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Creating Wealth from Waste: Application of Waste Oyster Shell in the Stabilization of Lateritic Soils as Sub-base Material in Road Construction

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ABSTRACT
The problem of lateritic soil not meeting the requirement as a base material in flexible pavement construction is a difficult task for the highway engineer. The preferred choice is to stabilize with locally available material due to the increase cost of conventional stabilizing material like cement and lime, the negative impact their production have on the environment and on the economy. This research presents the result of experimental investigation on the influence of Oyster shell powder (OSP) a locally available waste material on the liquid limit (LL), plastic limit (PL) and maximum dry density (MDD). The soils used in this study were A-2-6 and A-2-7 soils.The results show that liquid limit decreases with the addition of OSP while plastic limit and maximum dry density (MDD) increases with the addition of OSP. This implies that the OSP possesses the potential for use in the stabilization of lateritic soils. This research has clearly shown that apart from finding suitable means of disposing of oyster shell waste which constitutes a health hazard because of the environmental pollution, its use in soil stabilization for road construction will provide an economic way of turning waste to wealth.
Keywords: stabilization, Lateritic soil, oyster shell and road construction

I. INTRODUCTION

Rivers State situated in the coastal area of Nigeria and it is very rich in marine resource. The major occupation of the people living in these areas is fishing. Both fin and shell fishes are caught, sold, processed or eaten by the people resident in these areas. Oyster Crassostrea gasser is one of the most common shell fish eaten in the coastal areas of Rivers State. They are an important source of protein and other minerals like calcium, iodine etc. to humans.The oyster is typically processed for consumption by removing the inedible shells. The waste shells are thrown away, which causes environmental pollution. Even in South Korea, marine pollution by waste oyster shells has become one of the most serious problems of the aquaculture industry causing nasty odors as a consequence of the decomposition of fresh remnants attached to the oyster (Yoon et al., 2005, Jung et al., 2007).Ansa and Basir (2007) reported that the mean weight of the mangrove oyster in Rivers State to be 24.67g (n=100) with only 8.63% as edible meat, while the rest consists of the mostly shell waste.Unlike other sea foods for example periwinkle whose shells are used by the natives in building of houses because of its hard nature and shape. The people in the riverine area where the oyster shell dumps are found have not found any use of the shell because the shells are soft, brittle and mostly flat in shape which has made it unsuitable as a construction material in its natural form.Thousands of tons of oyster shells are produced and dumped into public waters and lands causing nasty odor as a consequence of the decomposition of the flesh ruminants' attached to the oyster shells. Thus, the recycling of oyster shells has arising as an imminent issue becauseto ensure a clean and safe environment, these wastes must be managed responsibly.

A number of useful materials have been produced from waste oyster shell. Perhaps one of the oyster shell's most popular uses in construction throughout history has been in its burnt form as lime, also known as quicklime. Documentation of oyster-based lime dates back several thousand years and crosses many nations and continents including Honduras, Brazil, Greece, Northeast India, and Australia.One early American reference to lime burning is found in Mechanick Exercisesby

Joseph Moxon, published in 1703. Moxon detailed his theories on the various tradesincluding carpentry, and bricklaying. In his discussion on lime, he states, "But the shellsof Fish, as of Cockles and Oysters are good to burn for Lime" (Sickels-Taves, 1996). Oyster shell was also used to produce shellcrete, indigenous to Spanish Texas and popular in the mid-1800s. Shellcrete was made by creating bricks out of a mixture of crushed shells, lime, water and thick, white local clay. A small amount of sand was used to temper the clay if necessary. The mixture was tamped into sand-dusted forms, sun-hardened then baked in a firewood-heated kiln (Matos, 2009).

