West Africa Built Environment Research (WABER) Conference
WABER 2021 Conference, 9-11 August 2021, Accra, Ghana
Proceedings Edited by Laryea, S. and Essah, E.
ISBN 978-0-620-95367-2

SUCTION OF CLAYEY SOIL TREATED WITH QUARRY DUST BASE GEOPOLYMER CEMENT FOR SUSTAINABLE PAVEMENT SUBGRADE CONSTRUCTION

Ezenwa Chinenye Amanamba[1] and Kennedy Chibuzor Onyelowe[2]

[1]*Department of Civil Engineering, Abia State University, Uturu, Abia State Nigeria*

[2]*Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria*

Suction is a very important factor in pavement subgrade materials whether treated or untreated, and it is more important with the influence of seasonal changes in moisture for hydraulically bound environments. This physical property was investigated in a cemented and uncemented clayey soil treated with quarry dust based geopolymer cement (QDbGPC). The representative clayey soil was preliminarily studied and was classified as A-7-6 group soil according to the AASHTO classification system. It was also classified according to USCS as poorly graded clay (CP) with high clay content (CH). It was further classified as highly expansive and highly plastic with plasticity index above 17%. 200g of the representative sample was further treated with synthesised QDbGPC at temperature of 20˚C. The effect of the varying proportions of the treatment mixed in the proportions of 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5 and 40% by weight of dry soil on the suction of cemented and non-cemented test soils was observed. The stabilisation procedure was conducted under varying curing time on the soil. The results obtained showed a consistent reduction in suction with increased proportion of QDbGPC and with increased curing time. But cemented soil showed a slightly higher reduction in suction than the non-cemented soil. Portland cement had high shrinkage, and less suction tendencies, though it showed lower values of suction but the difference between cemented and non-cemented soil was too small that QDbGPC can totally replace OPC because of the properties it exhibits as a modifier construction material in compacted subgrade.

Keywords: clayey soil, geopolymer cement, pavement subgrade, quarry dust, suction

INTRODUCTION

During the state of moisture exposure to pavement foundation materials, the strength properties and consequently the durability of the foundation materials; natural or treated are affected by physical factors for instance suction or absorption

[1] engr.namba@gmail.com
[2] konyelowe@mouau.edu.ng

Amanamba and Onyelowe (2021) Suction of clayey soil treated with quarry dust base geopolymer cement for sustainable pavement subgrade construction In: Laryea, S. and Essah, E. (Eds) Procs West Africa Built Environment Research (WABER) Conference, 9-11 August 2021, Accra, Ghana, 925-932

(Onyelowe and Duc, 2018). Several researchers have tried to understand how suction can be improved, especially in problematic soils.

Sauer and Monismith (1968) demonstrated that low suction values in soil samples can be achieved by compacting the soil wet of optimum for the particular compactive effort. On the flip side, compacting a soil sample dry of optimum for the particular compactive effort would result in higher suction values.

Petry and Jiang, (2007) in their study of soil suction and the behaviour of clay treated with hydrated lime and a solution of potash and ammonium lignosulfonate observed the increase in osmotic suction as the soil reacted with the chemical stabilizers.

A study conducted by Pooni et al. (2019) examined the strength of soils stabilized with enzyme-based stabilizer, taking into account the challenge of moisture fluctuation. The results showed that with addition of enzyme-based stabilizer, the strength of the soil was considerably increased, and showed evidence of maintaining the stiffness as moisture fluctuates. Hence, the enzyme-based stabilizer improves the suction of the soil.

Geopolymer cements (GPC) have been studied and discovered to possess properties that could counterbalance the effects of exposure to suction and absorption. This is achieved by withstanding exposure to moisture attack in a hydraulically bound medium, a factor dependent on the moisture sensitivity of GPCs (Davidovits, 2013).

