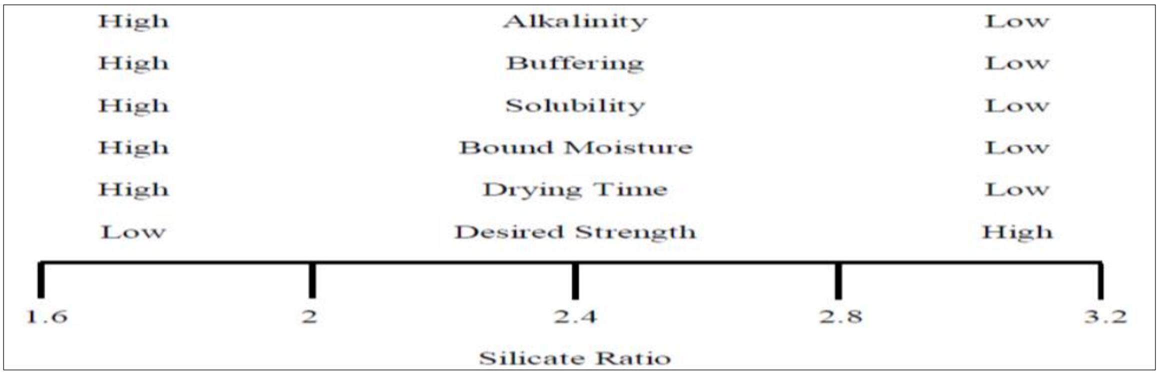


Figure 3 Properties of silicates as a function ratio

3.3 Effect of cement

From Fig. 1 cement is 7% by dry weight of the soil and rice husk ash is 8% by dry weight of the soil. The minimum amount of cement added to the second sample was determined according to AASHTO cement requirement for soil groups given in table 2. Since the soil is classified as A-2-7, the minimum quantity of cement that is required to stabilize the soil is 7% by dry weight of the soil. Similarly the quantity of cement added to lateritic soil sample was taken at 7%, 5% and 3% by dry weight of the soil.

Table 2 Cement requirement for AASHTO soil Groups

AASHTO Soil Group	**Usual Range in Cement Requirement in percent by**		**Typical Cement Content Percent by Weight**
Volume		**Weight**	
A-1-a	5-7	3-5	5
A-1-b	7-9	5-8	6
A-2	7-10	5-9	7
A-3	8-12	7-11	9
A-4	8-12	7-12	10
A-5	8-12	8-13	10
A-6	10-14	9-15	12
A-7	10-14	10-16	13

3.4 Effect on the compressive strength (CBR)

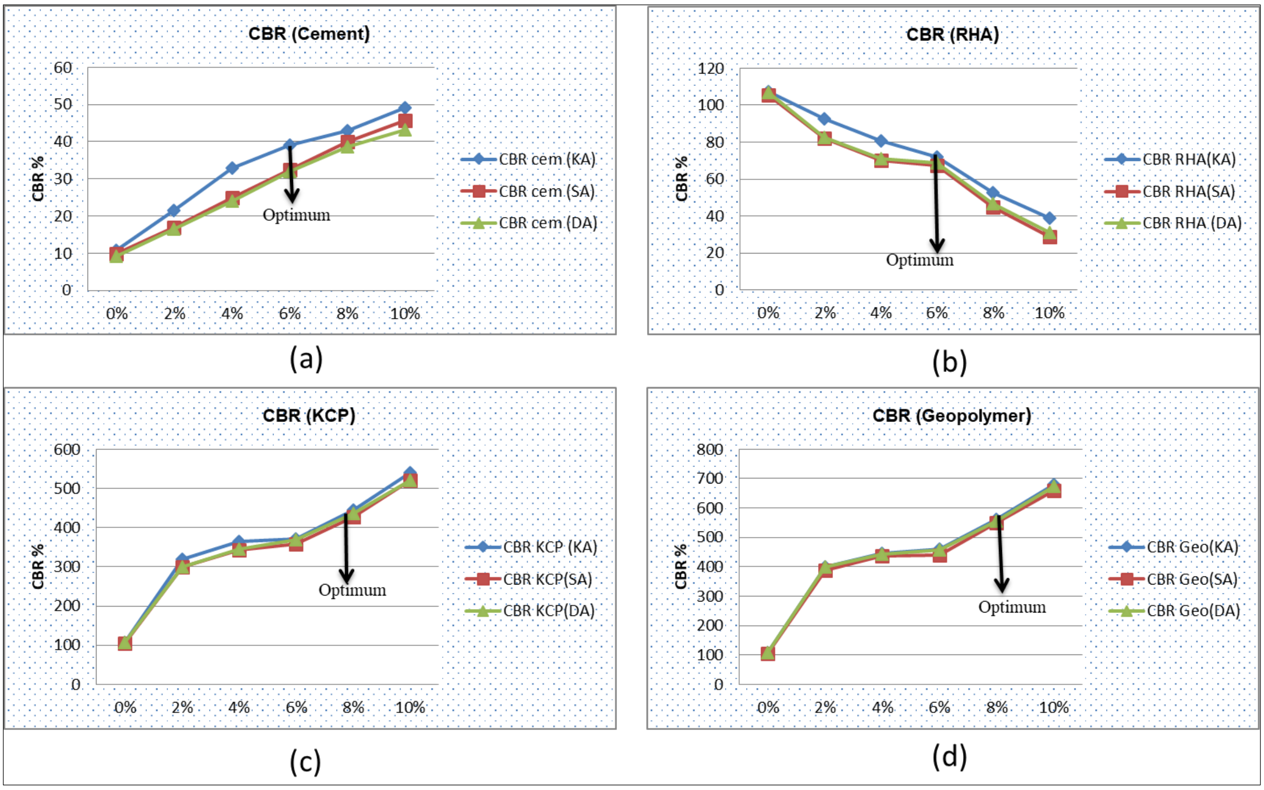
Figs. 4 (a-d) and Table 3, demonstrates the effect of the addition of cement, RHA, KCP and geopolymer mixtures on the CBR characteristics of the soils tested. Results show there is significant improvement in strength of soil as a result of cement addition. Lateritic soil treated with 2% stabilizer yielded CBR values of more than 405%. This value increases with the percentage of additive added to the soil. For soil treated with 6% sodium silicate, however, the CBR values increased at least by 14% compared to untreated soil which is in agreement with research work by Upshaw and Cai [1], Xu et al. [4] and Wattez et al. [7]. These results largely deviate for what is obtained 2.5% of sodium silicate by dry weight of the soil.