II. MATERIALS AND METHODS

The soil samples used in this study were collected from different locations in Eleme, Khana, Ikwerre,Ogba-Egbema-Ndoni and Ahoada-East Local Government Areas of Rivers State, southern Nigeria.Oyster shells used in this study were collected from a refuse dump Oba-ama a coastal town inOkrika Local Government Area of Rivers State. The samples were washed to remove any dirt, dried and grounded to powder form using an industrial grinder in Port Harcourt.

Table 3.1shows the physical properties of oyster-shell powders with a mean diameter of 0.075 mm.The chemical compositions of the ground Oyster shell sample is presented in Tables 3.2. It is noted that oyster-shell is entirely composed of $CaCO_3$ (approximately 96%) and other minerals of minute amount.

The distribution of different grain sizes affects the engineering properties of soil. Sieve analysis provides the grain size distribution, and it is required in classifying the soil.Sieve analysis was carried out in accordance with BS 1377 (1990) methods of testing soils for civil engineering purposes.The percent by weight of soil passing each opening was then plotted as a function of the grain diameter (corresponding to a sieve number) and the percentage passing sieve No. 200 was determined see Table 3.3.To classify fine grained soils in current engineering practice only two of the Atterberglimits, the liquid and plastic limits (from whence plasticity index is derived), are commonly used. The liquid limit and plastic limit tests were conducted in accordance with BS 1377 (1990) standard code of practice. The liquid limit and plastic limit tests were carried out on the natural soils and the modified soils (in varying percentages). Table 3.1 shows a summary of the liquid limit for the various samples. The graph of liquid limit against percent of OSP of various samples is shown in chapter 4 and the tabulated results of the liquid limit of various samples of OSP modified lateritic soil in varying percentages are shown in appendix B. the compaction characteristics of the soils were determined using the standard protor compaction test to determine the optimum moisture content at which the soil reaches maximum density (maximum dry density). The compaction test was carried out for the natural soil and the modified soils (in the different percentages); all according to BS 1377 (1990). Table 3.1 shows a summary of the maximum dry density and optimum moisture content of the various samples.

III. RESULTS AND DISCUSSION

3.1 Preliminary Tests

The result of laboratory tests to determine the physical properties and chemical compositionof oyster shell is presented in Table 3.1 and Table 3.2 respectively. While Table 3.3 contains the physical properties of the natural lateritic soil necessary for identification

Table 1: Physical Properties of Oyster Shell

Physical properties	Value
Bulk density (kg/m^3)	1173
Apparent density (kg/m^3)	2583
Porosity (%)	56.42
Mean particle size (mm)	0.075

Table 2: Chemical Composition of Ground Oyster Shell

Chemical compound	Composition (%)
$CaCO_3$	95.874
Na_2O	0.881
SO_3	0.674
SiO_2	0.827
MgO	0.562
Al_2O_3	0.616

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SrO	0.353
P_2O_5	0.213
Total	100

Table 3: Physical properties of lateritic soil

Sample	Properties						
	%age Passing Sieve No. 200	LL (%)	PL (%)	PI (%)	MDD Kg/m^3	OMC (%)	AASHTO Classification
1	37.4	32	200	12.0	1733	18.4	A-2-6
2	47.1	43	29.8	13.2	1690	27.1	A-2-7
3	45.8	43	27.8	15.2	1641	25.6	A-2-7
4	36.0	44	29.1	14.9	1492	17.9	A-2-7
5	43.3	29	15.5	12.5	1749	12.4	A-2-7

The oyster-shell is entirely composed of $CaCO_3$ (approximately 96%) and other minerals of minute amount. The lateritic soils are classified as an A-2-6 and A-2-7,subgroup soils based on the American Association of State and Highway Transportation Officials Soil Classification System (AASHTO, 1986).

