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Geo-Mechanical Enhancement of a Grained Soil Blended with Silicate-Portland Cement Powder for Usage in Construction Industry

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The mechanical, as well as geopolymer strength of a lateritic soil from three (3) different localities on the Lokoja- Abuja highway where road failure happen, was blended with rice husk ash (RSA), cement, and sodium silicate activator (SSA), with varying proportions examined via triaxial shear, Atterberg, and Compaction scrutinizes. The outcome displays that cement enhancement enriched the lateritic soil from Liquid limit values of 41.26 at 0% to 44.37 at 8%, but lessens at 10% to 35.68, whereas RHA (Rice husk ash) rises at increased percentages. Likewise, MDD enhanced with increased quantities of all the enhancers i.e SSA, cement as well as RHA contents, but OMC for both cement and RHA lessen from 18.66% at 0% to 11.72 and 18.06 correspondently. Further scrutiny reveals cohesion of the soil at 0%, 2%, 4%, 6%, 8% as well as 10% to be 19.01, 39.02, 49.01, 55.03, 58.01, and 65.02 KN/m^2 respectively, with peak angle of 65^{0}and minimum of 37^0. This indicates that the cohesion of the enhanced samplings was satisfied since the improved angle of internal friction is beyond the angle that makes the soil very plastic which is 28^0.

Keywords: Geopolymer; road engineering; sodium silicate; rice waste; shear.

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1. INTRODUCTION

In recent times, the usage of soil in construction road works has become a major crisis for civil engineers [1], specifically geotechnical engineers because most of the soils available do not meet some geotechnical engineering properties, on the other hand [2-3], the need for soil enhancement by either stabilization or modification might be needed for obtaining the required results of the properties [4-6]. Lateritic soils are the most common category of soil encountered during any road construction works in Nigeria, and most have a low bearing capacity and strength [7-9], due to high quantities of clay in its natural state [10-13]. Lateritic soil having a high quantity of clay mineral will possess weak strength under load, particularly when it comes in contact with moisture [14-17]. Similarly, lateritic soil with a high quantity of plastic clay instigates cracks, as well as damage to civil engineering, works as example building foundations, road pavement, or any correlated civil engineering project works [18-21].

Soil stabilization or enhancement can be categorized into two sets, precisely mechanical and chemical stabilization [22, 23]. Mechanical stabilization or improvement process signifies the changes in the physical properties [24] or parameters of the soil particles with the help of either revitalizing vibrations [25], compaction, or both [26], whereas chemical stabilization is a technique utilized for chemical modification between admixture or cementitious material and the pozzolanic materials (soil minerals) for achieving the best result from improving the principal geotechnical properties of the soil [27-31]. The key problem connected with chemical stabilization, especially cement enhancement or stabilization a major chemical stabilization widely accepted [32], consists of the following; the high price of cement production that triggers the high cost of stabilized road construction work [33-35], and high discharge of CO_2 during the manufacturing process which in turn responsible for global warming [36-38].

In the technologically advanced nations, the universal and cost-effective materials that are frequently used to partly substitute cement without economic significance are classified into industrial waste as well as agricultural-waste (agro-waste) materials [37-40], for instance, bagasse ash, wood ash, groundnut shell ash, iron ore tilling, sawdust ash, bone ash, rice hush ash, and coconut shell ash [41-44].

A literature review publicized that projected quantities of kaolin mineral deposit reserve in Nigeria is roughly 2 billion metric tons [45, 46]. Similarly, metakaolin is the remnant from the burning of kaolin (dehydroxylated kind of kaolin), normally via heating to roughly a temperature of 750^0C [47-49]. In view of the fact that kaolin mineral does not have carbonates, thus no amount of CO_2 is discharged during burning or calcination, as such will minimalize the detrimental impact of CO_2 released during manufacturing of industrially synthetic soil enhancement agent [50-52].

