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THE EFFECTS OF EGGSHELL ASH ON STRENGTH PROPERTIES OF CEMENT-STABILIZED LATERITIC

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ABSTRACT

Eggshell ash obtained by incinerating Fowls' eggshells to ash has been established to be a good accelerator for cement-bound materials and this would be useful for road construction work at the peak of rainy seasons for reducing setting time of stabilized road pavements. However this should be achieved not at the expense of other vital properties of the stabilized matrix. This is part of the effort in adding value to agricultural materials which probably cause disposal problems. Thus this study aimed at determining the effect of eggshell ash on the strength properties of cement-stabilized lateritic soil. The lateritic soil was classified to be A-6(2) in AASHTO rating system and reddish-brown clayey sand (SC) in the Unified Classification System. Constant cement contents of 6% and 8% were added to the lateritic soil with variations in eggshell ash content of 0% to 10% at 2% intervals. All proportions of cement and eggshell ash contents were measured in percentages by weight of the dry soil. The Compaction test, California Bearing Ratio test, Unconfined Compressive Strength test and Durability test were carried out on the soil-cement eggshell ash mixtures. The increase in eggshell ash content increased the Optimum Moisture Content but reduced the Maximum Dry Density of the soil-cement eggshell ash mixtures. Also the increase in eggshell ash content considerably increased the strength properties of the soil-cement eggshell ash mixtures up to 35% in the average but fell short of the strength requirements except the durability requirement was satisfied.

Keywords: *Eggshell ash, Cement, Lateritic soil, Road work, Strength characteristics.*

1.0 INTRODUCTION

Lateritic soils are residual soils and are mainly found in the tropical and sub-tropical regions. These are soils formed by the leaching of lighter minerals like silica and in consequent is the enrichment of the heavier minerals like iron and aluminium oxides (sesquioxides). It was stated that the degree of laterization is estimated by silica-sesquioxide ratio [1]. The major part of Nigeria is underlain by basement complex rocks, the weathering of which had produced lateritic materials spread over most of the area. It is virtually impossible to execute any construction work in Nigeria without the use of lateritic soil because they are virtually non-swelling [2].

Soil stabilization techniques for road construction are used in most parts of the world although the circumstances and reasons for resorting to stabilization vary considerably. In industrialized, densely populated countries, the demand for aggregates has come into sharp conflict between agricultural and environmental interests. In the less developed countries and in remote areas the availability of good aggregates of consistent quality at economic prices may be limited. In either case these factors produce an escalation in aggregate costs with maintenance costs. The upgrading by stabilization of materials therefore emerges as an attractive proposition [3]. This will go a long way in actualizing the dreams of the Federal government of Nigeria in scouting for readily cheap construction materials. Internationally, the World Bank equally has been spending substantial amounts of money on research aimed at harnessing industrial waste products for further usage.

Fowls' eggshells are agricultural waste materials generated from chick hatcheries, bakeries; fast food restaurants among others which can litter the environment and consequently constituting environmental problems/pollution which would require proper handling. In the ever increasing efforts to convert waste to wealth, the efficacy of converting eggshells to beneficial use becomes an idea worth embracing. The composition of eggshells indicates that the effect of its ash on cement treated materials should be articulated. It is scientifically known that the eggshell is mainly composed of compounds of calcium which is very similar to that of cement [4, 5, 6]. Eggshell was presented as being composed of 93.70% calcium carbonate, 4.20% organic matter, 1.30% magnesium carbonate, and 0.8% calcium phosphate [7]. Calcium trioxocarbonate (IV) was also presented as an important constituent of egg shells and seashells [8]. Since the dominating compound in egg shell is calcium carbonate, during incineration to ash the calcium carbonate will decompose into calcium oxide and carbon dioxide as shown in Equation 1.

$$CaCO_3 \xrightarrow{heat} CaO + CO_2 \quad \text{……………………………………………………………………}(1)$$

