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MICROSTRUCTURAL INVESTIGATION AND STRENGTH PROPERTIES OF CLAY STABILIZED WITH CEMENT, RICE HUSK ASH AND PROMOTER

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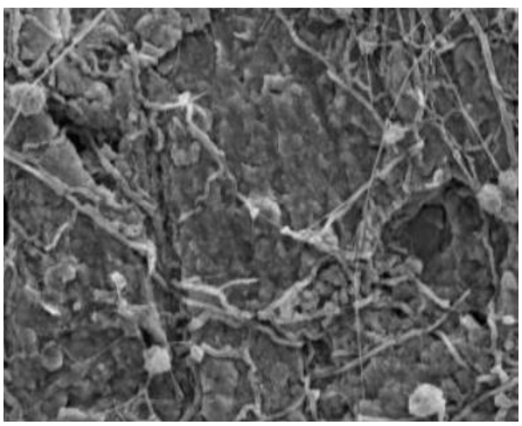
Graphical abstract



Abstract

A clay soil, classified as Clay of High plasticity (CH) according to Unified Soil Classification System (USCS) was stabilized with cement, Rice Husk Ash (RHA) and promoter. The mineralogy of the clay soil and the morphology of the clay and clay specimens admixed with varied composition of cement, RHA and promoter were evaluated in order to determine effect of the RHA on promoter stabilization of cement based clay soil. The promoter used in this study consists of calcium chloride and sodium hydroxide in the ratio of 1:1. The clay was remolded at standard Proctor compaction energy and the specimens were mixed with 0, 1.0, 2.0 and 3.0% cement, admixed with 1.0, 2.0, 3.0% RHA each, and 0.3, 0.6, 1.0% promoter each. The molded specimens were cured for 1, 7, 14, 28, 60 and 90days before testing for Unconfined Compressive Strength (UCS) and consequently the modulus of elasticity. The UCS of specimens without cement increased from 20 kN/m^2 for the natural clay soil to 95 kN/m^2 on addition of 3% RHA and 1.0% promoter after 28 days of curing, representing 475% increase in the UCS. This increase was confirmed by morphology of the clay soil mixed with RHA and promoter only, which showed presence of calcium silicate hydrate. Addition of 3.0% cement with 3 and 1.0% RHA and promoter respectively, increased the UCS from 220 to 375kN/m^2 after 28 days of curing, which was also confirmed by the morphology of the specimens. The highest elastic modulus of 48.3 MPa was observed at specimens containing 3% cement, 3% RHA and 1.0% promoter.

Keywords: Cement based clay, Microstructure, Promoter, Rice husk ash, Stabilization

1.0 INTRODUCTION

Stabilization of deficient soils with cement has been in use for decades [1]. Tsuchida and Tang [2] studied stabilization of marine clay using cement and developed a relationship to evaluate Unconfined Compressive Strength (UCS) of the soil treated with cement. Remarkable increase in properties of the stabilized soils was recorded. However, production of cement was later observed to be capital intensive and demanding enormous energy. These prompted some researchers to source for cheaper and available alternative soil stabilization additives, which can be used either solely or as admixtures to cement. These by-products range from industrial to agricultural wastes. Osinubi and Mustapha [3] worked on stabilization of deficient lateritic soil with cement and sugarcane bagasse ash, using UCS as evaluation criteria and observed 8% bagasse ash content (by weight of the dried soil) as the optimal mixture that gave highest strength and stability. Osinubi and Alhassan [4] carried out similar work, but using shear strength parameters as evaluation criteria. Mosa *et al.* [5] worked on improvement of properties of expansive soil using Cement Kiln Dust (CKD) and observed 14% CKD (by weight of the dry soil) as optimal in terms of strength. The swelling ratio of the clay was also observed to reduce from 23 to 9%. Bahmed *et al*. [6] stabilized clay soil with lime, and using Artificial Neural Network (ANN), evolved three models to predict Plasticity Index (PI), Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

Samanta [7] worked on investigation of geomechanical and microstructural characteristics of cement-stabilized fly ash, using two class F Fly Ashes (FA), which were stabilized with up to 10% cement and cured for 7, 14, 21 and 28 days. The results showed improvement in geotechnical properties of the ashes. Priyadarshee and Malik [8] worked on effect of RHA, fly ash and stone dust on compaction and swelling characteristics of black cotton soil, using standard Proctor compaction and one dimensional consolidation tests as evaluation criteria for compaction characteristics and swell respectively. The result showed decrease in OMC due to addition of the fly ash and stone dust. Vichan and Rachan [9] studied mixture of Calcium Carbide Residue (CCR) and Biomass Ash (BA), which will cause Pozzolanic reaction. The high pH value, resulting from the dissolution of these mixtures, dissolves the amorphous silica from the BA to form cementitious materials. Using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD), presence of ettringite and calcium silicate hydrate (C-S-H) were confirmed. 20% binder content was observed to be the optimal, required to give maximum strength after curing. Stabilization of silty clay using CCR and fly ash was carried out by Horpibulsuk *et al.* [10], by studying strength development in the mixtures. The study identified three zones, which were described as active, inert and deterioration zones. In the active zone, the natural Pozzolanic nature of the clay is enough to produce a Pozzolanic reaction and would not need FA. In the deterioration zone however, free lime hinders strength development, making the use of this zone completely discouraged. Apart from the strength gain, it was also observed that the ratio of un-soaked to soaked UCS ranges between 0.45 and 0.65.

