International Journal of World Policy and Development Studies
ISSN(e): 2415-2331, ISSN(p): 2415-5241
Vol. 9, Issue. 1, pp: 29-38, 2023
URL: https://arpgweb.com/journal/journal/11
DOI: https://doi.org/10.32861/ijwpds.91.29.38

Academic Research Publishing Group

Original Research **Open Access**

Compactability of Agro based Geopolymer using Sodium Silicate Activator

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Article History
Received: 2 September, 2022
Revised: 8 January, 2023
Accepted: 26 February, 2023
Published: 1 March, 2023

Abstract

The strength of a fine-grained lateritic soilfrom three (3) different localities on Abuja – Lokoja road where road failure happen was treated with rice husk ash (RSA), cement andsodium silicate activator (SSA), with varying percentage examined by means of Atterberg, Compaction and triaxial shear tests. The addition of optimum cement with additives changes laterite sample of plasticity index (PI) into non-plastic and resulted in a minimum of 11.90 % reduction in PI of lateritic soil which led to the belief that additives decreases plasticity of soils, and this is an advantage, because reduction in PI contents indicates animprovement.Thecompaction characteristics of the natural lateritic soils were altered with the addition of optimum contents of OPC with each of RHA, KCP and SSA. The MDD of cement-stabilized residual soil slightly increased with the increase in cement content, whereas by adding RHA, KCP and cement, the OMC is decreases steeply. Also, CBR results shows that CBR of the soil-cement-SSA content increases upon adding sodium silicate activator content up to 4% SSA content before the value experiences reduction at much higher SSA content. But, theRHA-treated residual soils decrease the CBR value from 6% upwards. This, again, alludes that RHA alone is not suitable as stabilizer.

Keywords: Geopolymer; Construction; Sodium silicate; Rice hush ash; UCS; Abuja.

1. Introduction

Geopolymer is a product of the alkali activation of aluminosilicate materials present in industrial waste materials such as furnace slag, slag furnace, granulated blast-furnace slag, fly ash, kaolin clay and red mud (Suksiripattanapong, 2021; Upshaw and Cai, 2021; Venkatesh *et al.*, 2021; Wattez, 2021). Geopolymer like ground granulated blast-furnace slag (an industrial waste produced from the cement production) and kaolin clay (natural occurring waste) (Abdullah *et al.*, 2020a; Pooria *et al.*, 2021; Rivera *et al.*, 2020; Zhu *et al.*, 2020b). Whereas rice husk fibre is waste from agricultural (Abdullah, 2021; Xu *et al.*, 2021; Zhu *et al.*, 2020a). Besides, globally, ground granulated blast-furnace slag and rice husk fiber produced by cement factories and rice industries have been increasing for the past few years (Adeyanju *et al.*, 2020a; Alshaba *et al.*, 2018; Wang *et al.*, 2020). The mass production of both ground granulated blast-furnace slag and rice husk fiber causes disposal problems and an increase in expenses for storage in available landfills (Dheyab *et al.*, 2019; Rahgozar *et al.*; Roychand, 2021; Yoobanpot *et al.*). This eventually poses a threat to the environment if it is not properly managed. The use of geopolymeric materials in setting soil improvement is growing daily. Unfortunately, little research has been completed to distinguish between products that deliver enhanced performance and those that do not (Adeyanju and Okeke, 2019b; Igibah *et al.*, 2020; Rivera O., 2020; Wattez, 2021; Wen *et al.*, 2019). The nature of soil stabilization dictates that products may provide soil-specific properties and/or provide compatibility with environment. In other words, some products may work well in specific soil types in a given environment but perform poorly when applied to dissimilar materials in a different environment (Adeyanju *et al.*, 2020b; Farhangi *et al.*, 2020; Ghadakpour *et al.*, 2020; Seyhan *et al.*, 2020). The use of geopolymer materials as soils stabilizers has been widely studied and results of such past studies indicate that geopolymers could be used as an effective soil stabilizer. The inorganic types cement (Abdulkareem, 2020; Abdullah *et al.*, 2019; Sharma *et al.*, 2019; Vitale *et al.*, 2020), lime (Abdullah *et al.*, 2020b; RezazadehEidgahee *et al.*, 2020; Saberian, 2020), fly ash (Dheyab *et al.*, 2019; Jahandari *et al.*, 2019; Khasib and Daud, 2020; Tan *et al.*, 2019; Teing, 2019; Wen *et al.*, 2019; Yaghoubi *et al.*, 2019), organic polymers (Anonymous; Amiri and Emami, 2019; Chang and Cho, 2019; Elandaloussi, 2019; Pradhan *et al.*, 2019) and their mixtures (Kuang, 2019). These inorganic stabilizing agents are mainly used in non-ecological soil stabilization. Though they have been found to improve the engineering properties of soils significantly, such inorganic materials do inhibit plant growth as they cannot meet the requirements for slope ecological stabilization (Adeyanju and Okeke, 2019a; Adeyanju and Okeke, 2019b; Alshaba *et al.*, 2018; Mohsenia *et al.*, 2019; Zhu *et al.*, 2020b;2020a).

