Potential of Oyster Shell Ash Activated with Cement as soil Stabilizer for Road Construction

Gbenga Matthew Ayininuola, Olaniyi Diran Afolayan

Abstract*: *The study investigated the suitability of oyster shell ash activated with cement as additive to improve soil geotechnical properties. Three Lateritic soil samples were collected and stabilized with varying percentages of oyster shell ash (OYSA) from 2% - 15% activated with 5 % cement by dry weight. The mixtures' geotechnical properties: Atterberg limit, specific gravity, California bearing ratio (CBR) and shear strength parameters (cohesion and angle of friction) were determined. Chemical analysis of the oyster shell ash was carried out in laboratory. Results showed that the OYSA is rich in calcium and silicon oxides (CaO and SiO_2) with other oxides. OYSA addition led to increase in specific gravity (2.42 to 2.43 sample 1; 2.24 to 2.50 sample 2 and 2.25 - 2.28 sample 3) , improvement in Atterberg's limit through decrease in the plasticity index, increase in the CBR (22.5% - 145% sample 1, 0.54% - 30.78% sample 2 and 1.56% - 54.54% sample 3) and improvement of cohesive shear strength property (50 - 65kN/m^2 sample 1, 20 - 21 kN/m^2 sample 2, and 42 – 78 kN/m^2 sample 3)) due to the formation of cementitious layer and alteration in the structure and grain composition of soil samples. Therefore, using 6% OYSA activated with 5% cement will enhance soil geotechnical properties.

Index Terms*: *Oyster Shell Ash, Soil Stabilization, Geotechnical Properties, Lateritic Soil

I. INTRODUCTION

Site feasibility study is carried out to know the inherent geotechnical properties of proposed site is of far most beneficial before a project design and construction can take off. Site survey usually takes place before the design process begins in order to understand the characteristics of subsoil upon which the decision on location of the project can be made. The following geotechnical design criteria have to be considered during site selection: design load and function of the structure; type of foundation to be used and bearing capacity of subsoil. The bearing capacity of subsoil plays major role in site selection. If the bearing capacity of the soil is very low, the engineer would alter the design to suit site condition, carte away and replace the in-situ soil and relocate to suitable site. Abandoned sites due to undesirable soil bearing capacities drastically increased which led to scarcity of land and increased demand for natural resources.

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However, in most geotechnical engineering projects, it is rare to obtain a construction site that would meet the design requirements without modify the soil. The current practice is to modify the engineering properties of soils to meet the design specifications. Nowadays, soils such as, soft clays and organic soils can be improved or stabilized to meet the civil engineering requirements. Soil stabilization technique, which is normally used for improving local soils, is considered an economical solution in places where granular materials are not available. Hydrated lime and Portland cement are excellent stabilizers for improving different soils in many sites.

Ordinarily, stabilizers can promote soil plasticity reduction, grain size distribution alterations caused by flocculation reactions, and expressive mechanical strength increase. The geotechnical behavior of stabilized soil depends on physical and chemical properties of soils and are directly related to soil formation conditions and mineralogical composition of the matrix [1], [2]. In general, temperate soils, usually composed of active clayey soils (montmorillonites and smectites minerals) can respond better than tropical soils (kaolinite soils) after lime stabilization. However, experiences have shown excellent mechanical improvement in lateritic soils treated with lime or cement in roadways applications. Portland cement is made by blending the appropriate mixture of limestone and clay or shale together and heating them at 1450ºC in a rotary kiln. The preliminary steps involved variety of blending and crushing operations. The raw feed must have a uniform composition and be of size fine enough so that reactions among the components can complete in the kiln. Subsequently, the burned clinker is ground with gypsum to form the familiar grey powder known as Portland cement. The word oyster is used for number of distinct groups of bivalve molluscs that live in marine or brackish habitats. The oysters are highly calcified. Some kinds of oyster are commonly consumed by humans after cooking or raw state. Other kinds, such as pearl oysters, are not. Over the years, large quantities of oyster shells have accumulated in many parts of Nigeria such as Bori, Western Ijaw, Burutu, Agoro, Ogalaga and Lotugbene. A large amount of oyster shells ends up as waste and fishermen should take care of but it seems difficult to handle it effectively due to the problems of securing landfill sites and collection and transportation of oyster shells [3], [4]. These waste piles up at coastal areas and can cause environmental problems including pollution of coastal fisheries, water surface, damage of natural landscape, and health/sanitation problem. As a way of managing this waste, a number of useful materials have been produced from the discarded shell of oysters.

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A study of ground oyster shells found that the shell is mainly composed of calcium carbonate and small organic compounds [5], [6]. Also, crushed oyster shell is used as supplement in poultry feed and also to make an excellent clutch, the bed of material laid by planters in oyster rearing areas on which oyster spat can settle. However not much information is available on the effect of adding of oyster shell ash (OYSA) activated with cement on the geotechnical properties of lateritic soil which is the center focus of the present study.