Few attempts have been made in the past by researchers with eggshell powder. Common salt was used on an eggshell stabilized lateritic soil with a view of obtaining a good compliment for eggshell powder as a useful stabilizer for road works [10]. Eggshell powder was also used to stabilize lateritic soil for the subgrade of a road work, it was found that eggshell powder possess very low binding property but significantly improved the strength properties of the subgrade soil [11]. Furthermore fly ash, rice husk ash and eggshell powder were used as partial replacement for cement and it was confirmed that the trio when mixed together with cement somewhat has equal strength with that of conventional concrete in mixes [12]. However, very scanty attempts have been made to work on eggshell ash. Eggshell ash has been used as an admixture to cement with a focus on the setting time and it was established as a good accelerator because of extra calcium oxide provided by the addition of eggshell ash [13]. It also satisfied the requirements for initial and final setting times of [14]. The following equations were proposed for the reaction of the hydration process by [13]:

$$2Ca_2SiO_4 + CaO + 5H_2O \rightarrow 2CaO.SiO_2.H_2O + 3Ca(OH)_2 \quad \text{……………...………………………}(2)$$

$$3Ca_3SiO_5 + CaO + 10H_2O \rightarrow 3CaO.SiO_2.H_2O + 7Ca(OH)_2 \quad \text{……………………………………..}(3)$$

$$3Ca_3Al_2O_6 + CaO + 10H_2O \rightarrow 3CaO.Al_2O_3.H_2O + 7Ca(OH)_2 \quad \text{.................... ....}(4)$$

$$4Ca_4Al_2Fe_2O_{10} + CaO + 17H_2O \rightarrow 4CaO.Al_2O_3.Fe_2O_3.H_2O + 13Ca(OH)_2 \quad \text{…………………….………}(5)$$

In the peak of rainy seasons, rainfall frequently interrupts road construction works and it is therefore much desirable to minimize the length of setting time of stabilized matrix as much as possible. The foregoing discovery could likely be a good option for this purpose. Nevertheless, this should be achieved without negatively affecting the other vital properties of the soil-stabilized matrix. Thus, this work focused on investigating into the effects of eggshell ash on the strength properties of cement stabilized lateritic soil.

2.0 METHODOLOGY

The materials used in this study were ordinary portland cement, eggshell ash, lateritic soil and clean tap water. The eggshells were incinerated into ash with temperature of about 500^0C, thoroughly ground and sieved through 75µm sieve in accordance with [14]. The lateritic soil was collected from a deposit in Oboro, Ikwuano Local Government Area of Abia state, Nigeria. It was collected with the method of disturbed sampling technique and air-dried after which preliminary tests were carried out on it in accordance with [15] and [16] for the particle size grading, both contain the details of the tests thus this was to properly classify the lateritic soil. The clay mineral identification was done using the Casagrande's plasticity chart, data in [17]. The summary of the results for the natural lateritic soil are shown in table 1 and the grain size analysis curve shown in figure 1.

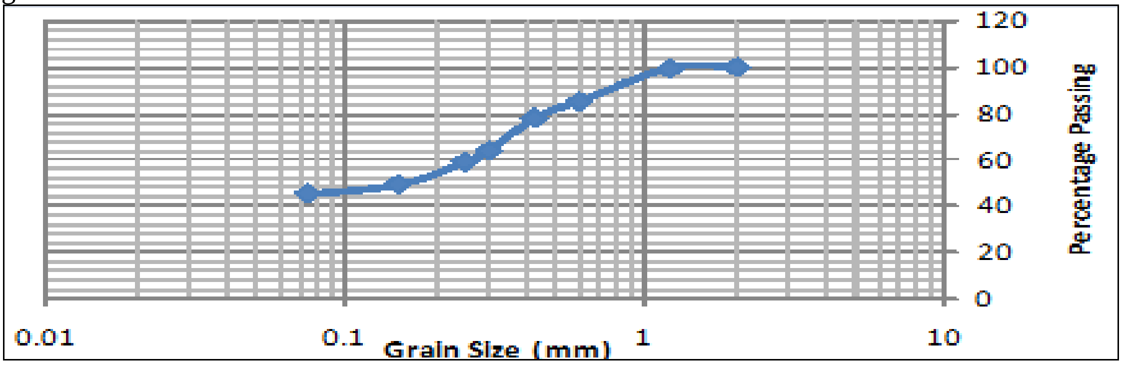

Figure 1: Grading Curve of the Lateritic Soil

The stabilized mixtures were prepared by first of all mixing thoroughly dry pulverized lateritic soil with cement and eggshell ash until a uniform colour was attained after which water was added. Constant cement contents of 6% and 8% with variations of eggshell ash of 0%, 2%, 4%, 6%, 8% and 10% by weight of the dry soil in all proportions of cement and eggshell ash were adopted for the mixes. The amount of water added was determined by the moisture-density relationship in which the Proctor mould was used to place the soil-cement eggshell ash mixtures in 3 layers and 25 blows were given onto each layer. The Unconfined Compressive Strength and California Bearing Ratio specimens were cured with the method of membrane curing. The California Bearing Ratio was modified so as to conform to [18], which stipulates that specimens should be cured for 6 days and immersed in water for 24 hours before testing while the unconfined compressive strength specimens were cured for 7 days before testing. The resistance to loss in strength (durability) was evaluated in accordance with [19] which specifies it as a ratio of the Unconfined Compressive Strength of specimens cured for 7 days and later immersed in water for another 7 days to the unconfined compressive strength of specimens cured for 14 days.