In the present research, GPC was synthesized from highly aluminosilicate bound materials under alkali-activator medium of NaOH + Na2SiO3. These materials rich in aluminosilicates are fly ash (FA), ground granulated blast furnace or metallurgical slag (GGBFS). Quarry dust (QD) was characterized and was discovered to possess great compositions of aluminosilicates. Quarry dust (QD) is a waste product of rock quarry operation of highly aluminosilicate content, with potentials to improve the physico-mechanical properties of treated soil especially highly expansive clayey soils (Fedrigo et al., 2017). This inorganic composition gives it the highly pozzolanic properties it possesses (ASTM C618, 2014; Bui, Onyelowe and Nguyen, 2018). Geopolymers on the same hand are produced from amorphous or organic or inorganic materials of highly aluminosilicate content though with activator compounds of sodium or potassium. These alkali activators enhance the attainment of a steady state with the stoichiometric release of Si and Al in the geopolymer synthesis chain leading to polycondensation (Bui, Onyelowe and Nguyen, 2018). In the present work, it is used as a replacement for FA in the synthesis of QDbGPC, which was used to treat the test clayey soil in the proportions of 2.5, 5, 7.5, 10..., 40% by weight of the treated matrix. It is also important to note that the constituents of the GPC possess high pozzolanic properties (ASTM C618, 2014), which triggers pozzolanic reaction causing condensation and densification of the dispersed clayey soil particles. However, the synthesized product possesses cementing properties, which ensures hydration and displacement reaction of certain metallic ions. GP cements, binders and concretes have found wide application in the infrastructures development industry and exhibits great use in solid waste management, construction repair as geopolymer injection, toxic metal

immobilization and coatings (Hamidi, Man and Azizi, 2016; Gopal and Rao, 2011; Onyelowe et al., 2020).

While several works have been done to reduce the damaging effect of suction on soil stability, the application of blended QD base geopolymer for the treatment of compacted soils was investigated in the present work. However, the specific objective was to study the effect of GP cement addition on the suction potential of the treated soils, adopting the methods described by Davidovits (2013) and Hamidi, Man and Azizi (2016).

MATERIALS AND METHODS

Materials

The test soil sample was collected from Amaoba borrow pit on Latitude 05°26′44.288′′N and Longitude 07°32′33.229′′E. The disturbed sample was collected, tapped to remove lumps, sun dried for 3 days and readied for use. Quarry dust was collected as waste (by-products) of quarrying (crushed-rock) operation from Amasiri quarry site in Afikpo, Ebonyi State, Nigeria. It was sundried and stored in silo bags for the laboratory exercise. Dangote Ordinary Portland Cement (DOPC) brand was used for this exercise; corresponding to 42.5N/mm2 grade. Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS)/Metallurgical Slag (MS) were collected from NigerPet Structures, Uyo, Nigeria and Delta Steel Company, Aladja, Warri, Nigeria respectively. The QD based Geopolymer (GP) was synthesized in accordance with the findings of Davidovits (2013) and Hamidi, Man and Azizi (2016). According to the above research findings, the aluminosilicate materials needed in the formation of GP are FA and GGBFS or MS under the reactive influence of Sodium Hydroxide (NaOH) and Sodium Silicate (Na2SiO3) as activators with a combined molar concentration of 12 as an eco-friendly material. QD contains high concentration of aluminosilicates (Al-O-Si), maintains a highly pozzolanic property and serves well in the synthesis of GP cement. These materials are mixed in the proportion of 12% by weight Activator plus 44% by weight QD plus 22% by weight FA plus 22% by weight GGBFS (MS), following Davidovits (2013) and Hamidi, Man and Azizi (2016). The GP cement dry powder was stored for use as supplementary cementing material in the laboratory stabilization exercise.

Experimental Program

The following conventional tests were conducted on the natural test soil for the purpose of characterization and classification in accordance with BS 1377-2 and Nigerian General Specification (BS 1377-2, 1990; NGS/FMWH, 1997); sieve analysis test, compaction test (Standard Proctor test), California bearing ratio test (CBR), Atterberg limit test, specific gravity test was conducted by Pycnometer method and chemical oxides composition test on the test soils and the test materials with XRF method and results were obtained. Furthermore, suction cylindrical specimens were prepared from the geopolymer treated fixed 5% cemented and uncemented soils in accordance with the standard proctor mould geometry, which were compacted in three layers and cured for 14 days under the same laboratory conditions as the unconfined compressive strength specimens. Extra specimens were prepared for each mixture to ensure accuracy and forestall time loss due to accidents. The tests were conducted in accordance with the British Standard (NGS/FMWH, 1997; BS 1924, 1990). After initial curing, the prepared specimens

were dried to steady mass at a temperature of 60°C ±5°C. Then, the height and mass of the specimens were measured as the control and standard reference values. The specimens were finally placed in a curing bowl with water level maintained at 10mm and at room temperature of 26.8°C ±2°C. The mean heights of water rising up the specimens were measured from the base of the sample specimens and equally their masses were determined at 24 hours, 48 hours and 72 hours curing periods. Suction as the percentage of the specimen height was determined and calculated as the percentage of the specimens 'dry masses (BS 1377-2, 1990; NGS/FMWH, 1997; BS 1924, 1990)