Table 1. Basic and Mechanical strength features of the selected lateritic soil prior to enhancement

Properties	Soil Samples (Control)		
	KA	**SA**	**DA**
Moisture Content (MC)	6.51	7.50	5.42
Specific Gravity (SG)	2.52	2.62	2.21
Grain Size Distribution			
Coarse-grain (%)	90.88	93.42	91.87
Fine-grain (%)	09.12	06.58	08.13
Bulk density (KN/m^3)	14.64 –29.76	12.23 – 22.36	14.63 – 22.76
Atterberg Scrutiny (%)			
LL	40.45	41.25	37.00
PL	17.09	24.59	12.00
PI	23.36	16.66	25.00
Compaction Investigation			
Maximum Dry Density (KN/m^2)	18.65	17.80	15.19
Optimum Moisture Content (%)	9.15	9.89	9.67
CBR (%)	9.88	8.46	7.42
Unconfined compressive strength (N/mm^2)	107.45	105.54	106.95

Properties	Soil Samples (Control)		
	KA	SA	DA
Triaxial Scrutiny			
Cohesion (KN/m2)	19	18	19
Angle of internal friction $Ө^0$	23.1	22.2	23.1
Soil Categorization	A-2-7	A-2-7	A-2-4
Colour	Reddish brown		Brown
Soil class	Silty- clayey gravel and sand		

2. MATERIALS AND TECHNIQUES

Soil samples utilized in this investigation were collected from three different borrow pits along Lokoja- Abuja express road Federal capital territory (FCT), Nigeria. It was taken at a depth that is below 150mm using the disturbed sampling technique and then air-dried. Portland cement powder (PCP) and sodium silicate activator (SSA) were bought from the local shops while rice husk was collected from a rice mill situated within Kwali town, FCT Nigeria [53, 54]. Rice husk/shell fiber was incinerated into ash in a furnace @ 500^{0}C temperature for over six (6) hours, followed by cooling activities before absolutely grounded. Subsequently, it was sieved thru a 75mm sieve as prescribed in BS 12 [50]. In the same way, Preliminary scrutiny on the collected three lateritic soil sampling was performed in the Civil Engineering Department laboratory, Federal University of Technology, Akure, Ondo State, Nigeria.

3. RESULTS AND DISCUSSION

3.1 Preliminary Tests results

Outcomes of preliminary investigations on the lateritic soil are demonstrated in Table 1. The outcomes display that the soil is categorized as A-7-6 based on the AASHTO classification system. This implies that it falls below the recommended standard for use for construction work and would therefore require improvement.

3.2 Atterberg limit

Results of Atterberg scrutiny for geopolymer blended Rice Husk Ash (RHA) and sodium silicate activator (SSA) are presented in Tables 2-4, and Figs. 1-3.

The outcome exhibits that cement enhancer improved the lateritic soil from Liquid limit (LL) values of 41.25 at 0% to 44.36 at 8%, but lessens at 10% to 35.67, but RHA rises at increased percentages. This indicates that RHA also has Portland cement powder key chemical constituents i.e SiO_2, MgO, Al_2O_3, CaO, and so forth. This is an indication that RHA is a good pozzolana that can assist in the promotion of the configuration of the cementitious compound during cement hydration reaction products which are in agreement with investigators like Adeyanju et al. [8], Zhu et al. [10], and Xia [11].

3.3 Effect of Compaction

Results of the compaction test for geopolymer, SSA, and RHA are displayed in Tables 5-7, and Figs. 4-6. The figure depicts that adding cement, RHA, as well as KCP, enriched both the OMC and quantities of the MDD correspond to an increase in cement, RHA, and KCP percentage. The increase in OMC is perhaps a consequence of two reasons:(1) the introduced water becomes extra and held with the flocculant soil structure resulting from cement interface, and (2) exceeding water absorption by RHA as a result of its porous physiognomies, as testified by Abdullah [3]. Above all, enhancement of lateritic soil dry density after the introduction of improver is a sign of improvement for both RHA and PCP, even if it increases the dry density gradually. Poona et al. [1] reveal an opinion that the change-up in dry density occurs because of both the particle size and specific gravity of the soil and stabilizer. Increasing dry density indicates that it needs high compaction energy (CE) to attain its MDD, thus making construction more durable and cost-effective Xu et al. [2], Wattex [5], and Agashua et al [53]. This increase in the dry density can be due to the particle flocculation and agglomeration caused by the slow cation exchange in the soil-stabilizer mixture.