2. Materials 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 (Agashua and OgbiyeAdebanji, 2018; Gutiérrez *et al.*, 2019). 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 (Wen *et al.*, 2019). 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, Ondo State, Nigeria.

Figure-1. Map of Kwali and 3 Sampling Points with coordinates

3. Results and Discussion

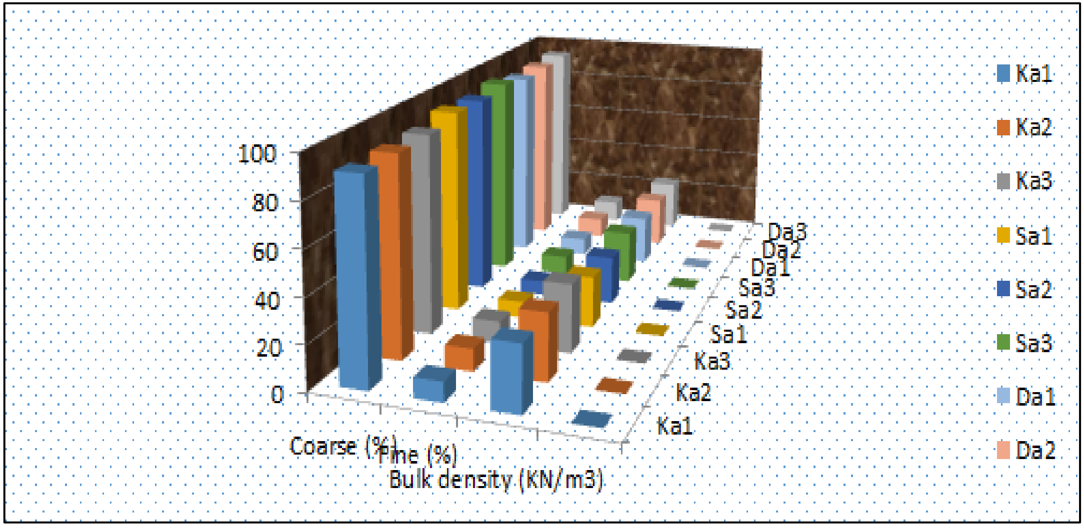
3.1. Preliminary Tests Results

Table 1 and Figure 2 shows summary of basic and engineering properties of the selected laterite soil before stabilization. The result showed that specific gravity ranged as follows: Kwali (A) (2.50 – 2.70%), Sheda (B) {2.6 – 2.7%} and Dabi (C) {2.2 – 2.5%}. The result showed that both Kwali and Sheda laterite soil has the highest specific gravity value (2.7%) while Dabi soil recorded the lowest (2.2%). Specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance. Natural moisture content values are: (7.80 – 8.00%), {6.5 – 7.0%} and {5.4 – 6.0%} for A, B and C respectively. The result showed that kwali soil has the highest NMC value (8.0%) and followed by Sheda (7.0%) while Dabi soil recorded the lowest (5.4%). This test indeed determines the varying in percentage quantity of moisture present in the laterite samples. For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.For sieve analysis the coarse and fine aggregate the values ranges as follows: A (90.88 - 91.58%) and (09.12 – 10.13%); B (93.42 – 95.34%) and (06.58 – 08.76%) as well as C (91.87 – 93.45%) and (08.13-10.02%).

Table-1. Preliminary test results

Properties	**Soil samples**								
	Ka1	Ka2	Ka3	Sa1	Sa2	Sa3	Da1	Da2	Da3
Coarse (%)	90.88	91.23	91.58	94.56	93.42	95.34	91.87	92.56	93.45
Fine (%)	09.12	10.13	10.08	07.65	06.58	08.76	08.13	09.56	10.02
Bulk density (KN/m3)	14.64-29.76	15.67-30.45	15.75-31.34	13.45-23.56	12.23-22.36	14.15 -24.57	14.63-22.76	15.78-23.56	16.34-23.89
Natural Moisture content (NMC) (%)									
	Ka1	Ka2	Ka3	Sa1	Sa2	Sa3	Da1	Da2	Da3
	7.8	8.0	7.9	6.5	6.8	7.0	5.4	6.0	5.8