3.0 RESULTS AND DISCUSSIONS

Table 1: Properties of the Lateritic Soil

S/N	Properties	Results
1	Colour	Reddish-brown
2	Percentage passing sieve No 200	45.3
3	Liquid Limit (%)	38
4	Plastic Limit (%)	11
5	Plasticity Index (%)	27
6	Linear Shrinkage (%)	8
7	Specific Gravity	2.75
8	AASHTO Classification [8]	A-6 (2)
9	Unified Classification System	SC (Clayey Sand)
10	Major Clay Mineral Present	Illite (Inorganic Clay of Medium Plasticity)
11	Maximum Dry Density (Mg/m^3)	1.70
12	Optimum Moisture Content (%)	14
13	California Bearing Ratio (%)	9
14	Unconfined Compressive Strength (KN/m^2)	186

The soil was classified to be A-6(2) soil in AASHTO rating system. Though the group is far to the right of the AASHTO table, it is fairly good for road construction works. This is because it has a group index of 2 and also from the point of view of Atterberg limits (liquid limit of 38%, plasticity index of 27% and linear shrinkage of 8%), it is satisfactory. In other words, the clay mineral present in the lateritic soil (illite) is inorganic clay of medium plasticity and the activity is moderately satisfactory thus the soil would be somewhat stable in volume at moisture content variations. However, the high percentage of finer particles (45.3% passing Sieve No 200) in the soil probably caused the soil to have high cement content requirement. It will be also noted that the coarse particles are almost inert in the reaction of the soil with cement rather the finer particles play the major role as the pozzolanic component in the reaction. Therefore higher finer particles results to higher cement content requirement.

Figure 2 shows the relationship between Optimum Moisture Content and eggshell ash content. The Optimum Moisture Content increased progressively from 15% to 17.30% and 16.50% to 18.50% at 6% and 8% cement content respectively with addition of eggshell ash of 0% to 10%. These increments in Optimum Moisture Content with increase in eggshell ash could be attributed to the increased amount of calcium oxide in the mixture as shown in equations (2) through (5) thus this stepped up the rate of hydration reaction which rapidly continued to use up the water in the system. Besides, as the amount of eggshell ash increased; the amount of water required in the system to adequately lubricate all the particles in the soil-cement eggshell ash mixture equally increased. Therefore in the overall, the Optimum Moisture Content continuously increased with increase in eggshell ash content.

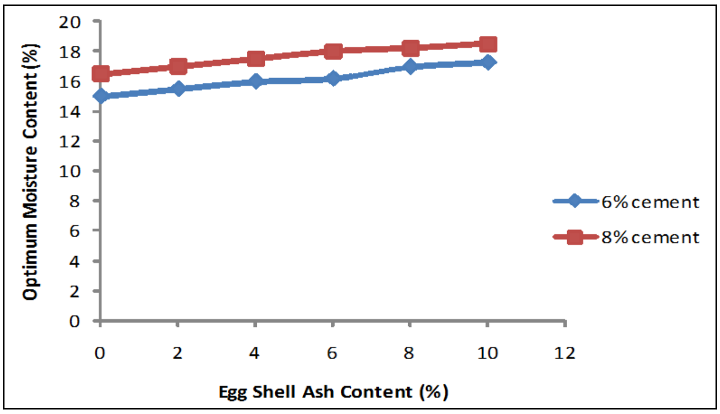

Figure 2: Variations of Optimum Moisture Content with Egg Shell Ash Content

Figure 3 represents the variations in Maximum Dry Density with increase in eggshell ash content. In the corollary of the increase in Optimum Moisture Content with the addition of eggshell ash to the soil-stabilized mixtures was the continuous decrease in Maximum Dry Density from 1.71 Mg/m^3 and 1.74 Mg/m^3 to 1.64 Mg/m^3 and 1.65Mg/m^3 at 6% and 8% cement content respectively with the addition of eggshell ash of 0% to 10%. This could be as a result of the reaction between cement, eggshell ash and fine fractions of the soil as pozzolanic component in which they form clusters like coarse aggregates. These clusters occupied larger spaces thus increasing their volume and consequently decreasing the Maximum Dry Density. Also in some cases the clusters formed were of weak bonding and the disruption was necessary in order to achieve higher level of compaction of the soil-cement eggshell ash mixtures. Therefore during compaction at a given energy level, part of the compactive effort was lost in overcoming the weak bonds which results in reduced density.