3.4 Effect of Triaxial Test

Results of the triaxial test for RHA, SSA, and geopolymer are shown in Tables 8-10, and graphically Figs. 7-9. The scrutiny result showed the impact of various percentages of RHA, SSA, and geopolymer on the soil sampling stabilized.

The highest cohesion (C) of 19KN/m^2, 11KN/m^{2}and65KN/m^{2}was achieved at 10% and frictional angles of 27°, 19°, and 57° for RHA, SSA, and geopolymer respectively. Likewise, site visitation, some laboratory experiment, and apparatus utilized for this research are presented in Fig.11-14.

Table 2. Effect of RHA on Atterberg limit test

%	Sheda Borrow Pit (SBP)			Dabi Borrow pit (DBP)			Kwali borrow pit (KBP)		
	PL	LL	PI	PL	LL	PI	PL	LL	PI
0RHA+6%PCP	24.59	41.25	16.66	12.01	37.00	25.01	17.09	40.45	23.36
2RHA+6%PCP	10.56	27.23	16.67	3.24	23.89	20.65	06.34	25.31	18.96
4RHA+6%PCP	13.24	31.23	17.99	3.67	27.54	23.87	07.32	28.23	20.91
6RHA+6%PCP	14.35	34.56	20.21	4.34	30.12	25.78	08.34	32.12	23.78
8RHA+6%PCP	15.56	37.05	21.49	4.91	32.76	27.86	08.98	35.23	26.25
10RHA+6%PCP	16.53	38.02	21.49	5.62	33.25	27.63	09.08	37.22	28.14

Table 3. Effect of SSA on Atterberg limit test

%	Sheda Borrow Pit (SBP)			Dabi Borrow pit (DBP)			Kwali borrow pit (KBP)		
	PL	LL	PI	LL	PL	PI	PL	LL	PI
0RHA+6%PCP	24.59	41.25	16.66	37.00	12.00	25.00	17.09	40.45	23.36
2RHA+6%PCP	12.56	20.98	8.42	19.78	11.05	8.73	14.05	20.98	6.93
4RHA+6%PCP	11.56	21.34	9.78	17.34	10.75	6.59	12.06	21.34	9.28
6RHA+6%PCP	10.75	30.67	19.92	20.67	10.04	10.63	10.05	30.67	20.62
8RHA+6%PCP	19.45	31.67	12.22	21.67	9.54	12.13	9.06	31.67	22.61
10RHA+6%PCP	17.45	29.65	12.20	19.65	8.75	10.90	8.56	29.65	21.09

Table 4. Effect of geopolymer on Atterberg limit test

%	Kwali Borrow Pit (KBP)			Sheda Borrow pit (DBP)			Dabi borrow pit (KBP)		
	LL	PL	PI	LL	PL	PI	LL	PL	PI
0RHA+6%PCP	40.45	17.09	23.36	41.25	24.59	16.66	37.00	12.00	25.00
2RHA+6%PCP	44.67	18.50	26.17	45.67	19.25	26.42	40.67	17.20	23.47
4RHA+6%PCP	49.52	19.50	30.02	50.12	20.45	29.67	42.75	18.50	24.25
6RHA+6%PCP	57.64	31.65	25.99	59.54	32.45	27.09	54.60	30.80	23.80
8RHA+6%PCP	64.80	33.60	31.20	67.50	34.56	32.94	61.50	31.50	30.00
10RHA+6%PCP	71.60	39.50	32.10	73.56	40.56	33.00	69.60	37.60	32.00