Specific gravity (%)									
	Ka1	Ka2	Ka3	Sa1	Sa2	Sa3	Da1	Da2	Da3
	2.5	2.6	2.7	2.7	2.6	2.7	2.2	2.4	2.5

Figure-2. Sieve analysis plot for nine samples



3.2. Effect of Compatibility

Results of compaction analysis for Rice Husk Ash (Farhangi *et al.*, 2020), sodium silicate activator (SSA) and geopolymer are presented in Table 2, 3, 4and Figure 3, 4, 5. The results reveals that the soil samplesstabilized with OPCincreased from 1742Kg/m^3, 1856Kg/m^3 and 1972Kg/m^{3}at 0% to 2108Kg/m^3, 2155Kg/m^{3}andto 2160Kg/m3 for soil samples A, B and C respectively, at 6%. Whereas OMC decreases from 16.85%, 17.75% and 18.65% at 0% to 15.34, 15.55 and 15.05% for samples A, B and C respectively at 10%, the finding of the study is similar to that of Wen *et al.* (2019).

Also, the results showed that maximum dry density (MDD) increased from 0% to 6% Optimum RHA and decreased thereafter, even with increase in RHA to 10% for all the samples. Optimum values for MDD in Kg/m^3 at 6% cement and 6% RHA are: A (1805Kg/m^3), B (2102Kg/m^3) and C (2045Kg/m^3).For KCP the result reveal optimum values at 6% cement and 8% KCP and the values in Kg/m^{3}are: A (2245), B (2730) and (2385). Meanwhile GP also follows the trends of 6% cement and 8% GP and the values are 2350Kg/m^3, 2351Kg/m^3 and 2250Kg/m^{3}for samples A, B and C respectively. But for SSA the styles are 6% cement and 4% SSA with optimum MDD values of 2085Kg/m^3, 2480Kg/m^{3}and 2508Kg/m^3. It is observed that MDD and CBR values increase asRHAcontent increases for both soil samples. Though MDD ofsoil sample a reached optimum at 6 % RHA. While OMCvalues decrease as RHA content increases for both soilsamples. These aredue to coating and replacement of soil bythe additives contents in the mixture, which resulted in largeparticles with larger voids and density.The addition of Cement and RHA contents also decreased thequality of free silt, clay fraction and coarse materials withlarge surface areas formed Chang and Cho (2019) and Alhmed *et al.* (2018).