Table 3 CBR for cement, RHA, Kaolin, sodium silicate and geopolymer mix

%	**Cement (%)**			**RHA (%)**			**Kaolin (%)**			**Sodium silicate (%)**			**Geopolymer mix (%)**		
	Ka	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***
0	10.88	9.85	9.25	10.88	9.85	9.25	10.88	9.85	9.25	10.88	9.85	9.25	10.88	9.85	9.25
2	21.45	16.98	16.45	60.45	65.45	63.89	69.75	20.25	19.98	11.65	10.05	10.00	82.45	81.80	75.25
4	32.96	24.97	23.95	70.56	74.45	72.54	75.85	45.65	39.95	11.96	10.56	10.25	91.45	89.85	87.45
6	39.09	32.56	31.95	82.60	87.45	85.64	89.50	59.25	53.45	12.09	10.86	10.29	102.45	101.25	100.05
8	42.95	40.05	38.65	90.05	93.50	91.45	100.95	78.52	76.05	12.65	11.35	10.54	125.75	120.75	115.75
10	49.05	45.75	43.25	98.65	100.25	98.90	112.95	110.25	109.85	12.84	11.75	10.75	144.45	142.75	138.75

Table 4 UCS for cement, RHA, Kaolin, sodium silicate and geopolymer mix

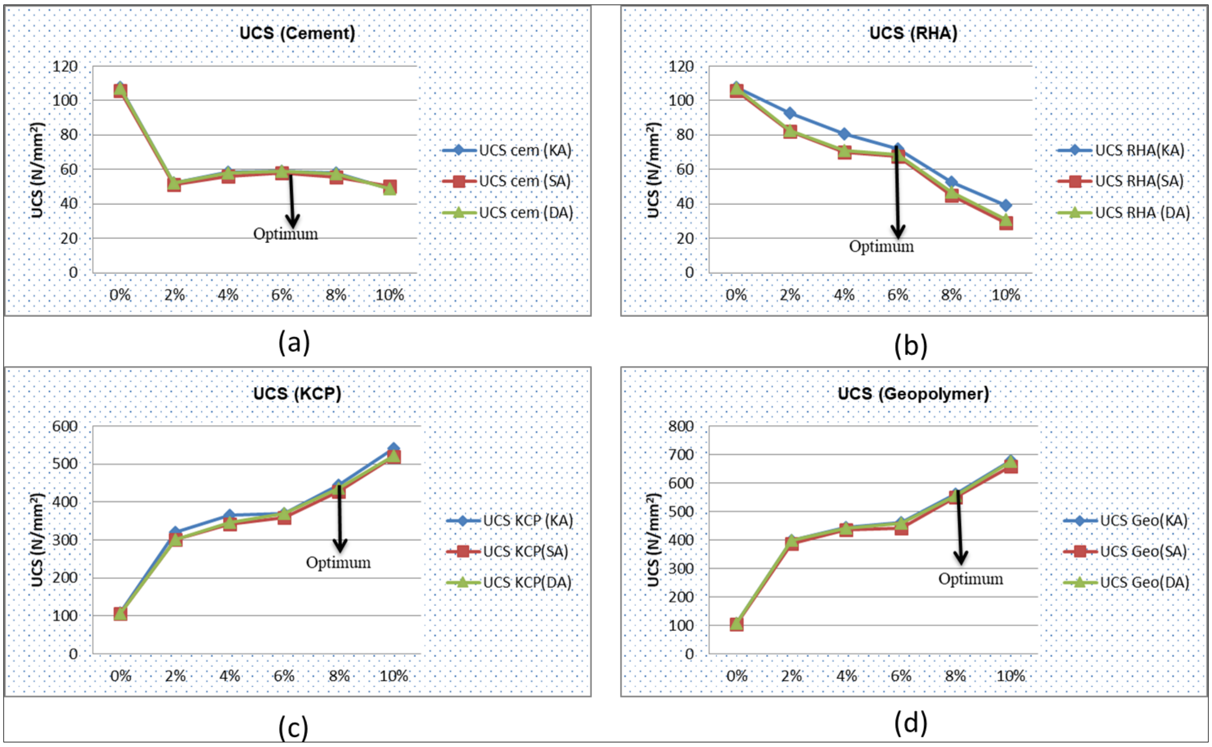
%	**Cement (N/mm^2)**			**RHA (N/mm^2)**			**Kaolin (N/mm^2)**			**Sodium silicate (N/mm^2)**			**Geopolymer mix (N/mm^2)**		
	Ka	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***	***Ka***	***Sa***	***Da***
0	107.45	105.54	106.95	107.45	105.54	106.95	107.45	105.54	106.95	107.45	105.54	106.95	107.45	105.54	106.95
2	52.34	51.34	52.00	92.48	81.92	82.48	320.26	300.12	300.46	62.34	61.34	62.30	399.54	387.44	398.42
4	58.65	56.05	57.85	80.65	69.95	70.85	365.65	342.25	345.45	65.55	64.05	64.50	445.20	435.80	442.40
6	59.05	58.05	58.85	71.95	67.52	68.75	370.45	359.25	369.35	70.05	69.05	70.05	460.32	440.42	458.72
8	57.80	55.60	57.30	52.84	45.05	46.84	445.35	426.95	435.35	75.60	73.60	74.50	560.98	550.78	556.75
10	49.05	50.25	48.65	39.05	28.85	30.95	540.05	519.65	520.75	84.05	82.05	83.25	678.35	658.45	675.35



Figures 4 (a-d) Effect of cement, RHA, KCP and Geopolymer on CBR test

3.5 Effect on Unconfined compressive strength

Figs. 5 (a-d) and Table 4, reveals the impact of the addition of cement, RHA, KCP and geopolymer mixtures on the UCS characteristics of the soils tested.



Figures 5 (a-d) Effect of cement, RHA, KCP and Geopolymer on UCS test