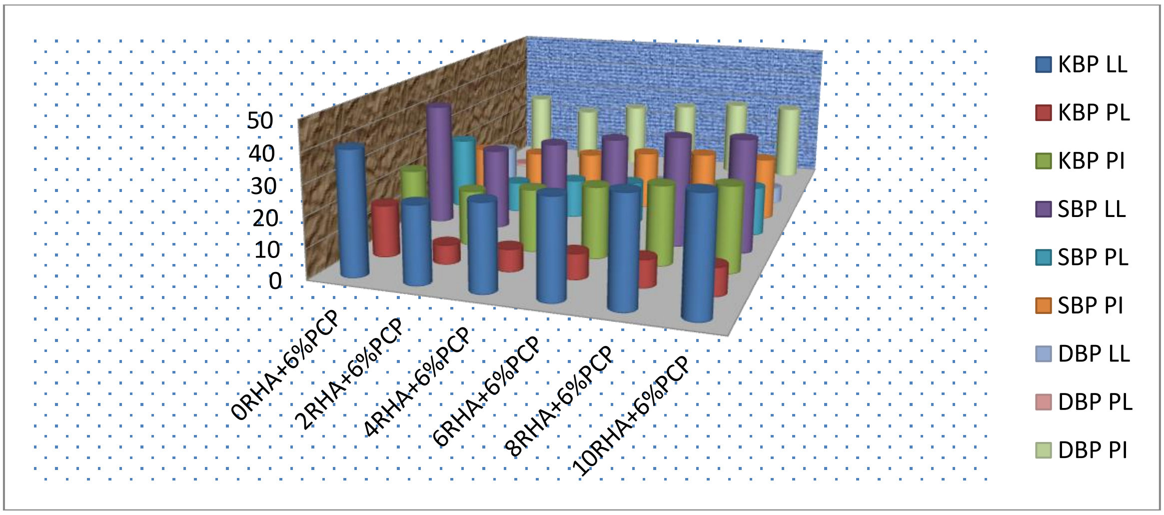

Fig. 1. Impact of RHA on Atterberg limit test

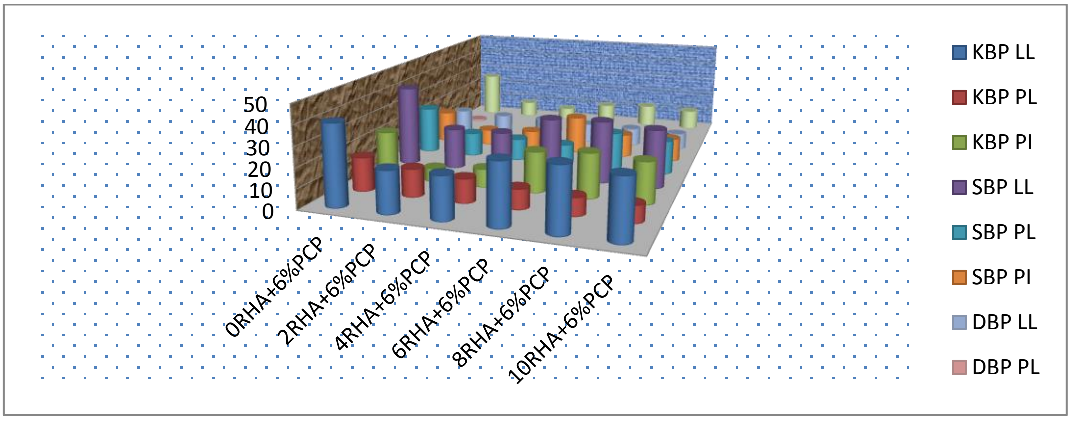

Fig. 2. Impact of SSA on Atterberg limit test

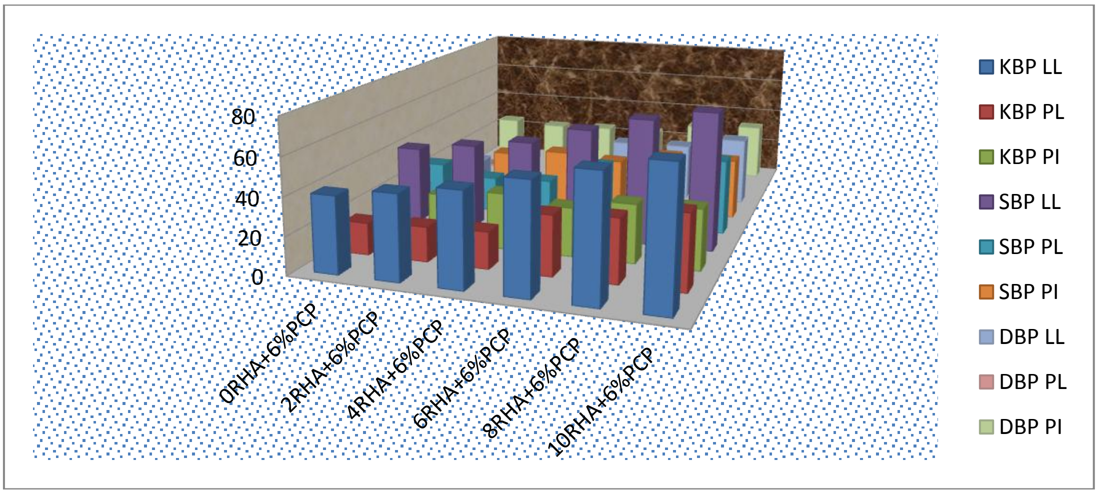

Fig. 3. Impact of geopolymer on Atterberg limit test

Table 5. Effect of SSA on compaction test

%	KA		SA		DA	
	MDD (mg/m^3)	**OMC (%)**	**MDD (mg/m^3)**	**OMC (%)**	**MDD (mg/m^3)**	**OMC (%)**
0RHA+6%PCP	1.342	16.85	1.456	17.75	1.572	18.65
2RHA+6%PCP	1.360	16.90	1.460	18.79	1.580	18.70
4RHA+6%PCP	1.385	17.01	1.465	19.02	1.588	18.75
6RHA+6%PCP	1.400	17.13	1.475	19.30	1.592	18.79
8RHA+6%PCP	1.420	17.30	1.479	19.40	1.598	18.82
10RHA+6%PCP	1.440	17.45	1.483	19.45	1.602	18.86

Table. 6. Effect of RHA on compaction test

%	KA		SA		DA	