II. PROCEDURE FOR PAPER SUBMISSION

The materials used for the study were: disturbed lateritic soil samples, oyster shell ash and cement. The three lateritic soil samples were obtained from three locations 7.8249°, 7.8245° and 7.8359° north and 4.1078°, 4.1074° and 4.1461° east. They were labelled 1, 2 and 3. The soil samples were taken at depths of about 1.2m below the earth surface to reflect the average depth of location of subsoil for foundation of structures in the study area. The oyster shell was obtained from riverine area (Fig, 1), air-dried, subjected to open air burning, calcined in an electric furnace at temperature of about 1000°C, milled and sieved with 75 micron sieve (Fig. 2). The percentage of cement used as activator was kept at constant rate of 5%. The lateritic samples were pulverized with mortar and pestle, air-dried and stock-pilled.

Fig.1. Showing Oyster Shell After Collection from a Riverine Area

The three lateritic soil were subjected to preliminary tests such as the natural moisture contents determination, specific gravity test, particle size analysis and the Atterberg's limits tests. The tests were carried out in accordance with [7] specifications. Further geotechnical properties tests carried out were compaction test to obtain soil maximum dry density (MDD) and the optimum moisture contents (OMC), California bearing ratio (CBR) test to determine soil resistance to load penetration and the undrained triaxial test to determine the shear strength of the soil samples. The tests were performed on stabilized soil samples that received different percentages of oyster shell ash OYSA (0 to 15%) and 5 % cement as activator in accordance with [7].

Fig. 2. Calcined Oyster Shell ash (OYSA)

III. RESULTS AND DISCUSSION

The results of the preliminary tests (grain size analysis, natural moisture contents, specific gravity, and Atterberg's limits test) as well as the engineering tests (compaction, California bearing ratio and triaxial test) carried out on both unstabilized and stabilized soils are presented below.

A. Preliminary Test Results

The grading test, natural moisture content, Atterberg's limit and soil classification of the three soil samples are presented in Table 1. The natural moisture contents of samples 1, 2 and 3 were 12.22, 15.28 and 9.04%, respectively and their specific gravities were 2.42, 2.18, and 2.25, respectively. The variation in soil samples' particle size analysis, Atterberg's limits and specific gravity with varied percentages of OYSA additive are shown in Figs. 3 to 8. Referring to Fig. 8, the specific gravity of the three samples fell within the range for clayey soil which is between 2.0 and 3.0 [8]. Sample 2 was the most expansive of the three samples due to its highest plasticity index. Samples 1 and 3 were A-2 soils and sample 2 an A-7 soils according to AASHTO method of classification and were sandy clay (SC) according to unified system of classification. The observed changes in grading curves, Atterberg's limits and specific gravity as shown in Table 1 were due to the denser nature of OYSA (2.59) and cement (3.15), changes in the silt, sand and clay constituents of the samples, pozzolanic reactions and flocculation of OYSA.

Generally, for all the samples' particle distribution curves, about 65% fine grain sizes were clay sized particles which further confirmed the results of the specific gravity test as shown in Table 1 and Fig. 8. The shifting of the grain size distribution curve (Figs. 3, 4 and 5) for stabilized soils was due to presence of silt sized particles from OYSA and cement. The shifting could also be attributed to the cation exchange process and some pozzolanic reactions among components in the soil matrix which caused the flocculation of clay particles [9]. The addition of OYSA and cement to samples 1 and 2 led to increase in their liquid limit (LL) and plastic limit (PL),

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thus causing reduction in their plasticity index (PI) which is in conformity with [10] in their findings that increase in liquid limit values show that the soil sample is clay mineral dependent. The reduction in their swell potential was as a result of the cation exchange that occurred when Ca^{2+}ions from the OYSA replaced weaker cations in the soil, resulting to stronger sealing of the voids through the agglomeration of the particles [9].

B. Engineering Test Results

The moisture density behavior, California bearing ratio (CBR) and the shear strength parameters of the three samples are shown in Table 2 and Figs. 9 to 13. The effect of the additives on the soils maximum dry density (MDD) is shown in Fig. 9. The increase in the soil MDD was as a result of increasing in additive particles that were involved in cations exchange and the soil particles, thus filling up the voids spaces resulting in the packing of soil particles together (Amu et al, 2011). The decrease in MDD recorded for soil 1 resulted from excess water and additive remaining after the soil had received optimum quantity of OYSA during the stabilization process. The decrease in soil optimum moisture content OMC shown in Table 2 could be attributed to absorption capacity of the OYSA ash due to its porous nature [11]. The increase in the soil OMC could be attributed to the hydration effect and the affinity for moisture of OYSA during the stabilization process.

The increase in soil CBR up to 6% OYSA addition as shown in Fig. 11 could be attributed to presence of Ca^{2+} in the additive leading to formation of cementitious compound, reduction in the swell potential and fineness ratio of soil. Also, increasing in soil workability, density and stiffness and formation of stronger and effective bonding of the soil particles to form a closely packed mass that would resist and inhibit water ingress into the soil matrix. The decrease in soils' CBR as OYSA added was increased beyond 6% was due to the increase in the fineness ratio of the samples resulting to formation of weaker bond among the soil particles. The increase in the cohesion property of the soils up to 6% OYSA as shown in Fig. 12 and Table 2 revealed the gaining in the soil strength as a result of presence of OYSA and cement. On the other hand, the reduction in soil cohesive property after 6% OYSA addition was due to change in the soil composition and structure [12].