Using soil, stabilized with bottom ash and strength as evaluation criteria, Gullu [11] employed factorial experimental approach to determine effective dosage rate of the stabilizer, and concluded that the approach and effective size estimation compared well in decision making. Mangi *et al*. [12] also showed that admixture of coal bottom ash and cement can reduce the negative effect of sulphate and chloride on the performance of cement. The negative effect of sulphate on cement was also studied by Demir *et al*. [13], and concluded that strength of specimens containing blend of cement with fly ash, bottom ash and blast furnace slag, cured in sodium sulphate solution for 360 days, increased by 2.0% compared to the controlled specimens. Thakare and Chauhan [14], treated soft black cotton soil with a mixture of micro-silica, lime and fly ash for pavement, and observed that with addition of 5% micro-silica, 3% lime and 3% fly ash, the CBR value increased by 3.8 times that of the unstabilized soil. Zhao *et al*. [15] worked on effect of some chemicals (lime, potassium based agent and a group of ionic agents) on expansive properties of swelling clay using laboratory injection method. The result showed that potassium based stabilizer is effective agent in control swelling potential of expansive clay soils. Du *et al*. [16] carried out field evaluation of strength properties of highway subgrade, stabilized with CCR, using California Bearing Ratio (CBR) test, plate loading test, dynamic cone penetration test and beam deflection tests as evaluation criteria on the compacted surface, and concluded that CCR is a viable alternative for stabilizing soft subgrade soils. Stabilization of kaolin clay at ambient temperature, using FA based geopolymer with Ground Granulated Blast Furnace Slag (GGBFS) was studied by Abdullah *et al*. [17], by carrying out comprehensive tests (index properties tests, strength tests, durability and leaching tests) on various mixtures of the materials, and showed that introduction of GGBFS as partial replacement for FA increases the strength of geopolymer stabilized clay soil. Changizi and Haddad [18] studied effect of nanocomposite on strength parameters of soils, by using glass fiber, mixed with nano-clay, and showed that nano-glass and nano-clay effectively improved engineering properties of clay soil. The author worked on improving geotechnical properties of soft clay with nano-silica particles, by studying compaction characteristics, CBR, consolidation and UCS of the stabilized soft clay, and concluded that increase in nano-silica improved the engineering properties of the soil.

Yoobanpot *et al.* [19] investigated the use of CKD and FA, as compared to cement, in improvement of strength of soft Bangkok clay. Using XRD and SEM tests to observe the type of reaction products that resulted from the reactions, they concluded that 13 and 20% CKD and FA respectively forms the optimum composition that gave the highest strength. Yoobanpot and Jamsawang [20] worked on soft soil stabilization with cement and RHA, and observed 30% RHA as the optimum to give maximum strength. Prasad *et al*. [21] studied effect of RHA on cement stabilized soft clay soil, considering MDD, OMC and UCS. Effect of natural pozzolana on geotechnical properties of lime stabilized clay was investigated by Al-Swaidani *et al*. [22]. The authors used 0 to 20% natural pozzolana and 0 to 8% lime, with consistency, compaction, CBR and linear shrinkage as evaluation criteria. Results showed that addition of natural pozzolana adversely improved the engineering properties of the clay. Permanent deformation behavior of subgrade soil stabilized with FA and RHA was studied by Anupam *et al.* [23], using resilient strain, permanent strain and resilient modulus from soaked CBR and UCS of specimens, compacted at modified Proctor, as evaluation criteria. It was concluded that better performance was demonstrated by subgrade soil admixed with FA and RHA. Geotechnical properties of clay soil stabilized with RHA and RBI grade 81 was studied by Kumar and Sharma [24]. Using compaction, UCS, modulus of elasticity and CBR as evaluation criteria, it was observed that strength increase with increase in the admixtures, with optimal performance at mixture of 86% clay, 10% RHA and 4% RBI grade 81. Xiao *et al.* [25] used SiO_2 and TiO_2 as Pozzolanic and non-Pozzolanic nanomaterials respectively, to treat cement-based material, with the aim of evaluating effect of reactivity, size and content on performance of the nanomaterial in the cement-based materials. Result showed that Pozzolanic nanomaterial performed better in terms of reactivity, while non-Pozzolanic nanomaterial performed better by reducing porosity of the cement-based material.

Potential of sodium silicate as clay stabilizer have recently been discovered. The work of Moayedi *et al.* [26] on effect of stabilizing soft clay with small percentage of sodium silicate showed that highest strength was obtained on addition of 5 mol/L sodium silicate. The use of sodium silicate in mine back-fill was also reported by Kermani *et al.* [27] in which series of laboratory experiments were carried out on gelfill and cemented hydraulic fill. Using UCS as evaluation criteria, the results showed that addition of appropriate amount of sodium silicate tremendously increased the strength and water retention properties of the backfill.

This technology was later extended to stabilization with sodium silicate in the presence of promoters. Cong *et al.* [28] stabilized cement-based clay soil with sodium silicate and composite promoter. The promoters used were sodium hydroxide and calcium chloride, which were individually added to the system to allow for reaction to form calcium hydroxide in the presence of sodium silicate and cement. Using UCS, failure strain and secant modulus as evaluation criteria, the results showed that addition of less than 2% sodium silicate and less than 4% promoter gave much enhanced UCS and other mechanical properties of the clay soil. The influential factors involved in cement-based stabilization of clay with sodium silicate and promoter as reported by Ma *et al*. [29], are the type of promoters, proportion of each binding agent, the binder content and curing time. It was observed that less sodium silicate and promoter is required to achieve higher UCS than equivalent amount of cement. They also observed that 1:1 ratio of calcium chloride to sodium hydroxide gave the highest strength. The use of UCS and SEM to effectively studied effect of sodium silicate and promoter was highlighted by Ma *et al*. [30]. They reported that 5 and 8% cement and composite promoter respectively, gave strength that is equivalent to that of 12% cement. The mechanism controlling strength development in clay-based stabilization with sodium silicate and composite promoter was investigated by Ma *et al*. [31], using mechanical, microstructural and mineralogical studies. They revealed that UCS and secant modulus increased with increase in composite promoter, while the microstructural analysis confirmed the formation of C-S-H gel in the stabilized clays.

Du *et al*. [32] studied effect of sodium hydroxide, calcium chloride, sodium silicate and triethanolamine on engineering properties of clay, and discovered that cement-based stabilizer supplemented with 1.5% promoter could produce more CSH gel and can effectively bond soil particles together. However, out of all the three chemicals that form the promoter system, sodium silicate is observed to be more expensive and more difficult to handle, this work is therefore aimed at studying the effect of these promoters on Black Cotton Soil (BCS) when sodium silicate is replaced with Rice Husk Ash (RHA).

2.0 METHODOLOGY

2.1 Materials

The materials used in this study are Black Cotton Soil (BCS), cement, Rice Husk Ash (RHA), calcium chloride, sodium hydroxide and distilled water (Figure 1). The BCS was collected at Bako village, along Gwagwalada–Abuja road using method of disturbed sampling. The soil was air-dried and prepared according to the method highlighted in BS 1377 [33]. The sodium hydroxide and calcium chloride pellets were obtained from a laboratory equipment vendor in Ibadan, Nigeria and formed into desired molarity in Biochemistry laboratory of Federal University of Technology, Minna. The distilled water was obtained from a hospital equipment vendor opposite General Hospital, Minna, Niger State, Nigeria. The cement was procured from a vendor at Gidan Kwanu village, opposite main campus, Federal University of Technology, Minna, Niger State, Nigeria. The RHA was however, obtained by collecting rice husk from a milling center and burning in a furnace at Urban Shelter Clay Bricks Company at Pogo village, along Paiko–Minna road, Niger State, Nigeria, at temperature of 700˚C.