	MDD (mg/m3)	**OMC (%)**	**MDD (mg/m3)**	**OMC (%)**	**MDD (mg/m3)**	**OMC (%)**
0RHA+6%PCP	1.342	16.85	1.456	17.75	1.572	18.65
2RHA+6%PCP	1.520	15.92	1.680	16.34	1.620	16.72
4RHA+6%PCP	1.720	15.60	1.895	15.89	1.870	14.60
6RHA+6%PCP	1.920	14.95	1.980	15.04	2.020	13.95
8RHA+6%PCP	2.150	13.48	2.190	14.02	2.250	12.48
10RHA+6%PCP	2.345	12.11	2.450	12.21	2.465	11.71

Table. 7. Effect of geopolymer on compaction test

%	KA		SA		DA	
	MDD (mg/m3)	OMC (%)	MDD (mg/m3)	OMC (%)	MDD (mg/m3)	OMC (%)
0RHA+6%PCP	1.342	16.85	1.456	17.75	1.572	18.65
2RHA+6%PCP	1.760	17.80	1.890	19.80	1.890	19.54
4RHA+6%PCP	1.850	18.01	1.970	20.02	1.970	20.00
6RHA+6%PCP	1.920	19.05	2.250	20.80	2.250	21.20
8RHA+6%PCP	1.980	19.45	2.480	21.40	2.480	21.75
10RHA+6%PCP	2.050	19.80	2.560	21.60	2.560	22.20