Table 1. Summary of the Preliminary Test Carried Out on the Samples

Sample	NMC	Atterberg's Limit					Sieve Analysis	Soil Classification	
		Gs	LL (%)	PL (%)	PI (%)	SL (%)	% ≤ sieve No. 200	AASHTO	USCS
SAMPLE 1	**12.22**	**2.4**	41	**30**	**11**	**6**	**28.45**	**A-2-7(0)**	**SC**
5%CT 0%OYSA		2.5	48	39	9	6	28.97	A-2-6(0)	SC
5%CT 2%OYSA		2.6	49	39	10	5	30.97	A-2-6(0)	SC
5%CT 4%OYSA		2.6	49	40	9	5	31.35	A-2-6(0)	SC
5%CT 6%OYSA		2.7	45	41	4	5	29.6	A-2-6(0)	SC-SM
5%CT 8%OYSA		2.6	48	39	9	4	28.57	A-2-6(0)	SC
5%CT 10%OYSA		2.6	50	43	7	4	27.87	A-2-6(0)	SC-SM
5%CT 15%OYSA		2.4	49	45	4	3	40.22	A-2-5(0)	SC-SM
SAMPLE 2	**15.28**	**2.2**	54	**27**	**27**	**9**	**37.6**	**A-7(5)**	**SC**
5%CT 0%OYSA		2.3	57	30	27	7	32.65	A-2-7(3)	SC
5%CT 2%OYSA		2.3	56	39	17	7	39.42	A-7(6)	SC
5%CT 4%OYSA		2.3	62	46	16	6	40.65	A-7(3)	SC
5%CT 6%OYSA		2.3	58	45	13	5	32.27	A-2-7(1)	SC
5%CT 8%OYSA		2.2	58	45	13	6	39.6	A-7(2)	SC
5%CT 10%OYSA		2.3	57	44	13	6	41.72	A-7(2)	SC
5%CT 15%OYSA		2.5	55	45	10	5	40.95	A-5(2)	SC
SAMPLE 3	**9.04**	**2.3**	54	**44**	**10**	**9**	**26.85**	**A-2-5(0)**	**SC**
5%CT 0%OYSA		2.3	50	39	11	6	30.9	A-2-7(0)	SC
5%CT 2%OYSA		2.3	48	37	11	6	30.45	A-2-7(0)	SC
5%CT 4%OYSA		2.3	47	35	12	6	28.15	A-2-7(0)	SC
5%CT 6%OYSA		2.4	46	34	12	5	33.5	A-2-7(0)	SC
5%CT 8%OYSA		2.4	44	34	10	5	34.32	A-2-7(0)	SC
5%CT 10%OYSA		2.4	43	33	10	5	34.3	A-2-7(0)	SC
5%CT 15%OYSA		2.3	41	32	9	5	33.8	A-2-5(0)	SC

Note: CT - Cement; OYSA - Oyster shell ash

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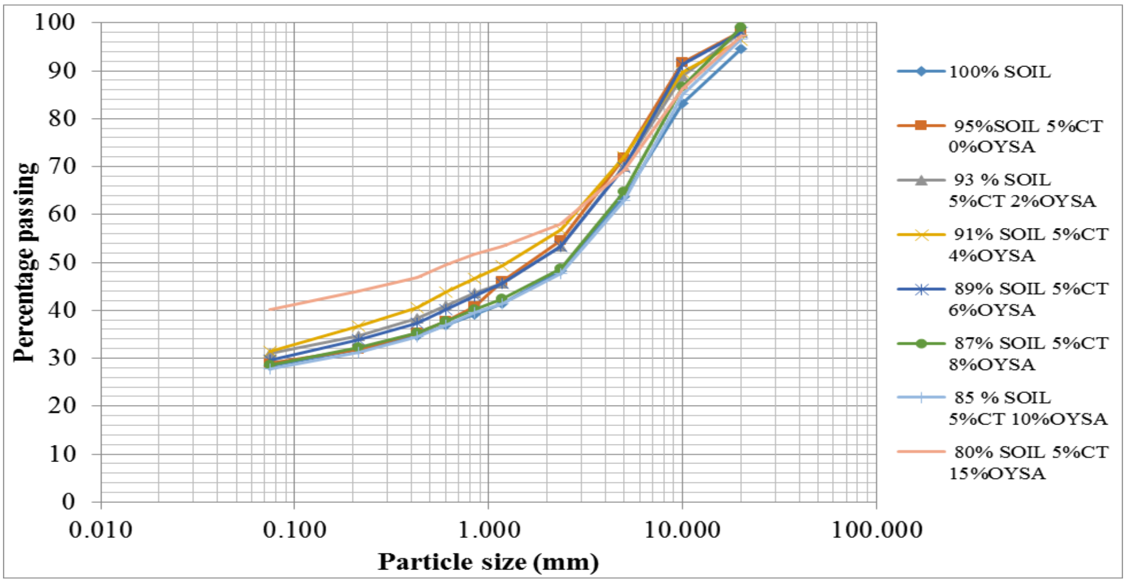