Figure 1 Additives used: a) sodium hydroxide, b) calcium chloride, c) distilled water, d) cement, e) RHA

2.2 Methods

The method involved carrying out index properties tests in Civil Engineering Laboratory, Federal University of Technology, Minna, Niger State, Nigeria, on the clay soil using the methods highlighted in BS 1377 [33] and the results were used to classify the clay soil. X-Ray Diffraction (XRD) test was carried out at Ithemba Laboratory, Somerset West 712, South Africa. Phase characterization of the minerals and estimate of the average crystallite size of the various synthesized materials were conducted on a Bruker AXS D8 XRD system.

Energy Dispersive Spectroscopy (EDS) test was also carried out at Electron Microscope unit, Department of Physics, University of Western Cape, South Africa. 0.05 mg of the synthesized materials, sprinkled on a sample holder, covered with carbon adhesive tape and wire sputter coated with Au-Pd using Quorum T15OT for 5 minutes prior to analysis. The sputter coated samples were characterized using Zeiss Auriga HRSEM.

The Scanning Electron Microscopy (SEM), which visualizes morphology and microstructure of the synthesized products were analyzed using Zeiss Auriga HRSEM. 0.05 mg of the synthesized materials were sprinkled on a sample holder, covered with carbon adhesive tape and were coated with Au-Pd for 5 minutes before analysis. The sputter coated samples were evaluated using Zeiss Auriga HRSEM. This was carried out to determine the structure of the mineral particles contained in the clay. X-ray fluorescence was conducted on the natural clay only. The test was also carried out in Scientific center, Cape town, South Africa.

The clay soil was compacted at standard proctor compaction energy level to obtain the MDD and OMC. Using the obtained OMC, the clay mixed, with varied quantities of cement, promoter (1:1 ratio of $CaCl_2$ and NaOH) as recommended by Ma *et al.* [30] and pozzolanic RHA, was remolded at the predetermined compaction energy level. The RHA, been a pozzolanic material, was intended to substitute Na_2SiO_2 solution in the mixture. The remolded mixtures are shown on Table 1.

The remolded specimens were cured and tested for UCS (Figure 2) after 1, 7, 14, 28, 60 and 90 days of curing. This was used to evaluate the effect of RHA on promoter stabilization of cement-based clay soil.

Figure 2 Unconfined compressive strength test

Table1 Mixtures of cement, Rice husk ash and Promoters

Cement (%)	RHA (%)	Promoter (%)
0.0	0.0	0.0
	1.0	0.3
	2.0	0.6
	3.0	1.0
1.0	0.0	0.0
	1.0	0.3
	2.0	0.6
	3.0	1.0
2.0	0.0	0.0
	1.0	0.3
	2.0	0.6
	3.0	1.0
3.0	0.0	0.0
	1.0	0.3
	2.0	0.6
	3.0	1.0

3.0 RESULTS AND DISCUSSION

3.1 Index Properties of the Soil

Results of the physical properties of the clay soil are shown on Table 2. As seen from the table, the clay soil classified as Clay of High plasticity (CH) based on BS 5930 [34]. The grain size analysis of the clay soil is shown on Figure 3. The grain size distribution showed gap-graded clay soil. The gap-gradedness is between 65 to 82% passing. This will create pores within the clay mass which can affect the compressibility of the molded clay.

Table 2 Summary of Index Properties of the clay

Description	Quantity
Sand	18.4
Silt	28.9
Clay	53.0
Liquid limit	64.3
Plasticity Index	35.9
Specific Gravity	2.66
MDD (Standard Proctor compaction)	1.634
OMC (Standard Proctor compaction)	24.5
AASHTO soil classification	A-7-6
Unified Soil classification	CH

3.2 Oxide Composition of the Clay

Result of the X-ray fluorescence test carried out on the clay is shown on Table 3. The oxides composition of the clay showed high percentage of silica and alumina, which are both important in formation of cementatious compounds in the presence of calcium ion. The 7.81% iron oxide content is relatively high. The RHA however, possesses 86.25% of silica, which classify it under class A pozzolana with little percentage of all other oxide compositions. Addition of the clay and RHA in the absence of any source of calcium ion will result into disadvantageous results.

3.3 Structure and Mineralogy of the Soil

Result of Scanning Electron Microscopy (SEM) and Electron Dispersion Spectroscopy (EDS) are shown in Figures 4 and 5. The EDS result showed 24.9% carbon, 39.8% oxygen, 0.76% magnesium, 9.8% Aluminium, 17.4% silicon, 0.59% potassium, 0.54% calcium, 0.36% titanium and 5.6% iron. The SEM image of the soil, remolded at standard Proctor compaction energy level (Figure 4), revealed occasional presence of air voids (as highlighted in the figure) and dense fabric of flecky clay particles similar to those reported by Zang *et al*. [35], Jaiswal and Lal [36] and Abdullah *et al*. [17].