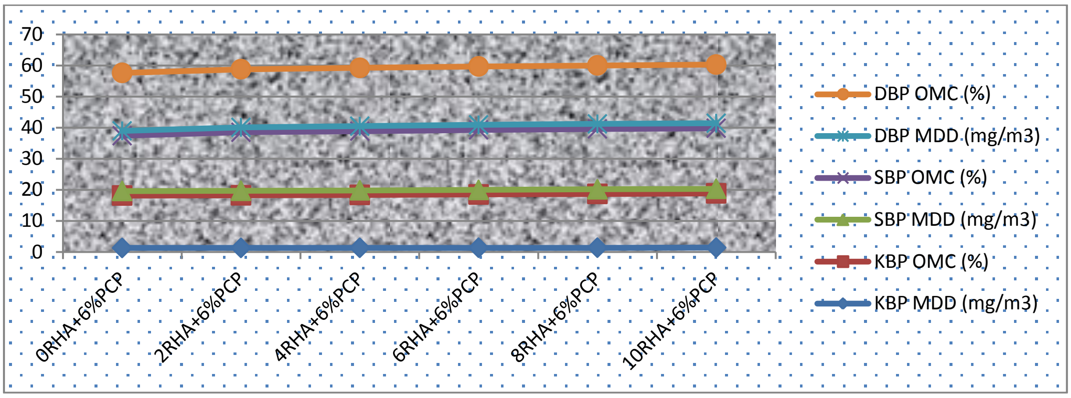

Fig. 4. Impact of SSA on compaction test

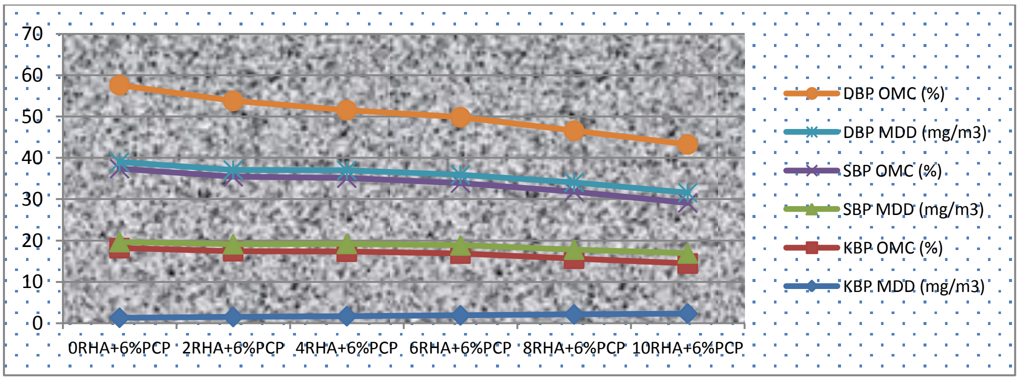

Fig. 5. Impact of RHA on compaction test

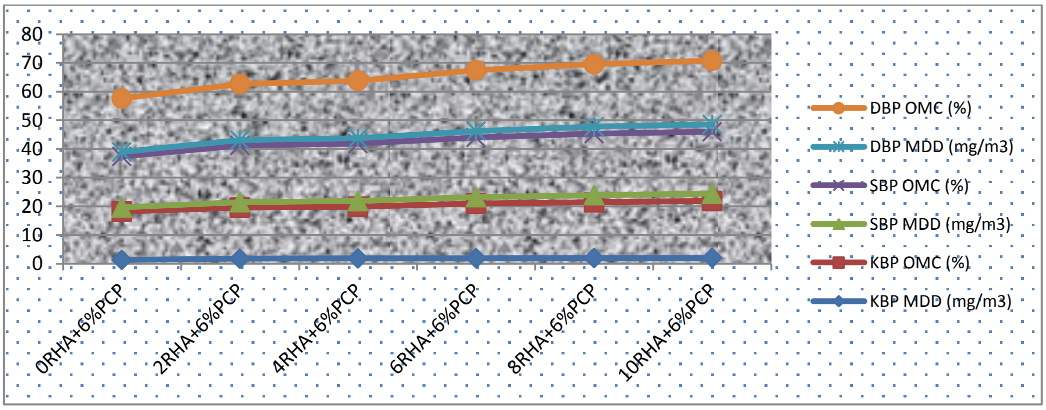

Fig. 6. Impact of geopolymer on compaction test

Table 8. Effect of RHA on compaction test

%	KBP		SBP		DBP	
	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0
0RHA+6%PCP	19.1	23.1	18.1	22.1	19.0	23.2
2RHA+6%PCP	11.2	26.0	11.0	25.0	11.1	25.1
4RHA+6%PCP	10.0	28.2	11.2	28.1	10.0	28.2
6RHA+6%PCP	16.1	21.0	16.1	20.0	15.2	20.0
8RHA+6%PCP	10.2	29.1	10.2	28.1	10.3	29.4
10RHA+6%PCP	19.1	27.2	18.0	26.2	19.0	27.2