Fig. 3. Effect of Varying OYSA and Constant Cement Addition on Sample 1

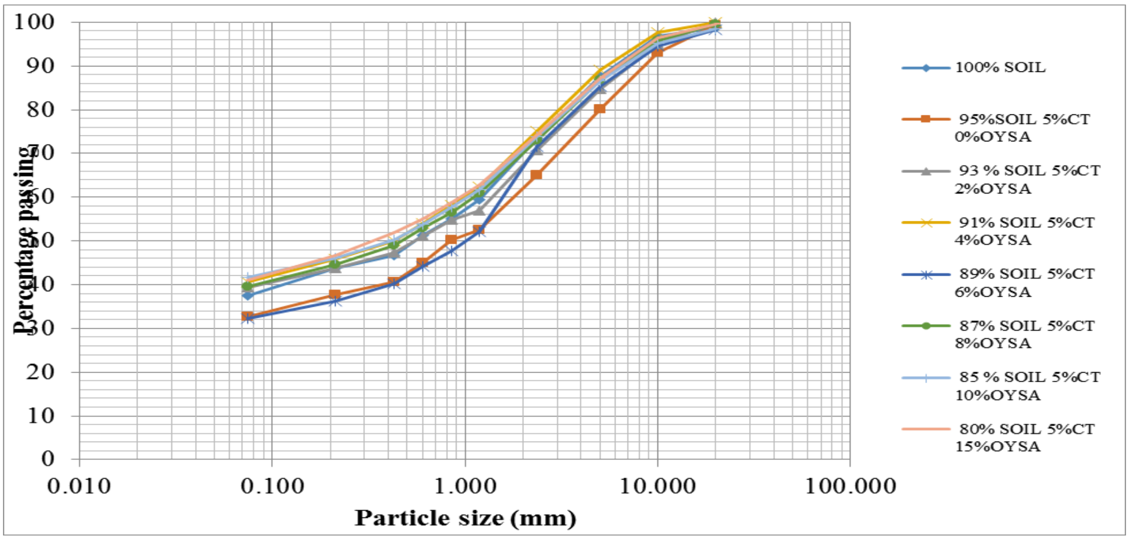

Fig. 4. Effect of varying OYSA and constant cement addition on Sample 2

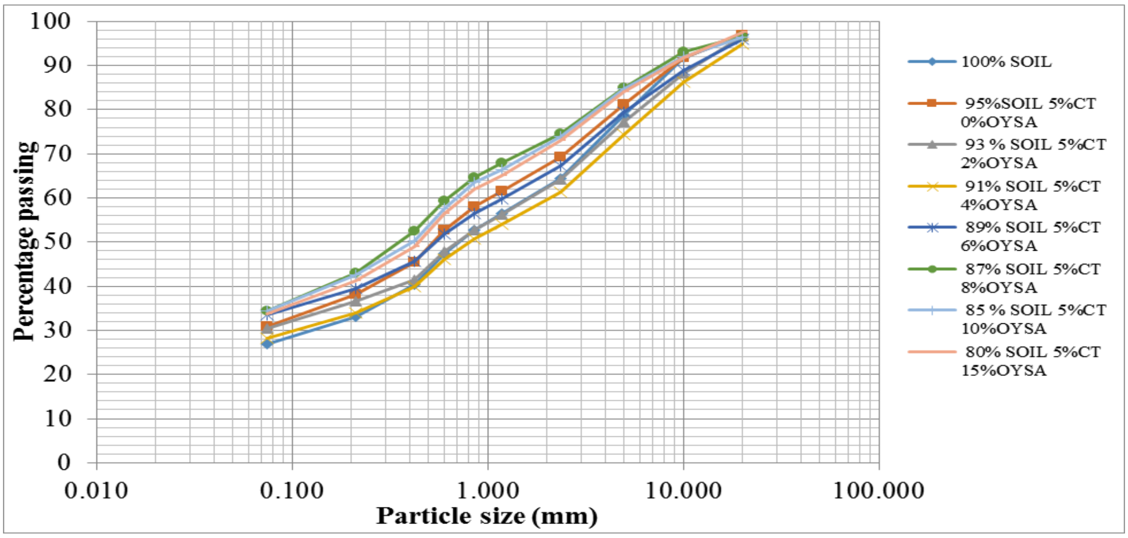

Fig. 5. Effect of varying OYSA and Constant Cement Addition on Sample 3