Unconfined compressive strength (UCS) is the most common and adaptable method for evaluating the strength of stabilized soil. UCS is the main test recommended for the determination of the required amount of additive to be used in the stabilization of soils (Wen et al., 2019). The Unconfined compressive strength test results showed that the unconfined compressive strength for natural soil is 107.45 N/mm^2 and the highest UCS value for the stabilized soil was 59.05 N/mm^2 at 6% stabilization using cement, 92.48 N/mm^2 at 2% stabilization using RHA, 540.05 N/mm^2 and 678.35 N/mm^2 at 10% for KCP and Geopolymer mix correspondently. There is 40.2% reduction in the UCS tests obtained for the natural soil sampling, while the lowest UCS occurred at 12.5% stabilization using RHA which is 28.85%. The UCS values decrease with -subsequent addition of RHA, whereas both KCP additive and geopolymer mixture increase rapidly. This rapid decrease in the UCS values after the addition of 4 and 6 % RHA may be due to the excess RHA added to the soil and thus forming weak bonds between the soil and the cementitious layers of soil produced.

Meanwhile Figs. 6a and b shows author visit to study location for collection of materials, Fig. 6c signifies lateritic soils in the Federal university of Technology Akure soil laboratory and Fig 6d shows laboratory test in progress.

Figure 6 (a-d) Field visit, material collection and laboratory test

4. Conclusion

The investigations on KCP-SSA stabilized soils revealed that the lateritic soils were A-7-6 soil and the addition of KCP and silicateat 6% contents above, the OMC is increased abruptly. Likewise, the introduction of KCP needs a lesser amount of SSA to obtain improved strength as compared to cement-stabilized soils. At the extreme CBR, as much as 60% isfound at blend of 6% KCP and 4% SSA. Thus, KCP, OPC, RHA and sodium silicate activator are confirmed to be a goodadmixture in lateritic soil stabilization using 6%as their control.

Compliance with ethical standards

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Disclosure of conflict of interest

Authors have declared that no competing interests exist.

Authors' contributions

BDA, OOA, LOA AND ECI participated in designing the study, LOA AND TEU performed the data collection, BDA statistical analysis, and was the lead author of the paper, AOA, OSA participated in data analysis, and BDA, LOA, ECI revised subsequent drafts of the paper. All the authors read and approved the final manuscript

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