Table-2. Variation of rice husk ash (Farhangi *et al.*) with 6% cement

Samples	**Cement content**	MDD (kg/m^3)	OMC (%)
A	6% cement + 2% RHA	1650	18.05
	6% cement + 4%RHA	1785	20.50
	6% cement + 6% RHA	1805	21.95
	6% cement + 8% RHA	1760	23.50
	6% cement + 10% RHA	1645	25.05
B	6% cement + 2% RHA	1905	13.90
	6% cement + 4% RHA	2040	15.04
	6% cement + 6%RHA	2102	16.95
	6% cement + 8% RHA	1945	18.00
	6% cement + 10% RHA	1875	20.50
C	6% cement + 2% RHA	1905	17.05
	6% cement + 4% RHA	1995	19.30
	6% cement + 6% RHA	2045	20.20
	6% cement + 8% RHA	1980	21.90
	6% cement + 10% RHA	1915	24.50

Figure-3. Compaction plot for various percentages of Additives and 6% cement

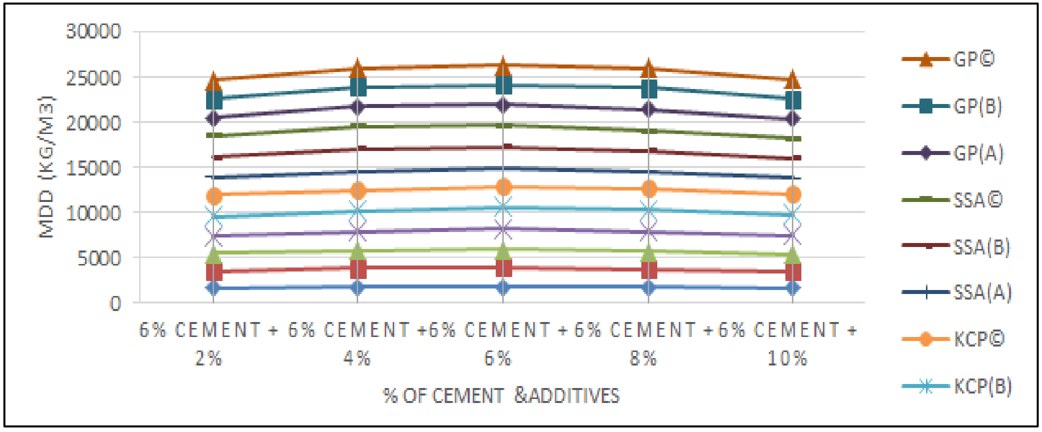


Figure-4. Maximum dry density (MDD) versus three Additives and 6% cement

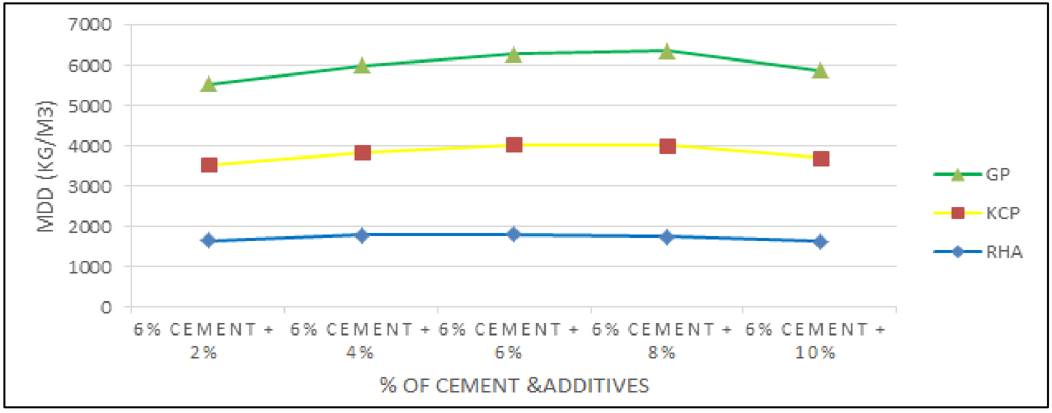
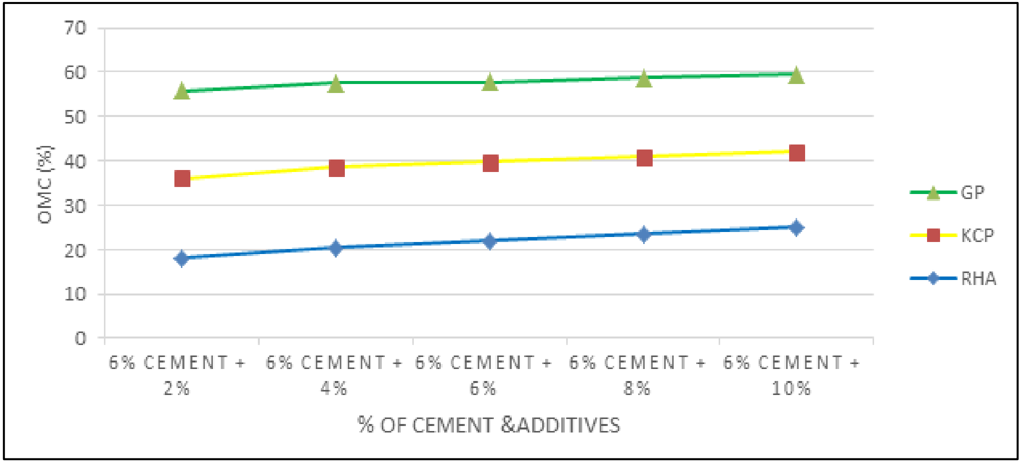


Figure-5. Optimum Moisture contents (OMC) versus three Additives and 6% cement



The increase in MDD, CBR and consequent decrease in OMCvalues is also due to gradual formation of cementitiouscompound between the additives and Calcium Hydroxide(Ca(OH)2) present in the soil, thus increase in coarse particlesof the soil through cementation. Furthermore, the figure depictsthat adding cement and RHA increasethe values of Optimum Moisture Content (OMC) with increasing content of OPC with RHA. The increasein OMC is probably a consequence of two reasons:(1) the additional water held with the flocculantsoil structure resulting from cement interaction, and(2) exceeding water absorption by RHA as a resultof its porous properties, as reported in Sharma *et al.