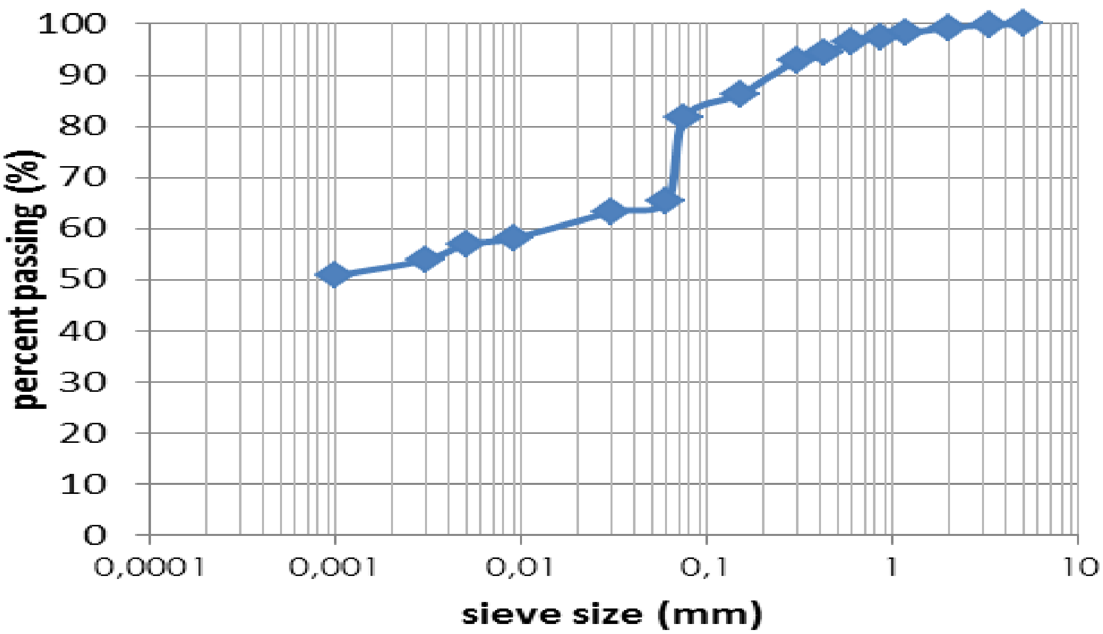


Figure 3 Grain size distribution for clay soil

Table 3 Oxide Composition of Clay and Rice Husk Ash

Oxide (%)	Fe_2O_3	MnO	Cr_2O_3	V_2O_5	TiO_2	CaO	K_2O	P_2O_5	SiO_2	Al_2O_3	MgO	Na_2O	LOI
Clay soil	7.81	0.22	0.01	0.03	1.57	2.13	1.68	0.11	58.81	15.86	0.99	1.16	8.99
RHA	0.45	0.13	0.01	0.00	0.15	0.76	1.03	3.56	86.25	0.96	2.08	0.14	3.92

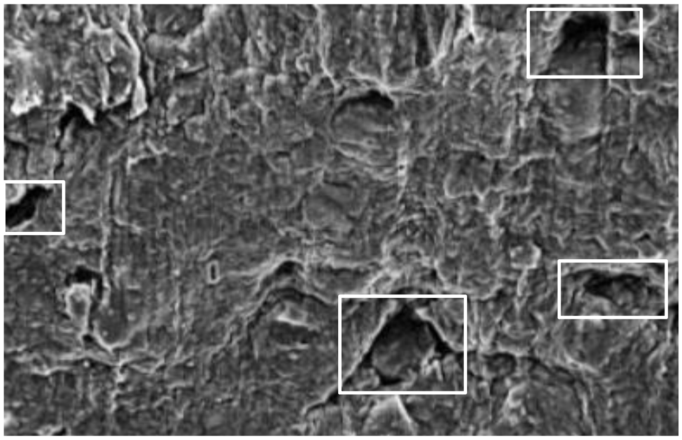


Figure 4 Result of SEM Test

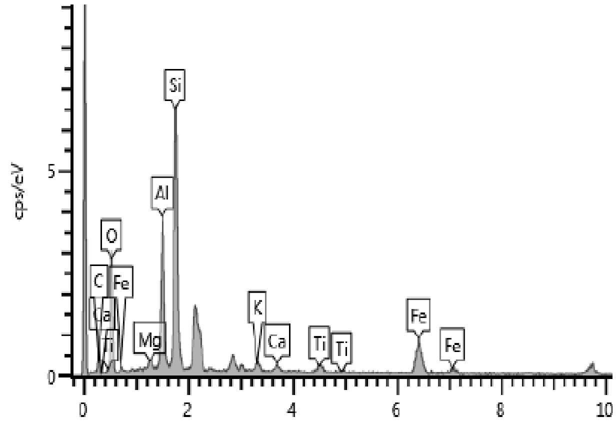


Figure 5 Result of EDS test

Figure 6 present result of XRD test on the clay soil. The result indicats that the soil contains substantial composition of minerals, including montmorillonite, ankerite, calcium silicide, anorthite, anothoclase and orthoclase minerals. These are both primary and secondary minerals. Montmorillonite can increase activity, and hence the consistency of the clay soil. The MDD and OMC of the clay soil, compacted at Standard Proctor energy level was observed to be 1.634 g/cm^3 and 18.5% respectively.