Effect of oyster shell powder (OSP) on liquid limit of lateritic soil

Table 4: Liquid Limit test results of varying percentage of OSP stabilized lateritic soils

Liquid limit of Lateritic Soil Sample (%)	Percentage of OSP					
	0	**2**	**4**	**6**	**8**	**10**
1	32	30	26	23	22	21
2	43	41	36	34	31	26
3	43	38	34	33	31	29
4	44	40	37	35	34	31
5	39	38	34	30	29	26

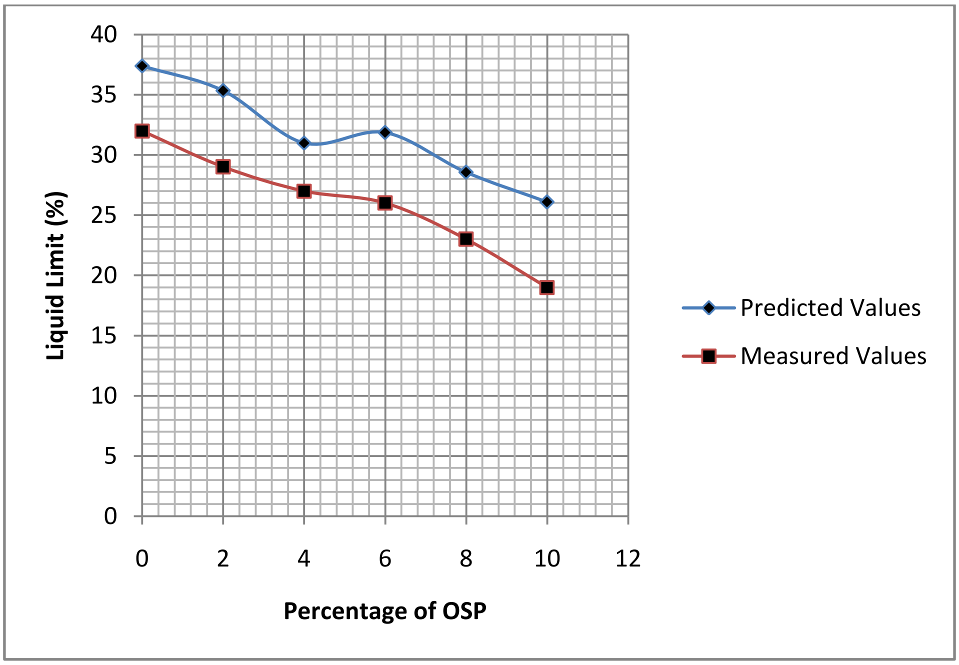

Figure 1: Effect of Percentage OSP content on liquid limit of Sample 1

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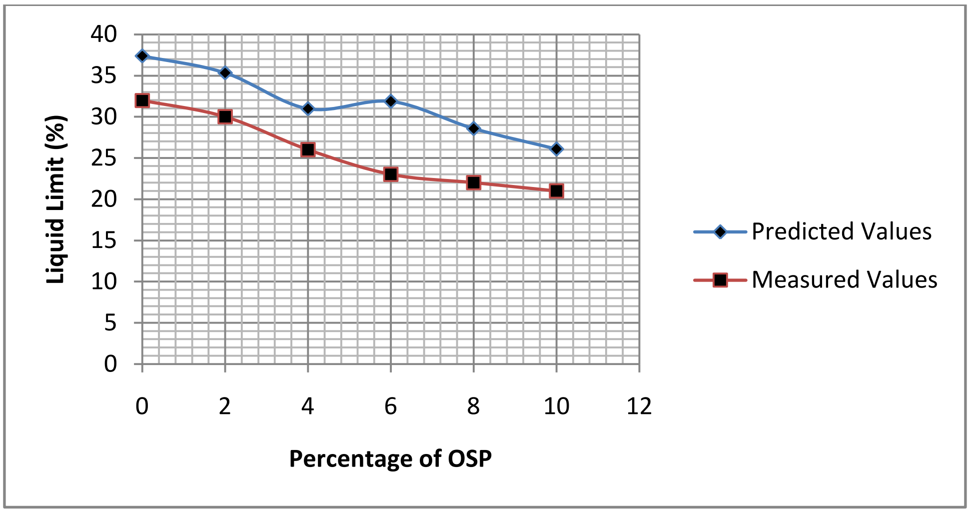