* (2019). Principally, increase in dry density is an indicator of improvement. Principally, increase in dry density is an indicator of improvement. But, unfortunately, both cement andRHA, instead, reduce the dry density from 6 – 10%. Because RHA has a unit weight less than the soil, the presence of RHA in the soil-cement mix reduces the density.

Adeyanju and Okeke (2019b), revealsan opinion that the change-down in dry densityoccurs because of both the particles size and specificgravity of the soil and stabilizer. Decreasing dry densityindicates that it need low compactive energy(CE) to attain its MDD. As a result, the cost of compaction becomes economical though, both cement and RHA, instead, increase the dry density gradually. Also Abdullah *et al.* (2020b), revealsan opinion that the change-up in dry densityoccurs because of both the particles size and specificgravity of the soil and stabilizer.

Table-3. Variation of kaolin clay powder (KCP) with 6% cement

Samples	Cement content	MDD (kg/m^3)	OMC (%)
A	6% cement + 2% KCP	1890	18.05
	6% cement + 4% KCP	2050	18.01
	6% cement + 6% KCP	2220	17.85
	6% cement + 8% KCP	2245	17.40
	6% cement + 10% KCP	2050	17.05
B	6% cement + 2% KCP	2250	16.65
	6% cement + 4% KCP	2275	15.30
	6% cement + 6% KCP	2385	15.00
	6% cement + 8% KCP	2395	14.50
	6% cement + 10% KCP	2245	14.35
C	6% cement + 2% KCP	2305	19.40
	6% cement + 4% KCP	2330	17.45
	6% cement + 6% KCP	2360	17.30
	6% cement + 8% KCP	2385	16.60
	6% cement + 10% KCP	2280	15.05