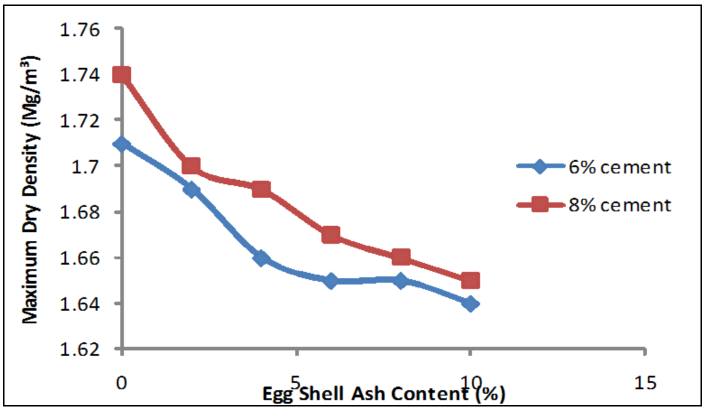

Figure 3: Variations of Maximum Dry Density with Egg Shell Ash Content

Figures 4 and 5 show the variations in California Bearing Ratio and Unconfined Compressive Strength which are the strength properties with increase in eggshell ash content. The California Bearing Ratio (CBR) increased from 26.45% to 56.19% and 82% to 93% at 6% and 8% cement content respectively with the addition of eggshell ash from 0% to 10%. Similarly, the Unconfined Compressive Strength (UCS) at 6% and 8% cement content increased considerably from (370KN/m^2 and 471KN/m^2) for 7 days curing period and (432KN/m^2 and 655KN/m^2) for 14 days curing period to (614KN/m^2 and 687KN/m^2) and (680KN/m^2 and 988KN/m^2) respectively with increase in eggshell ash content from 0% to10%. These could also be linked to the progressive increase in the amount of calcium oxide as a result of the gradual increase in the amount of eggshell ash added to the mixtures. Thus increasing the amount cementitious compounds formed as shown in equations (2) through (5) which equally increased the strength properties.