Figure 2: Effect of Percentage OSP content on liquid limit of Sample 2

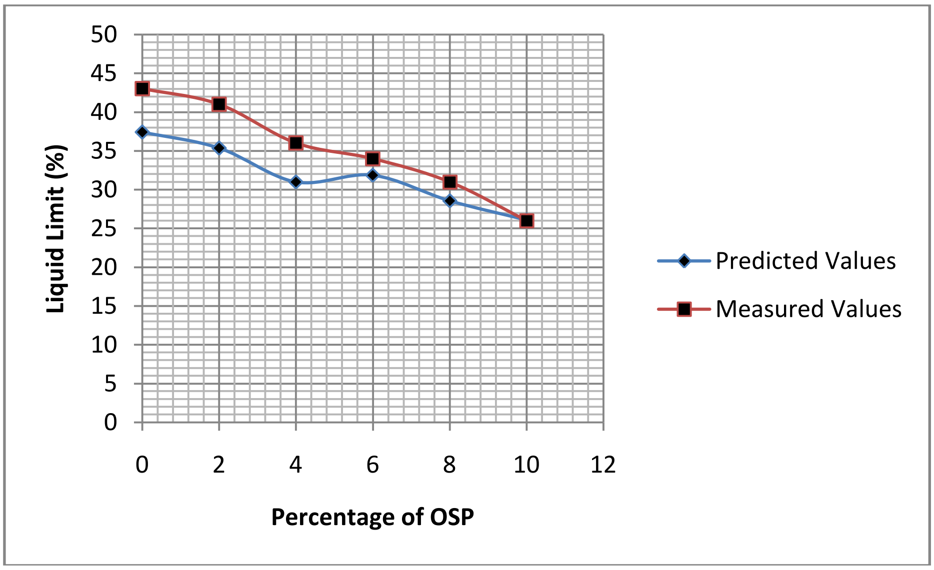

Figure 3: Effect of Percentage OSP content on liquid limit of Sample 3

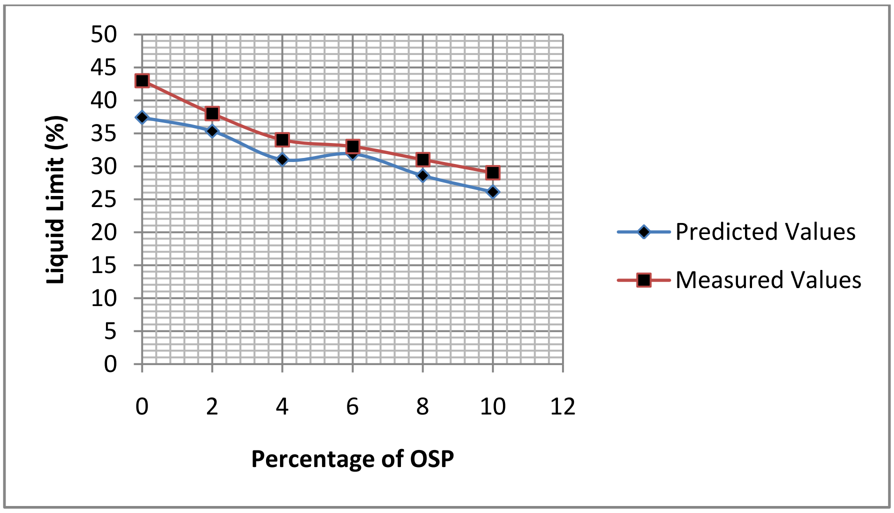

Figure 4: Effect of Percentage OSP content on liquid limit of Sample 4

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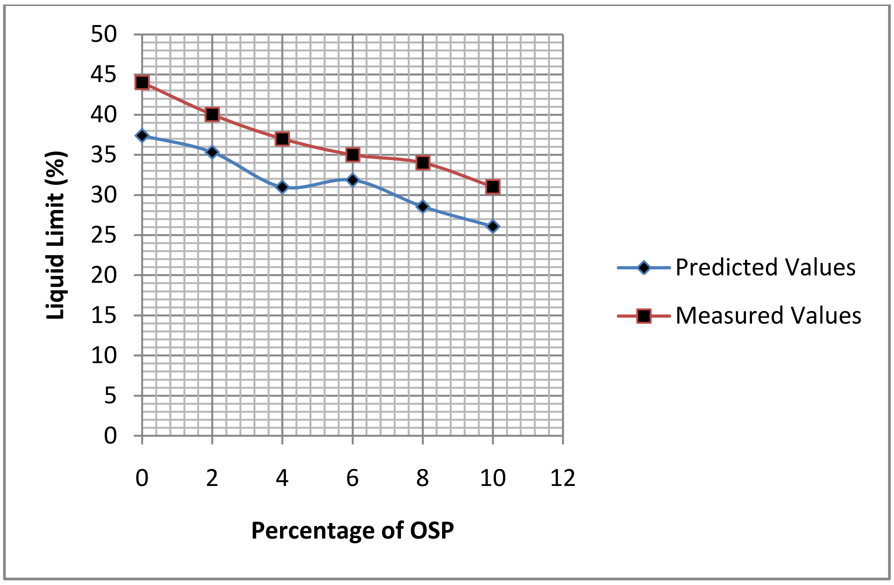

Figure 5: Effect of Percentage OSP content on liquid limit of Sample 5

In Table 4, at 0% OSP, the liquid Limit (LL) of sample 1 is 32%, while at 2% of OSP, the LL was 30% and this drops further to 21% (about 34% reduction) as the OSP content increased to 10%. it can be seen in Figure 1 that there is a linear relationship between OSP content and LL, the graph moves downwards to the right indicating that as the OSP content increases in lateritic soil sample 1, its LL decreases. The same trend was noticed for lateritic soil sample 2 to 5 (but with different percentage reduction in LL). The graphs for soil sample 2 to 5 also shows the same linear relationship of moving downwards to the right indicating the same trend of decrease in LL as OSP content increases, see Figure 2 to 5. This is in agreement with (Uche and Abubakar, 2010) work on using Neem seed Husk ash in stabilizing lateritic soil. They reported that the LL of the soil decreases as the Neem seed ash increases. The decrease in LL is also in agreement with (Amu and Adetaberu, 2010) who reported decrease in LL of soil on addition of bamboo leaf ash. The same trend also conforms to findings by(Muntohar, 1999) that LL reduces