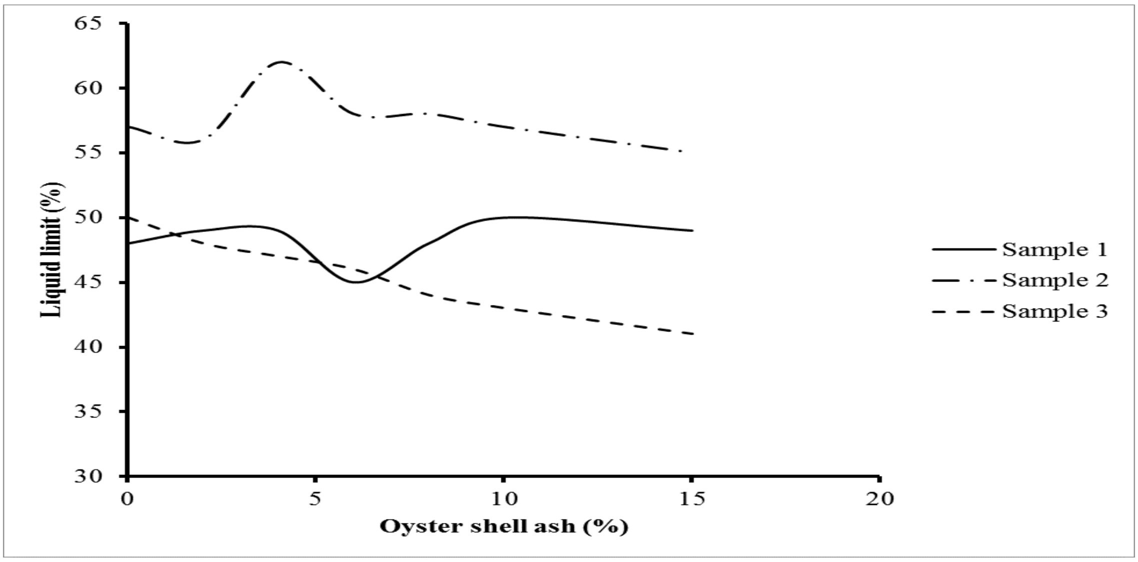

Fig. 6. Variation of Liquid Limit with Additive Content for the Three Soil Samples

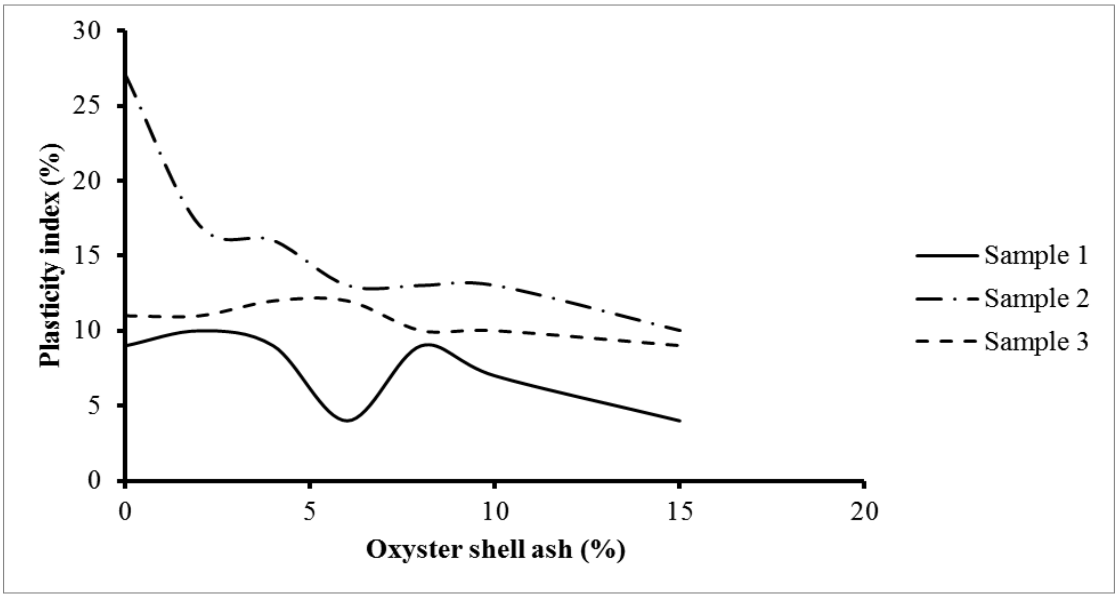

Fig. 7. Variation of Plasticity Index with Additive Content for the Three Soil Samples