RESULTS AND DISCUSSION

Properties of the raw materials

The test soil sample was investigated and characterized under the laboratory conditions with the preliminary tests as presented in Tables 1& 2 and Fig. 1. The test soil was classified as A-7-6 group according to the AASHTO classification system (AASHTO, 1993). It was also classified according to USCS as poorly graded clayey soil (CP) with high clay content (CH, SP-SC). It was also classified as highly plastic soil with plasticity index above 17% and expansive (Gopal and Rao, 2011). Table 2 presents that the test materials have high aluminosilicate content and possess pozzolanic properties with aluminosilicate strength of over 70% (ASTM C618, 2014).

Table 1. Geotechnical Properties of the Test Soil

Soil properties	%passing no. 200	NMC (%)	LL (%)	PL (%)	PI (%)	Cc	Cu	AASHTO	USCS	OMC (%)	MDD (g/cm^3)
Results	42	13	40	18	22	4.54	4.23	A-7-6	CP/CH	16	1.83

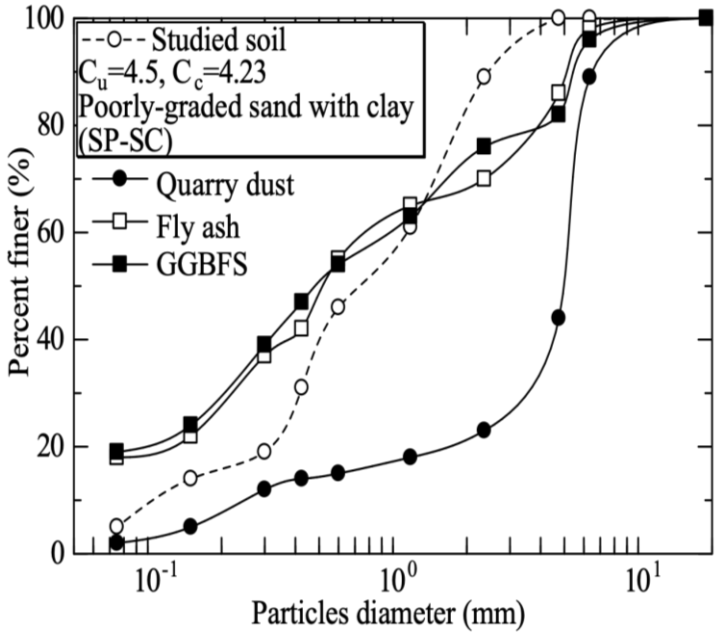


Fig. 1. Grain size distributions of studied materials

Table 2. chemical oxide composition of the test materials

Materials	Oxides Composition (content wt %)												
	SiO2	Al2O3	CaO	Fe2O3	MgO	K2O	Na2O	TiO2	LOI	P2O5	SO3	IR	Free CaO
Test Soil	77.73	16.65	1.42	3.22	0.07	0.89	0.02	-	-	-	-	-	-
QD	63.48	17.72	5.56	1.77	4.65	2.76	0.01	3.17	0.88	-	-	-	-
FA	63.45	4.14	12.11	1.23	0.78	1.09	0.01	1.78	1.89	0.71	0.11	-	0.03
GGBFS	33.45	12.34	42.10	0.05	11.45	-	-	-	0.21	-	-	-	0.40
DOPC	21.45	4.45	63.81	3.07	2.42	0.83	0.20	0.22	0.81	0.11	2.46	0.16	0.64