with increase lime and rice husk ash combination. The findings which is consistent with similar works as reported is due to the chemical reactions that took place during the process of stabilization, the addition of OSP suplied an excess of Ca+ which goes to replace the weaker metallic cations from the exchange complex of the laterite. The exchange of these cations which causes a reduction in the plasticity is attributed to the change in soil nature (granular nature after flocculation and agglomeration) resulting in reduction in the amount of clay size particles in the soil. Which resulted in more stable clay-sand-like structure, making the mixture more workable this is consistent with the views of (Emesiobi, 2000) on changes of the liquid limit of engineering soils. The results show that samples 1 met the Nigerian specification for liquid limit of < 35% at 0% OSP stabilization for sub-base material, samples 3 and 4 met the requirement at 4% and while samples 2 and 4 was at 6%.

By applying the excel software, the resulting model, equation 1 was developed

$$L = 0.0137p^2 + 1.0005p + 37.393 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad 1$$

Where:
L = Liquid limit
p = Percentage of OSP

Equation 1 can be used to predict LL of OSP stabilized lateritic soils. The same trend of reduction in LL as OSP content increase of the measured values is also noticed in the predicted values, this is confirmed in the graphical relationship see Figures 1 - 5. Equation 1 has a R^2 value of 98.66% indicating a close approximation between the predicted and measured values.