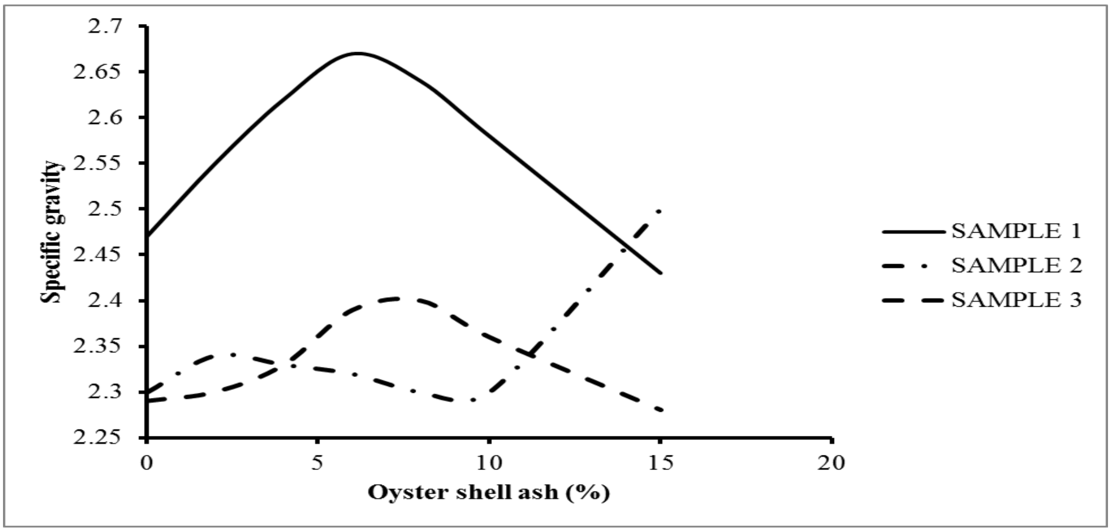

Fig. 8.Variation of Specific Gravity with Additive Content for the Three Soil Samples

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Table 2. Soil Samples Geotechnical Properties

Sample	MDD (mg/cm^3)	OMC (%)	CBR (%)	C (kN/m^2)	Pavement Use
Sample 1	1.95	11.3	1.98	50	Fill, subgrade and subbase
5%CT 0%OYSA	2.04	10.42	43	66	All courses
5%CT 2%OYSA	2.1	10.65	50.6	67	All courses
5%CT 4%OYSA	2.13	10.8	76.8	80	All courses
5%CT 6%OYSA	2.2	11	88.7	82	All courses
5%CT 8%OYSA	2.16	11.8	60.5	80	All courses
5%CT 10%OYSA	2.15	12.2	56.5	77	All courses
5%CT 15%OYSA	2.14	12.8	44.5	65	All courses
Sample 2	1.81	16.4	0.54	20	Unsuitable for all
5%CT 0%OYSA	1.83	17.5	36.75	22	All courses
5%CT 2%OYSA	1.84	17.01	41.58	28	All courses
5%CT 4%OYSA	1.85	16.76	44.4	36	All courses
5%CT 6%OYSA	1.86	16.54	47.37	44	All courses
5%CT 8%OYSA	1.85	16.95	45.63	29	All courses
5%CT 10%OYSA	1.86	17.4	43.8	22	All courses
5%CT 15%OYSA	1.87	17.6	30.78	21	All courses
Sample 3	1.93	12.4	1.56	42	Unsuitable for all
5%CT 0%OYSA	1.95	10	46.26	44	All courses
5%CT 2%OYSA	1.91	10.18	54.42	55	All courses
5%CT 4%OYSA	1.92	10.3	66.3	72	All courses
5%CT 6%OYSA	1.93	10.34	73.62	78	All courses
5%CT 8%OYSA	1.94	10.73	53.55	40	All courses
5%CT 10%OYSA	1.94	11	52.05	31	All courses
5%CT 15%OYSA	1.95	11.3	54.54	24	All courses