*IR is Insoluble Residue; LOI is Loss on Ignition, FA: Fly Ash

QD: Quarry Dust, GGBFS: Ground Granulated Blast Furnace Slag

DOPC: Dangote Ordinary Portland cement

Suction of the treated clayey soil under varying curing time

The effect of varying proportions of QDbGPC by weight of treated sample on the suction of the treated soil expressed as the percentage of the original mass of the treated sample under varying curing time on both cemented and non-cemented soil was presented in Fig. 2. It was observed that increased proportion of QDbGPC brought about a reduced suction on both cemented and non-cemented treated test soil and at the same time at a prolonged curing time, suction equally reduced. The consistently reduced suction with the increase in QDbGPC proportion may be due to the GPC acting as fillers to reduce the porosity of the treated soil thereby reducing suction. The reduction in porosity reduced the quantity of cementitious products occupying the matrix voids eventually reducing suction (Onyelowe et al., 2020; Meegoda and Ratanweera, 1994; Gidigasu and Dogbey, 1980). At increased QDbGPC, the treated soil achieved a more densified microstructure which does not allow the absorption of moisture due to the flocculation and agglomeration of the treated soil particles (Meegoda and Ratanweera, 1994). Hydration reaction of a GPC takes place at room temperature within 24 hours letting the material at high degrees of suction within which it gains its maximum strength and used up the highest amount of moisture needed for this process (Onyelowe et al., 2020; Austroads, 2002). This showed that if water is used as pore fluid, the influence of the mechanical factors would remain the same (Meegoda and Ratanweera, 1994; Gigigasu and Dogbey, 1980; Austroads, 2002; BS 8615-1, 2019). During this procedural exercise, the rate of suction decreased as the water content of the treated matrix increased even at increased water exposure time (Bui and Onyelowe, 2018; Hervé et al., 2009). So, at prolonged curing beyond 24 hours, the rate of moisture intake is reduced drastically hence the behaviour that was observed (Gidigasu and Dogbey, 1980).

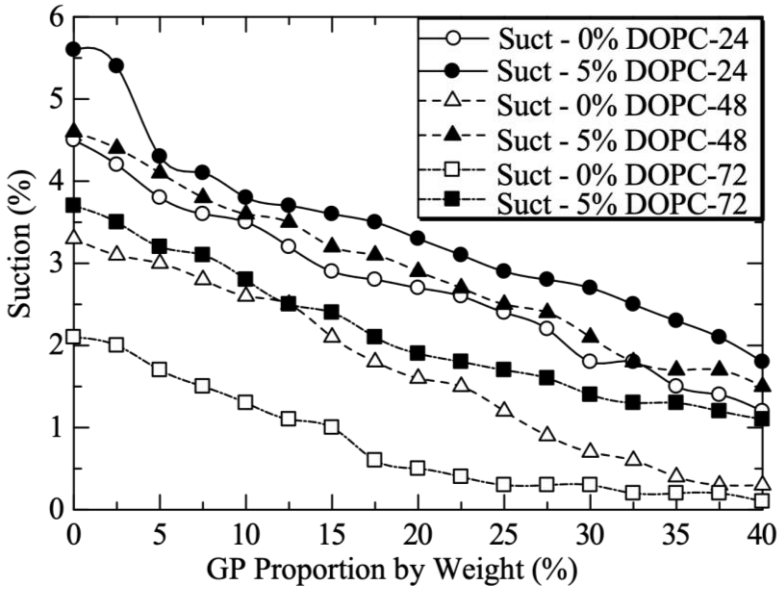


Fig.2.Effect of Geopolymer Addition on the Capillary Rise at different curing time on the treated Soil

CONCLUSIONS

Taking into consideration the results of the laboratory exercises conducted on the QD base GPC treated soil, it can be concluded with the following remarks;

1. The test soil was tested for the basic properties and results show that it was classified according to AASHTO classification system and USCS as A-7-6 and GP groups respectively; it was also classified as a highly plastic soil with plasticity index above 17% and expansive.

2. The QD base GPC was synthesized in accordance with the conditions suggested by previous research findings, was used to treat the test soil under the laboratory conditions and was added in the proportions of 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5 and 40% and under varying water exposure time to determine the capillary and suction behaviour and strength development behaviour of the treated soils.

3. The alkali-activated (NaOH + Na2SiO3) cement produced under dry condition provided the possibility to adapt waste inorganic materials and the properties of such cements are always better than those of ordinary Portland cement (OPC). The concentration of NaOH was kept lower than the concentration of Na2SiO3 to check the excessive release of OH- which may have led to inefficient geopolymerization reaction.

4. Results from the above procedure showed that the QD base GPC treated soils demonstrated significant and consistent reduced suction with increased QD base GPC proportion by weight. This showed that the properties of GPC may be fully utilized in the stabilization protocol to achieve a hydraulically bound stabilized material that possesses resistant to high moisture exposures. This behaviour may be attributed to the properties of the constituent elements of the GPC where GGBFS produced high level of calcium and QD produced high

concentration of aluminosilicates, which contributed to prolonged hydration, calcinations, cation exchange reactions and polycondensation.

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