Table 9. Effect of SSA on compaction test

%	KBP		SBP		DBP	
	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0
0RHA+6%PCP	19	23	18	22	19	23
2RHA+6%PCP	8	15	8	15	8	15
4RHA+6%PCP	9	16	9	16	9	16
6RHA+6%PCP	10	18	10	18	10	17
8RHA+6%PCP	10	18	10	18	10	18
10RHA+6%PCP	11	19	11	19	11	18

Table 10. Effect of geopolymer on compaction test

%	KBP		SBP		DBP	
	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0	Cohesion (KN/m^2)	Frictional Angle (Ɵ)^0
0RHA+6%PCP	19.1	23.1	18.2	22.0	19.0	23.1
2RHA+6%PCP	39.2	37.0	37.3	32.3	39.2	37.2
4RHA+6%PCP	49.3	40.2	44.0	37.2	49.3	40.3
6RHA+6%PCP	52.0	48.1	49.1	41.1	52.3	48.1
8RHA+6%PCP	58.1	53.2	56.2	48.2	58.2	53.2
10RHA+6%PCP	65.2	57.0	60.1	52.0	65.1	57.2

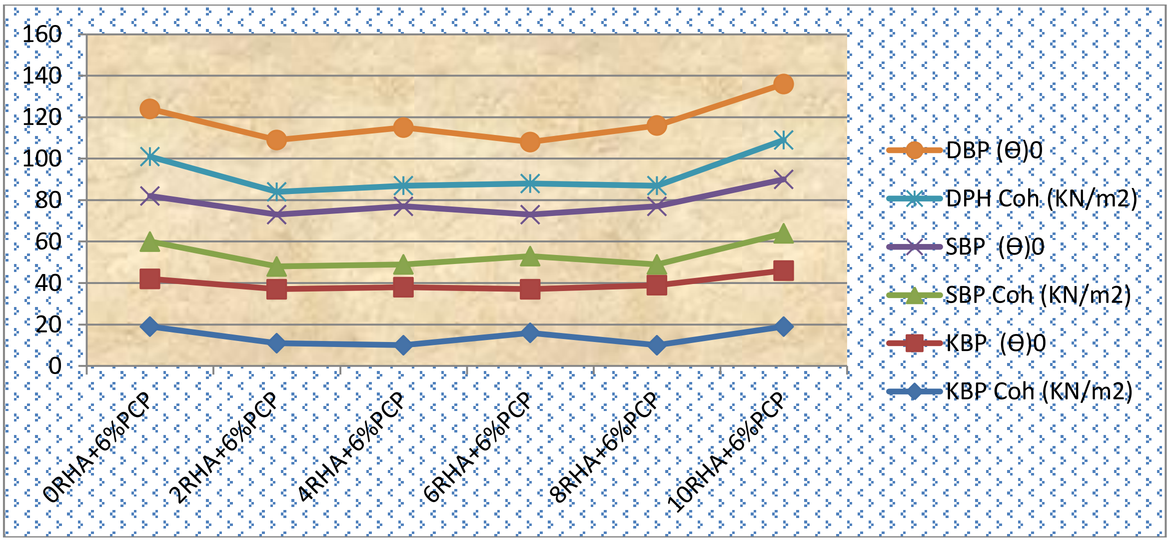

Fig. 7. Impact of RHA on compaction test

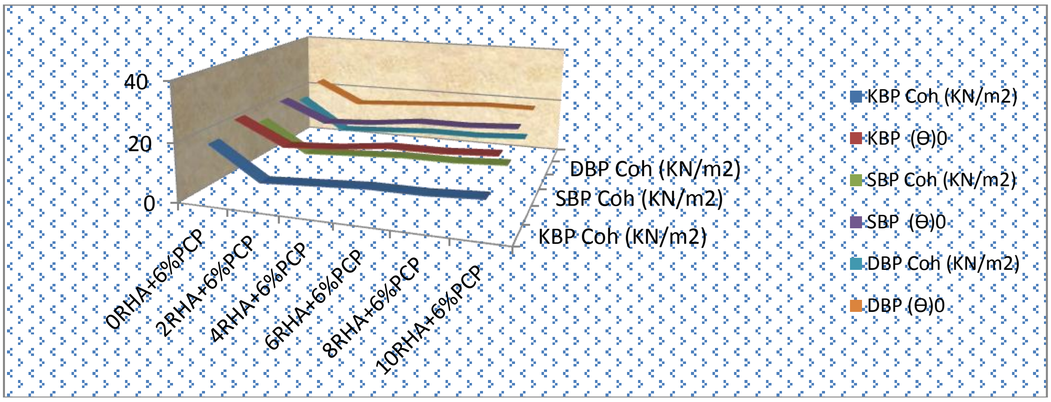

Fig. 8. Impact of SSA on compaction test

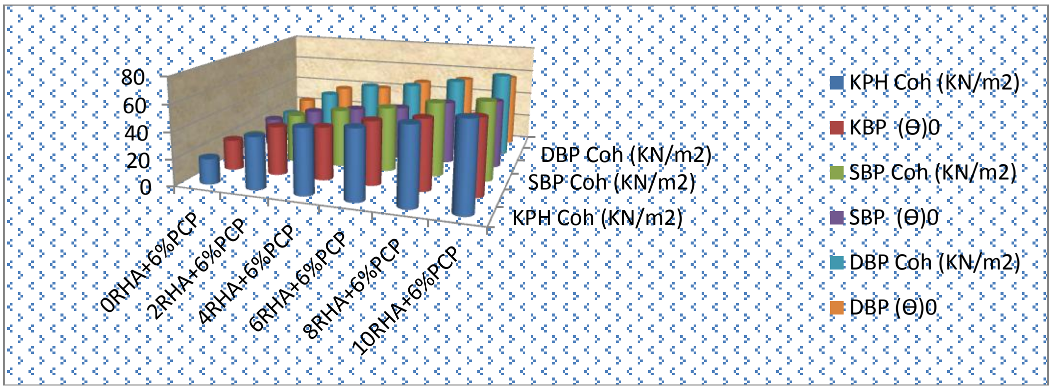

Fig. 9. Triaxial tests result for RHA, sodium silicate, and geopolymer mix

Fig. 10. Samples collection at Dabi site where Dantata and Sawoe Construction Company is using for Gwagwalada-Kwali road construction