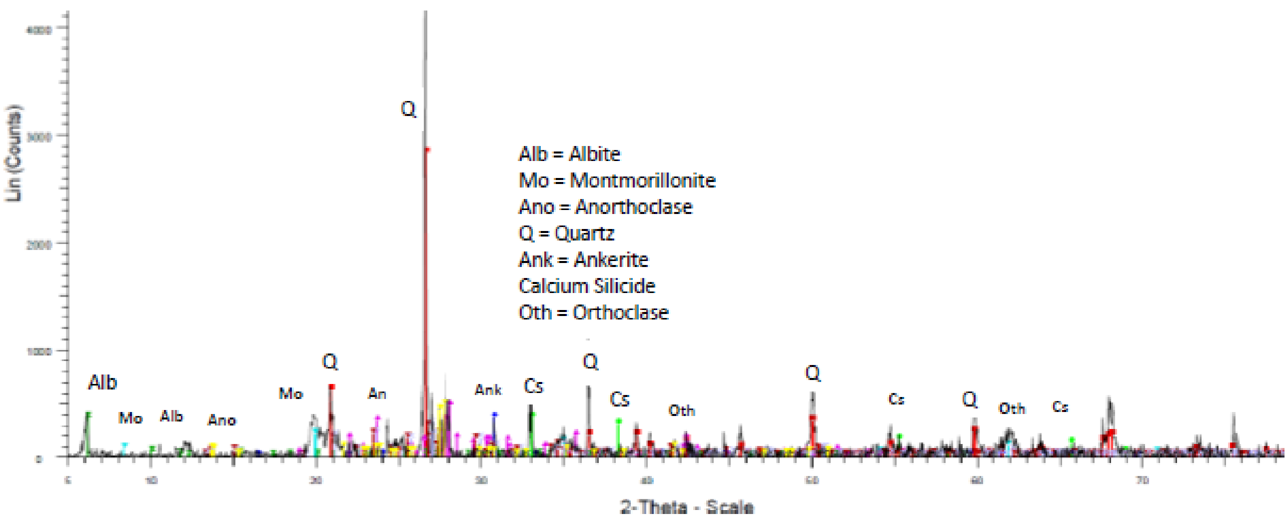
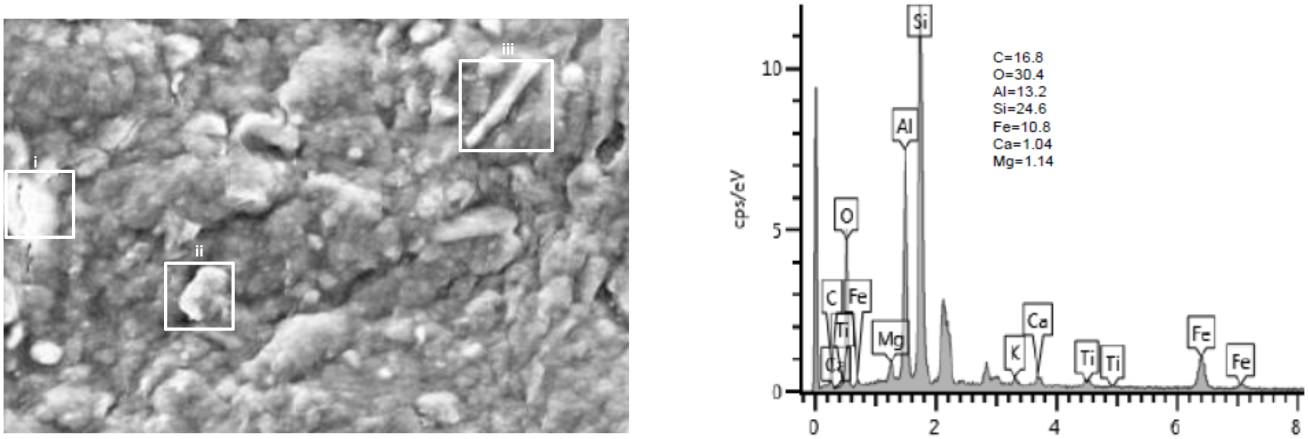


Figure 6 Graph of XRD Result

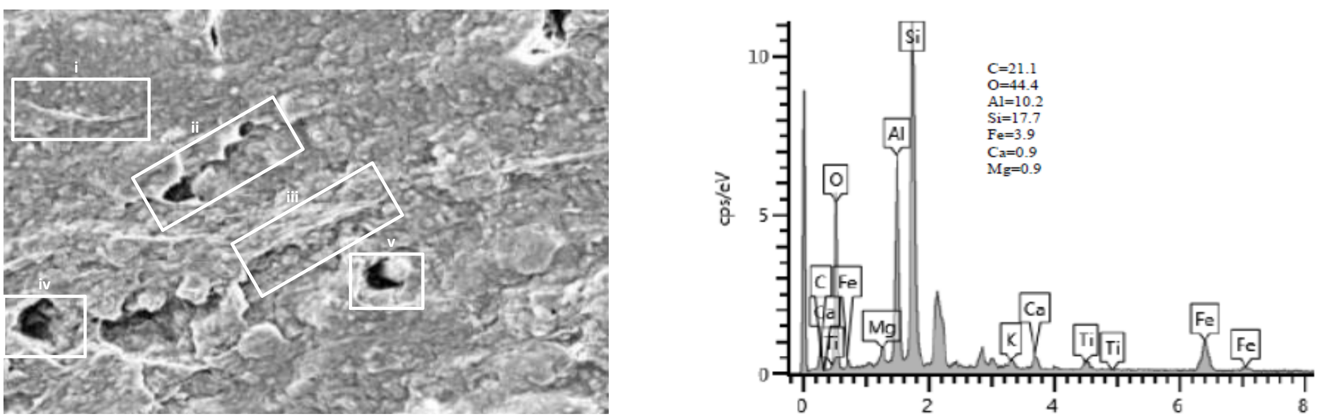
3.4 SEM and EDS Results of Some Sellected Mixtures

SEM and EDS analysis were conducted on some sellected mixtures to investigate and confirm the changes in strength, observed in some of the remolded mixtures. Figures 7 to 11 show the surface mophology of some selected samples which can be compared with the SEM result of the natural clay soil shown in Figure 4. Figure 7 (a) and (b) is the SEM and EDS results respectively, of specimen containing 0% cement, 3% RHA and 1.0% promoter. The SEM result shows whitish formation of cementetious material (marked i, ii and iii on Figure 7-a), with some forming slight fibrous of C-S-H gel (marked iii on Figure 7-a). This is a clear indication that RHA and promoter reacted effectively to form cementetious material in the absence of cement. Addition of 1.0% cement and reduction of RHA and promoter to 1.0% and 0.3% respectively (Figure 8), resulted in the transformation of the slight fibrous gel observed on Figure 7-a, to a thin laminated C-S-H gel (marked i and iii on Figure 8-a). Some occational pore spaces (marked ii, iv and v on Figure 8-a), which is higher than the mixture in Figure 7-a, were also observed.



(a) (b)

Figure 7 SEM (a) and EDS (b) for 0%C/3%RHA/1.0% Pro



(a) (b)

Figure 8 SEM (a) and EDS (b) for 1%C/1%RHA/0.3% Pro

Increase in cement content to 3.0% (Figure 9) without RHA and promoter shows tremendous formation of fibrous C-S-H gel quite higher than that observed in Figure 7 and 8, coupled with some few pores. Addition of 3.0% RHA and 1.0% promoter (Figure 10) resulted in the formation of a closely bonded, dense laminated C-S-H gel. This also showed that the additives (RHA and promoter) reacts effectively with cement to form cementatious metarials. This mixture showed tension crack (higlighted on Figure 10-a), which must have resulted from dehydration during reaction of the cement, RHA and promoter. Figure 11 consists of 2.0% cement, 2.0% RHA and 0.6% promoter. This mixture also resulted in formation of laminated C-S-H gel, giving rise to the dense microstructure. Little cracks were also observed in the specemen but much less than those in Figure 10.

The microstructural image of the soil containing 3% cement, 3% rice husk ash and 1% promoter cured for 28 days (Figure 10) showed a structure with high homogeneity, in which some unreactive particles closely bonded with the C-S-H gel [35]. The observed micro-cracks may have resulted from shrinkage due to curing.