Table-4. Variation of geopolymer (Yoobanpot *et al.*) with 6% cement

Samples	Cement content	MDD (kg/m^3)	OMC (%)
A	6% cement + 2% GP	1985	19.80
	6% cement + 4% GP	2150	19.05
	6% cement + 6% GP	2250	18.01
	6% cement + 8% GP	2350	17.80
	6% cement + 10% GP	2180	17.34
B	6% cement + 2% GP	2045	21.60
	6% cement + 4% GP	2190	20.80
	6% cement + 6% GP	2270	20.02
	6% cement + 8% GP	2350	19.80
	6% cement + 10% GP	2160	12.98
C	6% cement + 2% GP	2005	22.20
	6% cement + 4% GP	2100	21.20
	6% cement + 6% GP	2170	20.00
	6% cement + 8% GP	2250	19.54
	6% cement + 10% GP	2160	18.85

3.3. Effect of UCS

Unconfined compressive strength (UCS) is themost common and adaptable method forevaluating the strength of stabilized soil. UCS isthe main test recommended for the determinationof the required amount of additive to be used inthe stabilization of soils by Wen *et al.* (2019).The Unconfined compressive strength testresults presented in Table 5, 6, 7 and Figures 6 shown the behaviour of lateritic soil treated with Ordinary Portland Cement for compression strength test. The results showed that the optimum unconfined compressivestrength for RHA at 6% with specified cement content of 6% are A (91.95), B (87.52) and C (88.75) N/mm², while the highest UCS value for the KCP and GP stabilized soil was (285.30, 280.00 and 270.40) N/mm² as well as (295.30, 294.25 and 288.95) at 8% stabilization respectively, using cement, (59.05, 58.05 and 58.85) N/mm² at 6% content.UCS increases and decline from 6% cement and 6% RHA. The compressive strength increases nonlinearly with RHA. In the case of cement, the increase in.

Figure-6. UCS versus three Additives and 6% cement

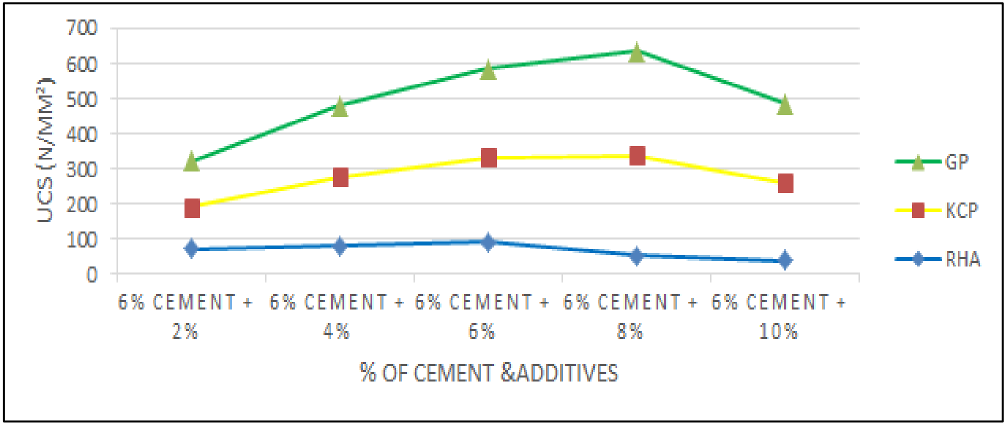


Table-5. UCS for RHA with 6% cement

Samples	**Cement content**	**Uncured** (N/mm²)
A	6% cement + 2% RHA	72.48
	6% cement + 4%RHA	80.65
	6% cement + 6% RHA	91.95
	6% cement + 8% RHA	52.84
	6% cement + 10% RHA	39.05
B	6% cement + 2% RHA	71.92
	6% cement + 4% RHA	79.95
	6% cement + 6%RHA	87.52
	6% cement + 8% RHA	45.05
	6% cement + 10% RHA	28.85
C	6% cement + 2% RHA	72.48
	6% cement + 4% RHA	80.85
	6% cement + 6% RHA	88.75
	6% cement + 8% RHA	46.84
	6% cement + 10% RHA	30.95