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Effect of OSP on Plastic limit of lateritic soil

Table 5: Plastic Limit test results of varying percentages of OSP stabilized lateritic soils

Plastic limit of Lateritic Soil Sample (%)	Percentage of OSP					
	0	2	4	6	8	10
1	20.0	21.6	22.9	24.7	27.3	30.4
2	29.8	31.7	32.7	34.2	35.1	37.4
3	27.8	28.6	30.1	33.4	36.4	37.8
4	29.1	31.5	32.9	34.7	35.4	38.2
5	26.5	28.2	29.6	32.2	34.8	35.8

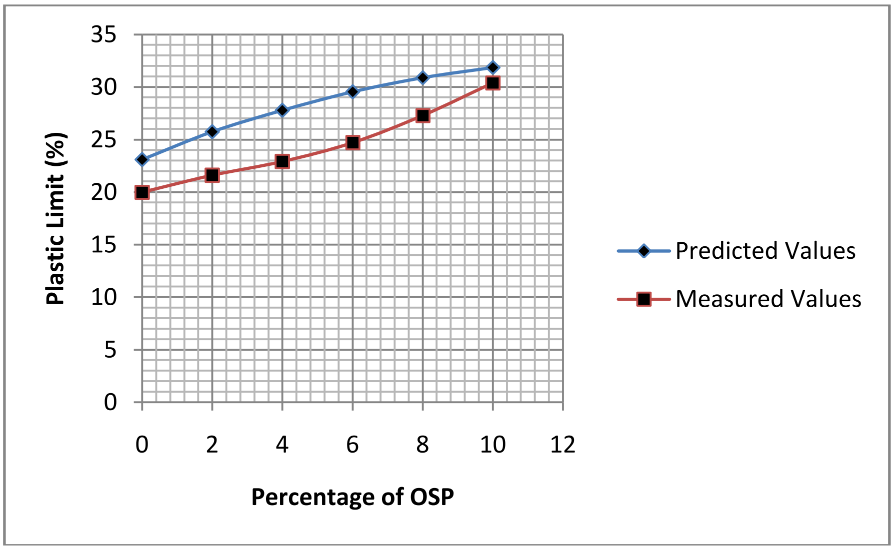