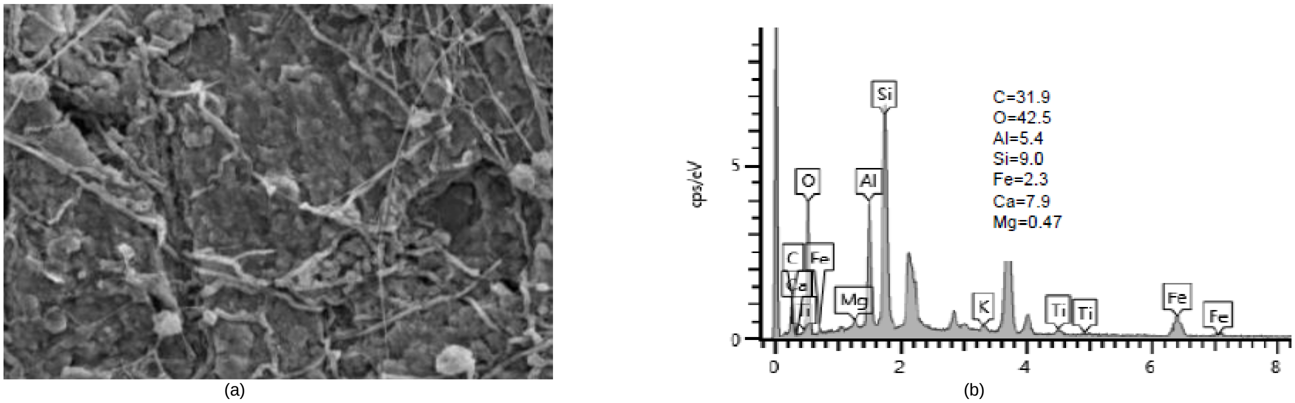


Figure 9 SEM (a) and EDS (b) for 3%C/0%RHA/0% Pro

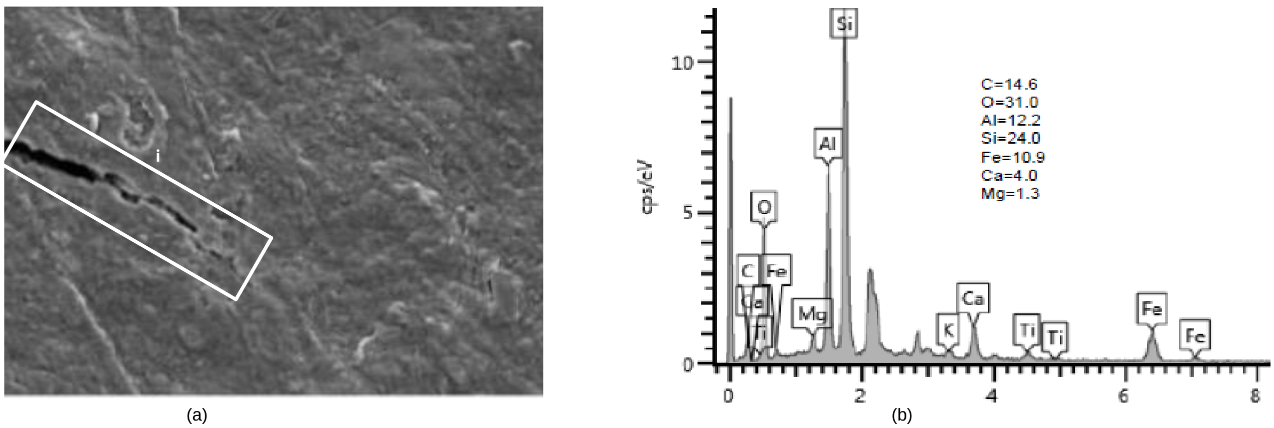


Figure 10 SEM (a) and EDS (b) for 3%C/3%RHA/1.0% Pro

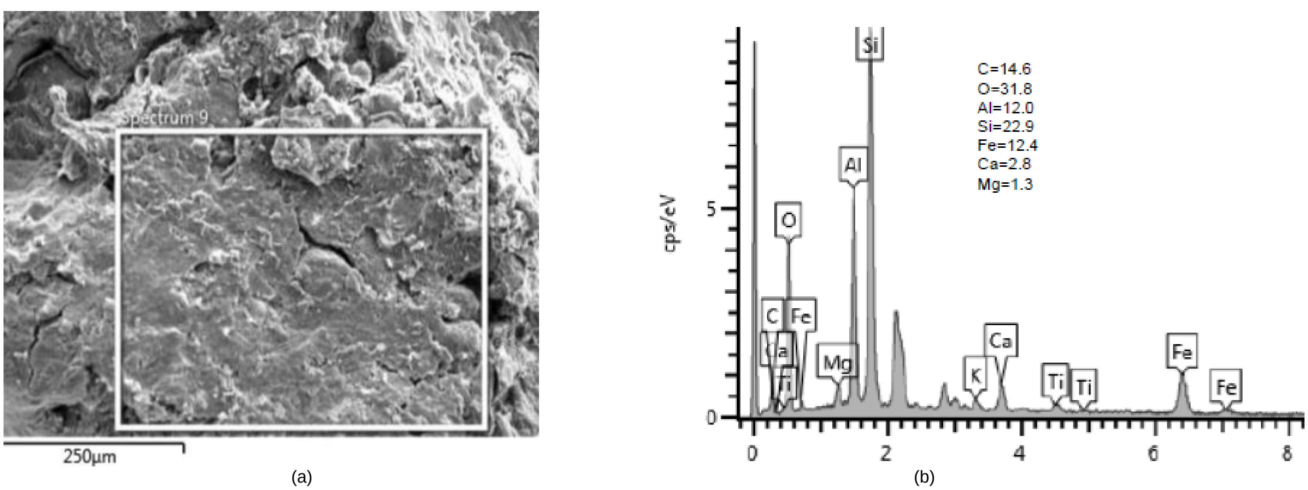


Figure 11 SEM (a) and EDS (b) for 2%C/2%RHA/0.6% Pro

3.5 Variation of UCS with RHA and Promoter at Varied Curing ages

For 0% cement and 1 day curing (Figure 12-a), the UCS values increased from 20 kN/m² at 0% RHA and Promoter to 60 kN/m² at 2% RHA and 0.6% promoter, after which the values reduced to 52 kN/m² at 3% RHA and 1.0% promoter. This represents 200% increase in UCS on addition of 2% RHA and 0.6% promoter. These strength gains must have resulted from reaction between the two promoters (sodium hydroxide and calcium chloride).

$$NaoH + Cacl_2 \rightarrow Ca(OH)_2 + NaCl \quad (1)$$

The resulting cacium hydroxide reacts with the silicate ion present in the RHA to form the whitish cementatious cacium silicate hydrate (C-S-H), observed in Figure 7-a. At 2.0% RHA and 0.6% promoter, the UCS of the mixture increased from 63 kN/m² after curing for 7 days to 146 kN/m² after 90 days of curing. This represents 134% increase in strenght, which must have resulted essentially from pozzollanic reaction. Increase in RHA and promoter to 3.0% and 1.0% respectively, recorded slight reduction in strength. This is probably due to the complete utilization of the resultant calcium hydroxide by the silica in RHA, thus resulting to marginal decrease in UCS.