Table-6. UCS for RHAKCP with 6% cement

Samples	**Cement content**	**Uncured** (N/mm²)
A	6% cement + 2% KCP	120.25
	6% cement + 4% KCP	197.60
	6% cement + 6% KCP	240.50
	6% cement + 8% KCP	285.30
	6% cement + 10% KCP	220.50
B	6% cement + 2% KCP	118.55
	6% cement + 4% KCP	197.20
	6% cement + 6% KCP	238.55
	6% cement + 8% KCP	280.00
	6% cement + 10% KCP	219.20
C	6% cement + 2% KCP	118.20
	6% cement + 4% KCP	196.50
	6% cement + 6% KCP	235.56
	6% cement + 8% KCP	270.40
	6% cement + 10% KCP	215.40

Table-7. UCS for GP with 6% cement

Samples	**Cement content**	**Uncured** (N/mm²)
A	6% cement + 2% GP	128.25
	6% cement + 4% GP	199.65
	6% cement + 6% GP	250.50
	6% cement + 8% GP	295.30
	6% cement + 10% GP	225.55
B	6% cement + 2% GP	127.20
	6% cement + 4% GP	198.80
	6% cement + 6% GP	248.50
	6% cement + 8% GP	294.25
	6% cement + 10% GP	208.50
C	6% cement + 2% GP	127.50
	6% cement + 4% GP	197.85
	6% cement + 6% GP	247.90
	6% cement + 8% GP	288.95
	6% cement + 10% GP	206.85

Unconfined compressive strength is higher and almost linear. The UCS values decrease with -subsequent addition of RHA after 6%, whereas sodium silicate activator mixture increase rapidly to 4% before gradually reducing. This rapid decrease inthe UCS values after the addition of 4 and 6 % RHA-SSA may be due to the excess RHA added tothe soil and therefore forming weak bondsbetween the soil and the cementitious layers ofsoil formed.

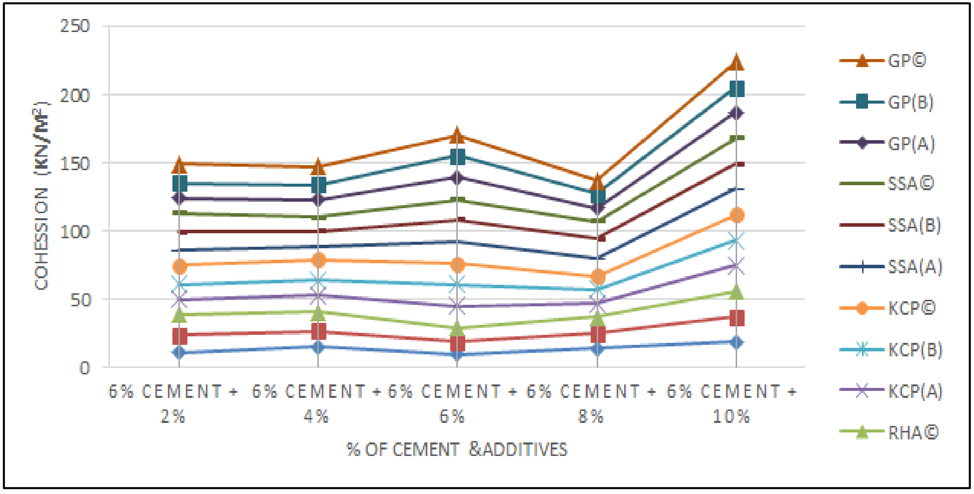
Meanwhile cement and kaolin shows undoubtedly a very effective additiveto enhance the strength of tested soils with little additive for better improvement. Itcan be observed that the optimum cement content is 6%; optimum RHA content (6%), optimum KCP content (8%) and optimum geopolymer is 8%. It corresponds with the optimum cement contentthat reaches to the atterberg or consistency limit. Though RHA–soil mixturesslightly increase thestrength,but RHA cannot be used alone for stabilization of soil becauseof its lack of cementitious property. It can only be used as anadmixture with other cementitious materials which is in agreement of research work by Chang and Cho (2019). Moreover, the soils showed an appreciable strength gain overuntreated soil with addition of only 2 percent cement by weight though its optimum is at 6%. Silty soils treated with 2 percent cement can be used as a goodsubbase and subgrade material in low-volume paved-roadconstruction. Earth roads stabilized with a cement-RHA blendare expected to be more durable than untreated earth roads,reducing annual maintenance costs and providing a good subbaseor base for stage construction of paved roads.