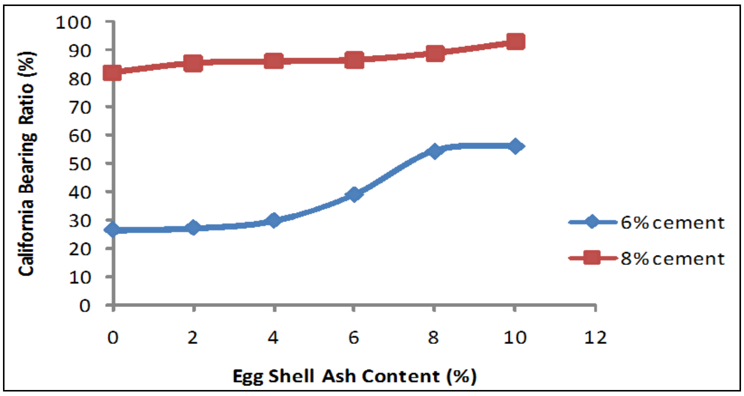

Figure 4: Variations of California Bearing Ratio with Egg Shell Ash Content

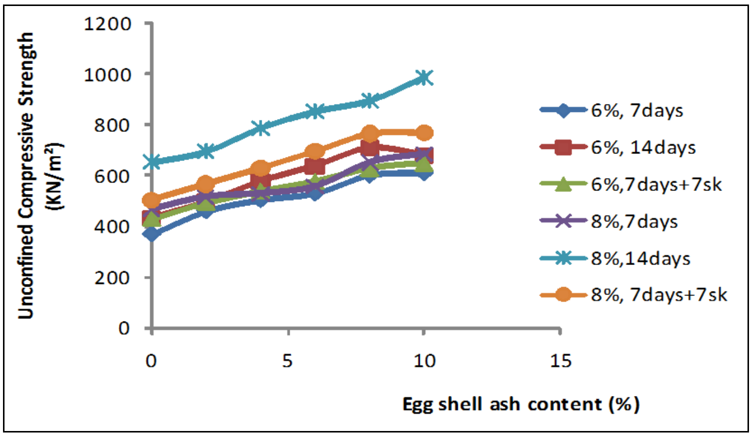

Figure 5: Variations of Unconfined Compressive Strength with Egg Shell Ash

Judging by the 180% value of California Bearing Ratio as stipulated by [18] and the minimum conventional values at 7 days for cement-stabilized soils of 750KN/m^2 - 1500KN/m^2, 1500KN/m^2 - 3000KN/m^2 and 3000KN/m^2 – 6000KN/m^2 for sub-base, base (light trafficked roads) and base (heavily trafficked roads) respectively. The soil-cement eggshell ash mixtures fell short of the requirements however the durability is satisfactory because in most cases of comparing the Unconfined Compressive Strength of 14 days curing period with that of 7 days curing and 7 days soaking, the 20% maximum loss in strength as stipulated by [19] were not exceeded.

The typical products of the hydration process as shown in equations (2) through (5) are composed of the respective hydrates of dicalcium silicates, (2); tricalcium silicates, (3); tricalcium aluminate, (4); tetra calcium aluminoferrite (5) and a common product to the four equations, calcium hydroxide. The calcium silicate hydrates and calcium hydroxide have been described as dominant products of hydration which are produced at the early stage of hydration mainly by the selective hydration of dicalcium silicate and tricalcium silicate [6, 20, 21, 22]. Between the two foregoing, the tricalcium silicate reacts first and dominates the reaction within first few days of hydration [6, 22]. Tricalcium silicates was described as the most important phase of cement and the calcium silicate hydrate gel resulting from this reaction is reported to be principally responsible for the mechanical properties of hydrated cement [20, 22].

Therefore in order to economically improve on the soil material available and also to take care of the huge amounts of calcium hydroxide produced as a result of the hydration reaction of cement and eggshell ash as shown in equations (2) through (5) which might be disadvantageous because it could be a potential source of instability [3], any of the cheap agricultural materials that is rich in silica (pozzolanic material) like bagasse ash, rice husk ash among others should be used together with the eggshell ash and cement. The silica provided by any of these materials will react with the excess amounts of calcium hydroxide produced after hydration reaction of cement and eggshell ash to further produce additional calcium silicate hydrates which is very vital for strength development. The additional amount of calcium silicate hydrates produced will depend on the amount of calcium hydroxide given out from the hydration reaction of cement and eggshell ash. The strength of the resulting stabilized matrix will be tremendously improved considering the amounts of calcium silicate hydrates that would be produced in equations (6) through (8) to meet the requirements of the evaluation standards for strength properties. The following are the proposed equations for the reaction between silica and calcium hydroxide, the common product of hydration reaction of cement and eggshell ash:

$$3Ca(OH)_2 + 3SiO_2 \longrightarrow 3CaO.SiO_2.H_2O \quad (6)$$

$$7Ca(OH)_2 + 7SiO_2 \longrightarrow 7CaO.SiO_2.H_2O \quad (7)$$

$$13Ca(OH)_2 + 13SiO_2 \longrightarrow 13CaO.SiO_2.H_2O \quad (8)$$

4.0 CONCLUSIONS

After the investigation into the effect of eggshell ash on the strength properties of a reddish-brown lateritic soil classified to be A-6(2) in the AASHTO rating and SC (Clayey Sand) in the Unified Classification System, the following conclusions were drawn:

1. The lateritic soil is fairly good for road construction work.
2. The increase in eggshell ash content increased the Optimum Moisture Content but reduced the Maximum Dry Density of the soil-cement eggshell ash stabilized lateritic soil.
3. The increase in eggshell ash content increased the strength properties of the cement-stabilized matrix up to about 35% averagely.

4. The other strength properties of the soil-cement eggshell ash mixture fell short of the requirements for stabilized materials whereas the durability requirement was satisfied.
5. On the basis of this investigation, it would be more beneficial to use any other cheap agricultural material that is rich in silica together with cement and eggshell ash in the lateritic soil. However, detailed investigation will be needed to determine the adequate requirement of the preferred agricultural material.

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