For specimen of 2.0% cement, cured for 1 day (Figure 12-c), the UCS increased from 112 kN/m^2 at 0% RHA and 0% promoter to 160 kN/m^2 at 3.0% RHA and 1.0% promoter, representing about 43% increase in UCS. When this mixture was further cured for 90 days, the UCS increased from 190 kN/m^2 at 0% RHA and 0% promoter to 360 kN/m^2 at 3.0% RHA and 1.0% promoter, representing about 90% increase in strength. At 3.0% RHA and 1.0% promoter, UCS of the mixture increased from 262 kN/m^2 after 7 days to 360 kN/m^2 after 90 days of curing, representing 38% increase. This must have resulted from pozzollanic reaction between calcium hydroxide, generated during the reaction of cement and silica present in the RHA. The observed increases in strength are justified by the whitish C-S-H gel, conspicuously observed in Figure 7-a. For 3.0% cement (Figure 12-d), the trend of the UCS was similar to that of 2.0% cement, except that the strength increase between 1 and 7 days was observed to be relatively higher than other curing ages. After 7 days curing, the strength increased from 200 kN/m^2 at 0% RHA and 0% promoter to 324 kN/m^2 at 3.0% RHA and 1.0% promoter, representing 62% increase in strength.

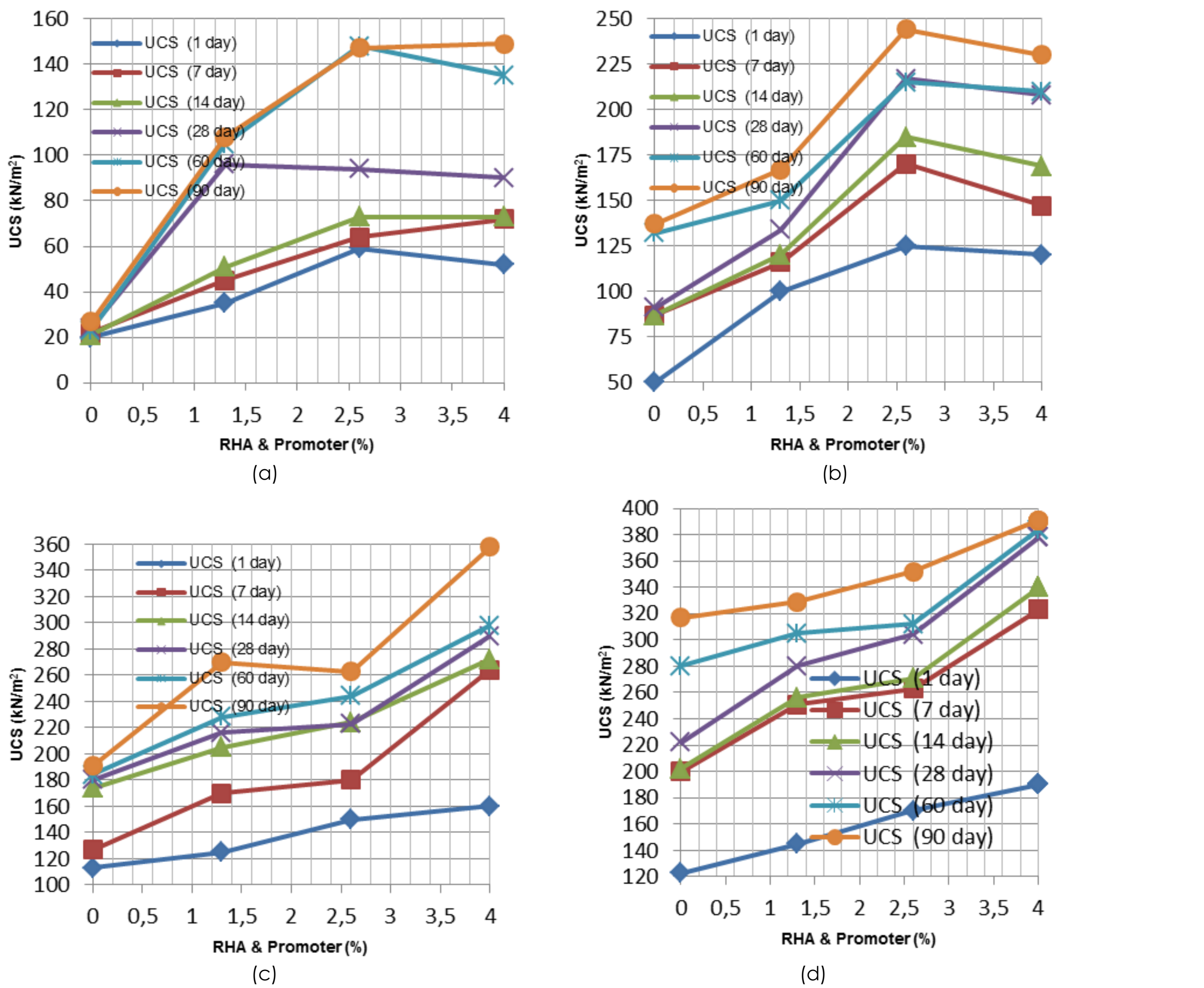


Figure 12 Variation of UCS with RHA plus promoter at 1, 7, 14, 28, 60 and 90 days, for (a) 0% cement, (b) 1.0% cement, (c) 2.0% cement, (d) 3.0% cement