Fig. 11. Samples and rice husk ash at Federal University of Technology Akure Geotechnical lab

Fig. 12. Specific gravity and Atterberg limit test in progress

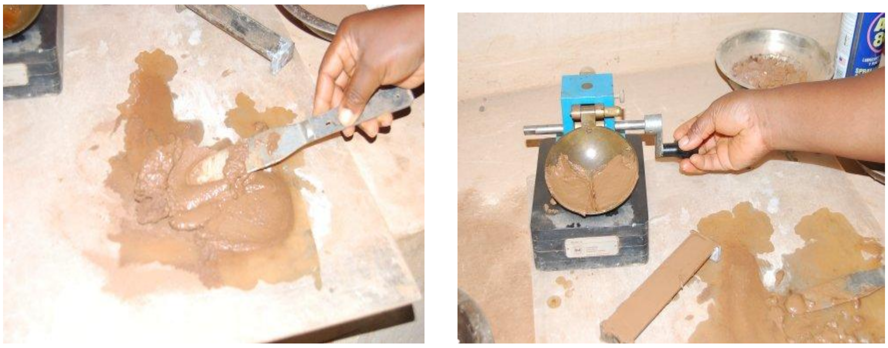

Fig. 13. Atterberg limit test in progress

Fig. 14. FITR apparatus and Set up compressive strength

4. CONCLUSION

From the analysis, the investigations on KCP-SSA stabilized soils show that the lateritic soil was categorized as A-7-6 soil. Besides, at 6% contents, the scrutiny showed a general improvement in MDD and OMC with an increase in SSA as well as RHA contents. The addition of RHA-SSA requires a lesser amount of SSA to obtain improved strength as compared to cement-improved soils. Further, the highest cohesion of 19KN/m^2, 11KN/m^2, and 65KN/m^2 was achieved at 10% and frictional angle of 27°, 19°, and 57° for RHA, SSA, and geopolymer respectively. Hence, the Sodium silicate activator together with rice husk ash was confirmed to be a good enhancer for lateritic soil stabilization using 6% as their control.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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