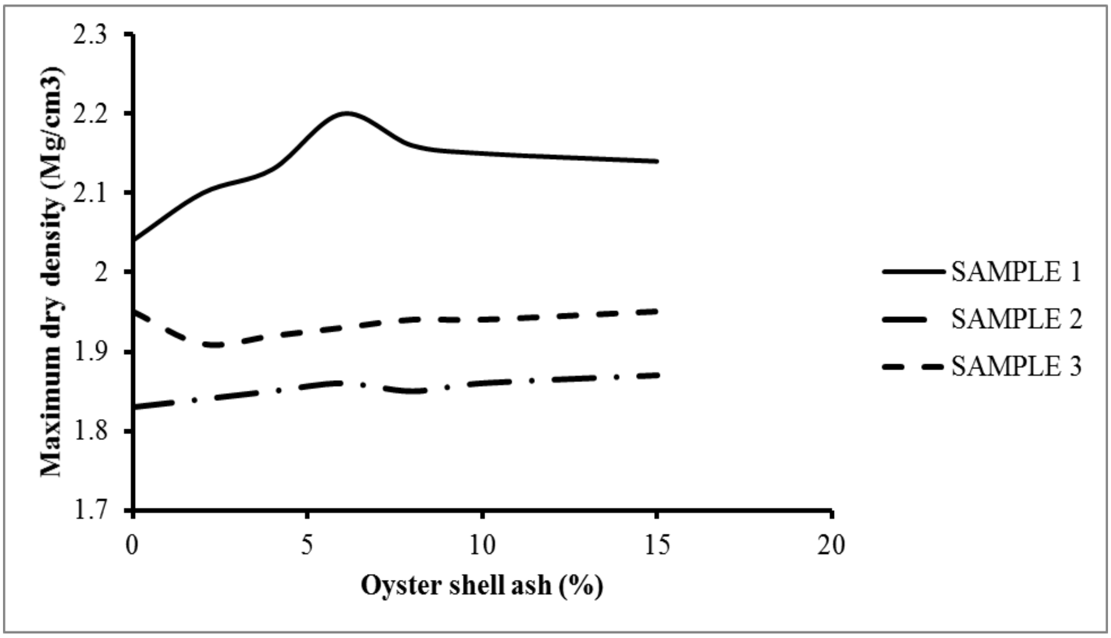

Fig. 9. Variation of M.D.D with Additive Content for the Three Soil Samples

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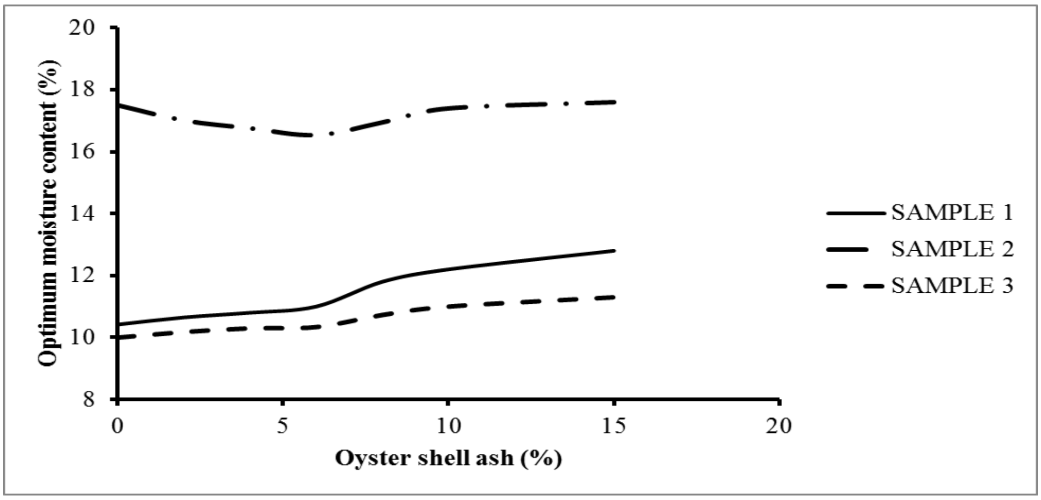

Fig. 10. Variation of OMC with Additive Content for the Three Soil Samples

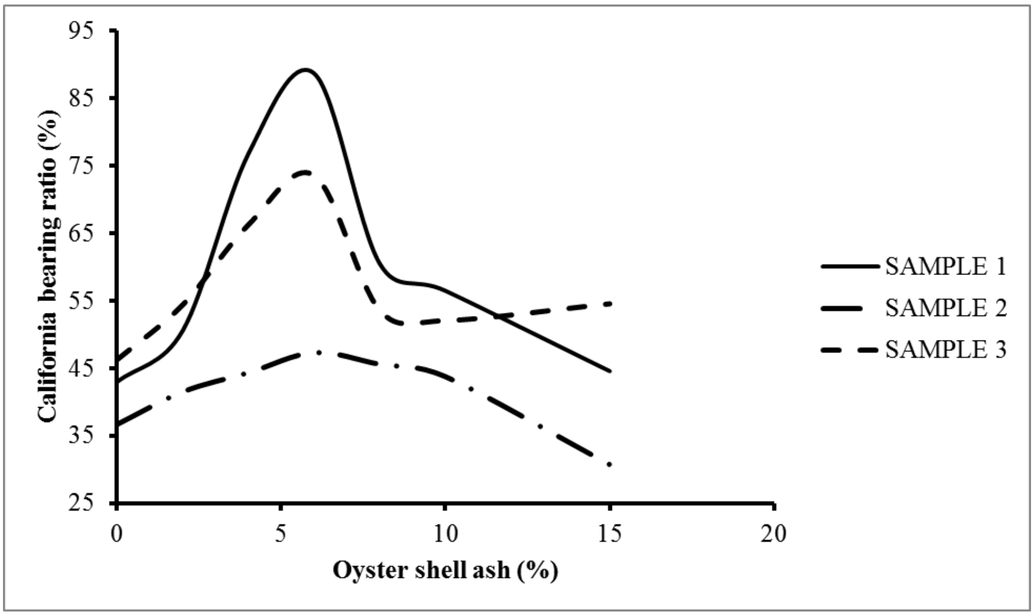

Fig. 11. Variation of Soaked CBR with Additive Content for the Three Soil Samples