3.6 Elastic Modulus of Compacted Specimen at Varied Mixed Proportions

Figure 13 a-d show the stress-train relationship of specimens at varied compositions of RHA and promoter at 0, 1.0, 2.0 and 3.0% cement. For 0% cement in Figure 13-a, the modulus of elasticity increased from 3111 kN/m^2 at 0% RHA and 0% promoter to 9555 kN/m^2 at 2% RHA and 0.6% promoter, after which the values reduced to 8000 kN/m² at 3.0% RHA and 1.0% promoter. The natural soil, which is represented by 0% RHA and 0% promoter showed initial concavity with stress-strain curve starting with gradual stiffness which increased after achieving some strain. This can be attributed to pores present in the clay mass due to gap-gradedness which gradually closed up on initial application of load. The stiffness is observed to have risen after closure of the voids. The stress-strain curves for clay soil, mixed with cement alone, without RHA and promoter(as shown for C = 1, RHA = 0, Pro = 0 in figure 13-b, C = 2, RHA = 0, Pro = 0 in figure 12-c and C = 3, RHA = 0, Pro = 0 in Figures 13-d), showed lower slopes compared with those samples admixed with RHA and promoters. The remaining curves show the strain at peak to reduce with increase in RHA and promoter, which is an indication of increase in rigidity with increase in RHA and promoter. This trend was observed to be similar for 1.0, 2.0 and 3.0% cements, which is in agreement with James and Pandian [37] and Cong *et al*. [38].

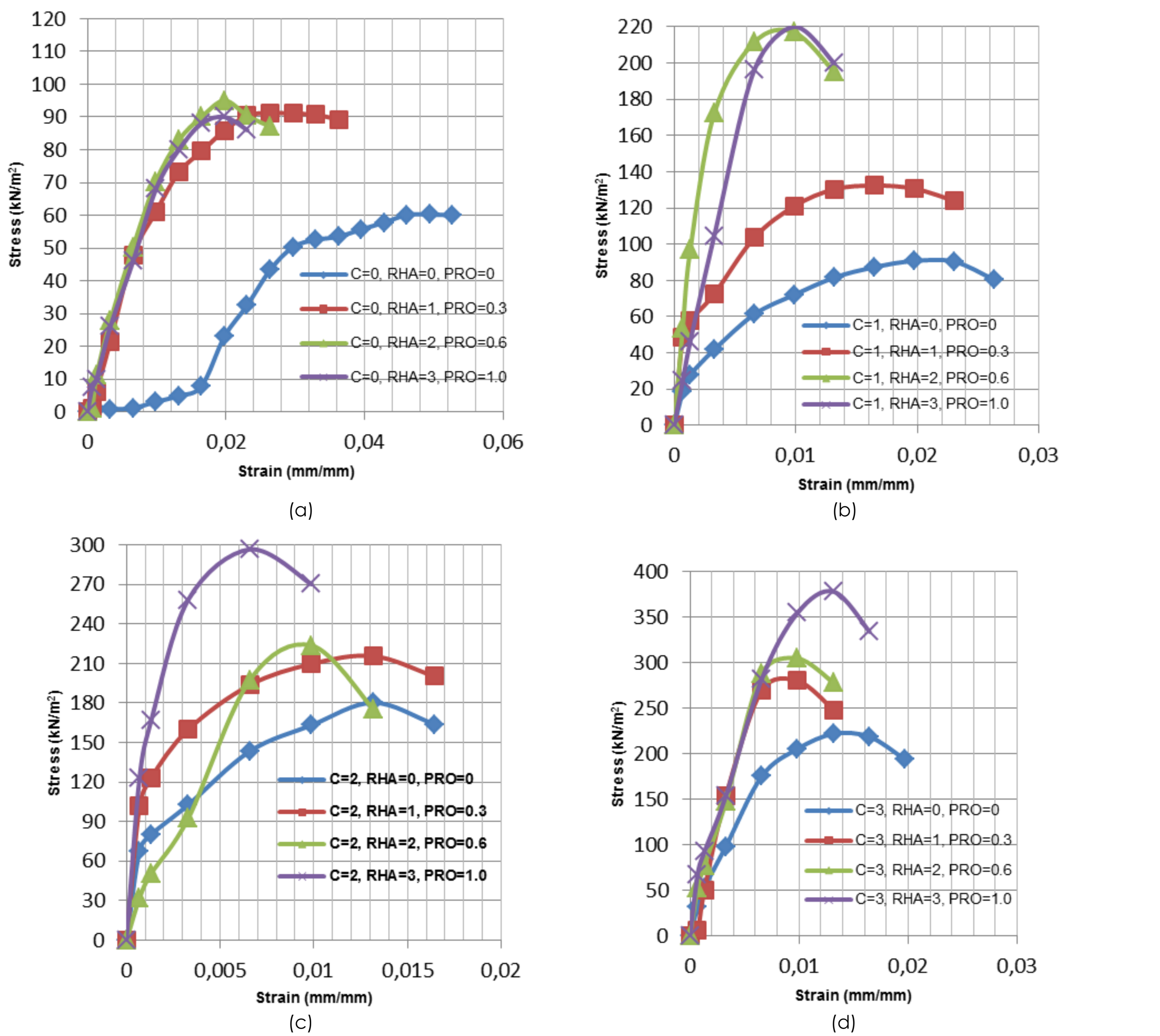


Figure 13 Stress-Strain curves for specimen cured for 28 days at varied mixtures: (a) 0% cement, (b) 1.0% cement, (c) 2.0% cement, (d) 3.0% cement

4.0 CONCLUSION

From the study, the following conclusion is drawn:

The clay studied classified as Clay of High plasticity (CH) base on based on BS 5930 and revealed gap-gradedness in its grain size analysis curve. This can cause pore spaces in the soil mass that can affect strength and compressibility of the molded clay.

The clay soil consists predominantly of primary minerals altering into secondary minerals including montmorillonite.

From both UCS and SEM test results, the strength of the soil specimens mixed with RHA and promoter without cement, increased by four times, indicating that RHA can substitute liquid silica in stabilization using promoter. However, the soil samples mixed with cement, without of RHA and promoter showed lower slopes in their stress-strain curves.

Specimens mixed with 3% cement, 3% RHA and 1% promoter recorded increased in UCS from 220 to 375 kN/m^2, which also represents 70.5% increase in UCS.

Maximum elastic modulus of 48.3 MPa was recorded with specimen containing 3% cement, 3% RHA and 1% promoter after 28 days curing.

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