3.4. Effect of Triaxial Test

Results of triaxial test for ordinary Portland cement (OPC) stabilized lateritic soilare shown in Figure 7. The result shown the impact of various percentages of RHA, SSA and geopolymer on the soil sampling stabilized. The results showed that the optimum Triaxial test result for RHA at 6% with specified cement content of 6% are: A (Deviation stress 595.45KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 28^0 and Shear stress 175.5KN/m^2), B (Deviation stress 514.75KN/m^2, Cohesion 9KN/m^2, Angle of internal friction 28^0 and Shear stress 168.5KN/m^2), and C (Deviation stress 530.58KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 29^0 and Shear stress 162.0KN/m^2).

While the highest triaxial values for the KCP and GP stabilized soil was A (Deviation stress 608.25KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 29^0 and Shear stress 175.5KN/m^2), B (Deviation stress 578.20KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 28^0 and Shear stress 173.5KN/m^2), and C (Deviation stress 556.50KN/m^2, Cohesion 15KN/m^2, Angle of internal friction 20^0 and Shear stress 176.5KN/m^2), as well as (A (Deviation stress 638.05KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 29^0 and Shear stress 195.5KN/m^2), B (Deviation stress 628.30KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 28^0 and Shear stress 193.5KN/m^2), and C (Deviation stress 615.40KN/m^2, Cohesion 10KN/m^2, Angle of internal friction 29^0 and Shear stress 188.40KN/m^2), at 8% stabilization respectively, using cement, (59.05, 58.05 and 58.85) N/mm² at 6% content.

Figure-7. UCS versus three Additives and 6% cement



4. Conclusions

From the analysis the laterite was identified to be an A7 soil according to AASHTO grouping system, which is a Silty or clayey gravel and sand. The compaction characteristics of the natural lateritic soils were altered with the addition of RHA, KCP and SSA. The MDD of cement-stabilized residual soil slightly decreases with the increase in cement content. Adding RHA, KCP and cement, the OMC is increased steeply.The Optimum RHA and cement content was found at 6% for Triaxial tests for which indicate an improvement in the treated soil compared with the UCS of the natural. Also the UCS values were at their peak at 6% RHA.The increase in Triaxial value corresponds to the increase in cement content. Adding RHA, KCP and SSA into cement- treated residual soil, the CBR value increase multiply. The unconfined compressive strengths of cement-stabilized soils increase with addition of RHA and KCP. Addition of RHA needs a lesser amount of cement to achieve a given strength as compared to cement-stabilized soils. Since cement is more costly than RHA this can result in lower construction cost.In general, 6% of cement and RHA and 8% and 4% KCP and SSA show the optimum amount to improve the properties of soils. Reduce in PI and increase in strength and resistance to immersion indicate an improvement. Thus, RHA and kaolin clay can potentially stabilize the residual soil, either solely or mixed with cement. Utilizing is an alternative, it is available to reduce construction cost, particularly in the rural area of developing countries.

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