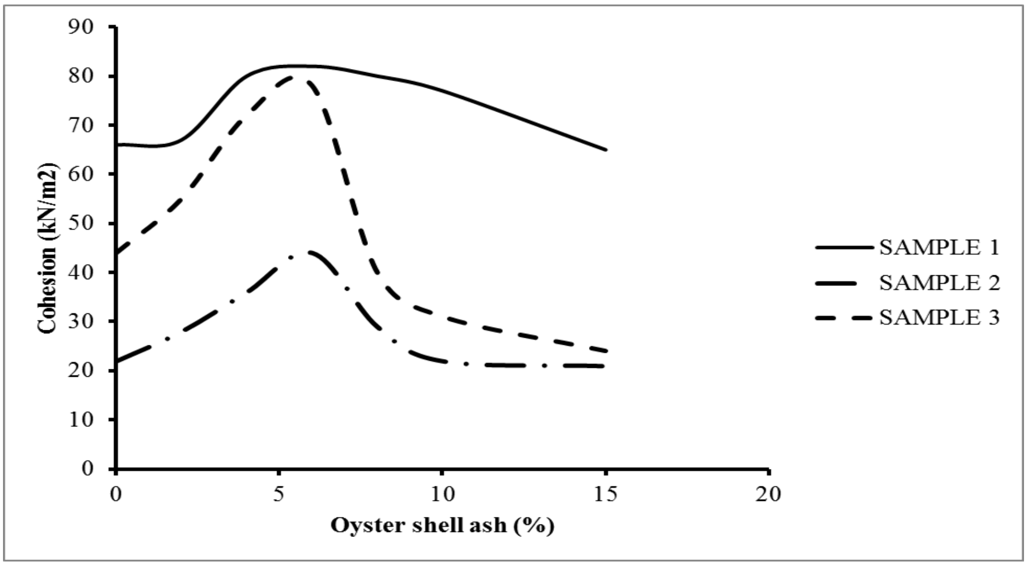

Fig. 12. Variation of Soil Cohesive Property with Additive Content for the Three Soil Samples

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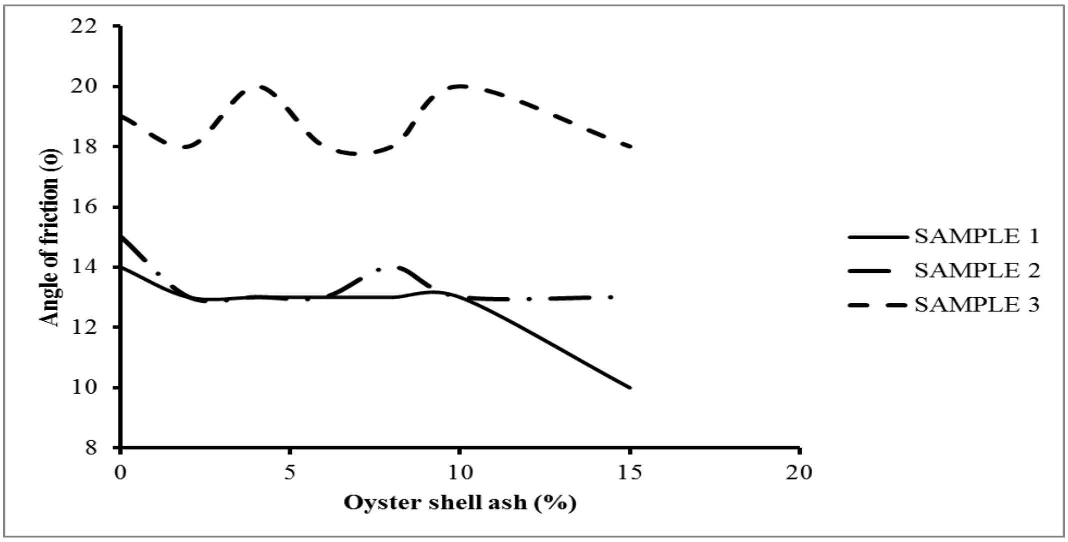

Fig. 13. Variation of Ø (Degrees) with Additive Content for the Three Soil Samples

IV. CONCLUSION

The potential of oyster shell ash activated with cement additive on the index and engineering properties of some selected soil samples were investigated in laboratory. The OYSA was introduced as additive up to a maximum of 15% while cement was introduced as activator at a constant rate of 5% by dry weight of soil, The following inferences were drawn. The alteration of the grain size distribution and specific gravity of the soil samples with the addition of OYSA and cement was due to addition of fine sized particles from the additive. Also, the cation exchange process and some pozzolanic reactions that caused the flocculation of clay particles have strong effect on the grain size distributions of the stabilized soil samples. Addition of OYSA and cement led to increase in the plastic limit and liquid limit of soil samples 1 and 2, decrease in the liquid limit and plastic limit of sample 3, decrease in the plasticity index of samples 1 and 2, increase in plastic limit of sample 3 as compared to the soils in their natural state. Also, there was improvement in the soil samples' CBR up to 6% OYSA 5% cement addition.

Addition of OYSA and cement altered the grain size distribution of the soil samples. The silt and fines fractions increased, whereas the clay fractions decreased. The optimum additive percentages needed for all the soil samples was 6% OYSA 5% cement. In their natural states, soil sample 1 would be suitable for sub-grades and fairly for sub-bases and samples 2 and 3 unsuitable for any of the stated functions. However, stabilized soil samples 1 and 3 would be suitable for subgrade, subbase and base course while soil sample 2 could be used for subbase and subgrade course.

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