Figure 6: Effect of Percentage OSP content on Plastic limit of Sample 1

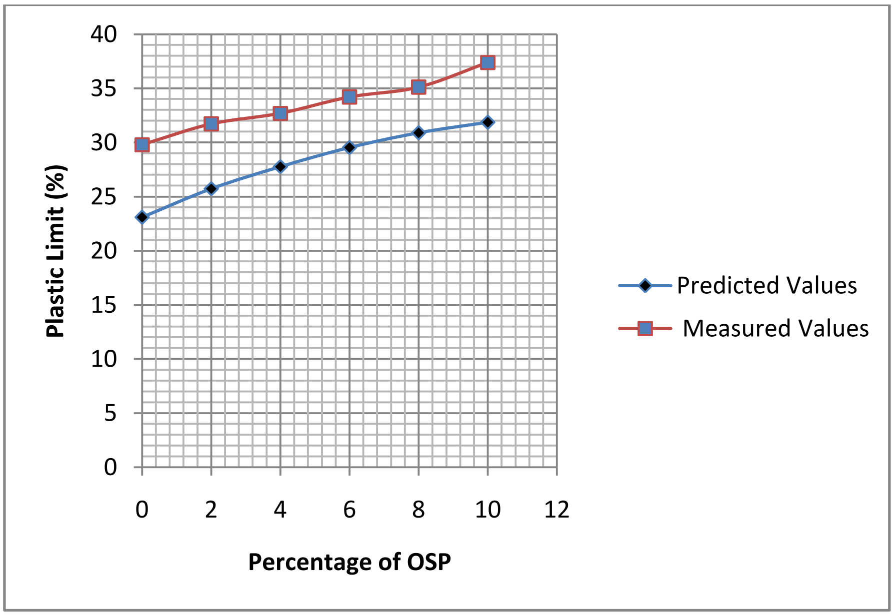

Figure 7: Effect of Percentage OSP content on Plastic limit of Sample 2

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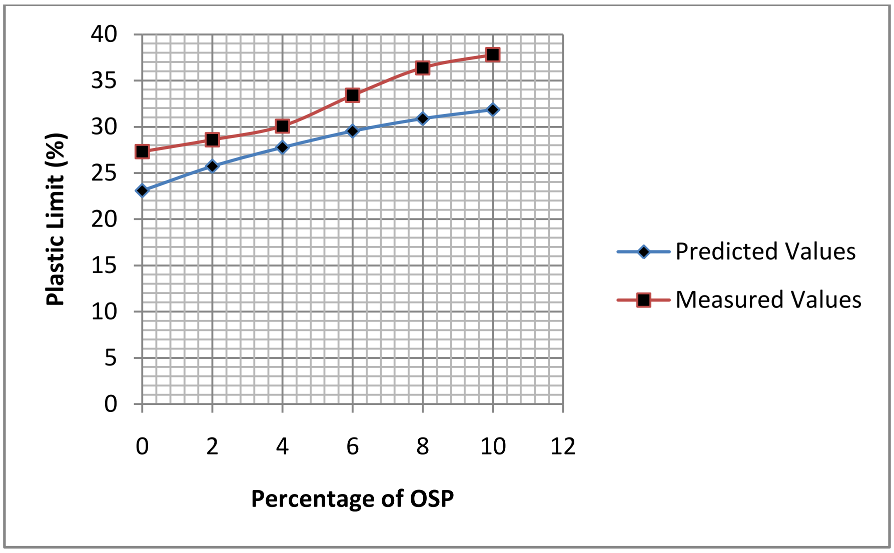

Figure 8: Effect of Percentage OSP content on Plastic limit of Sample 3

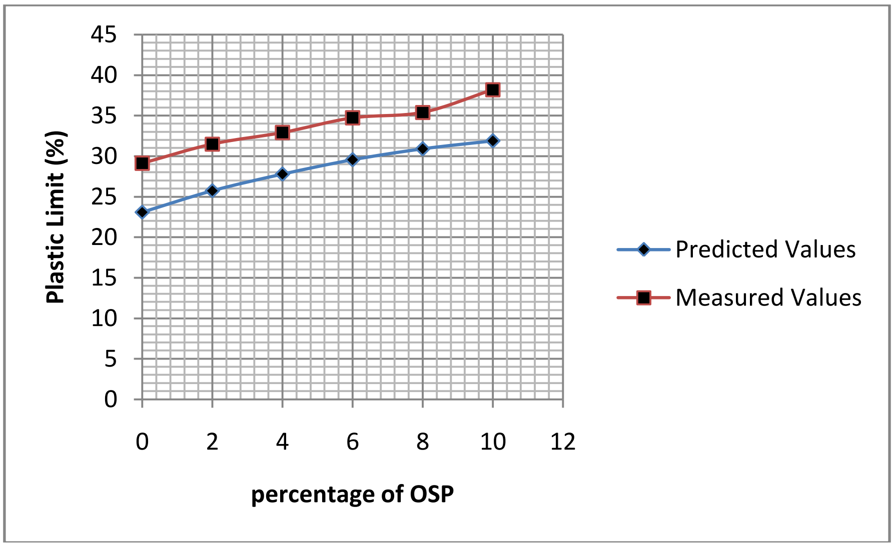

Figure 9: Effect of Percentage OSP content on Plastic limit of Sample 4

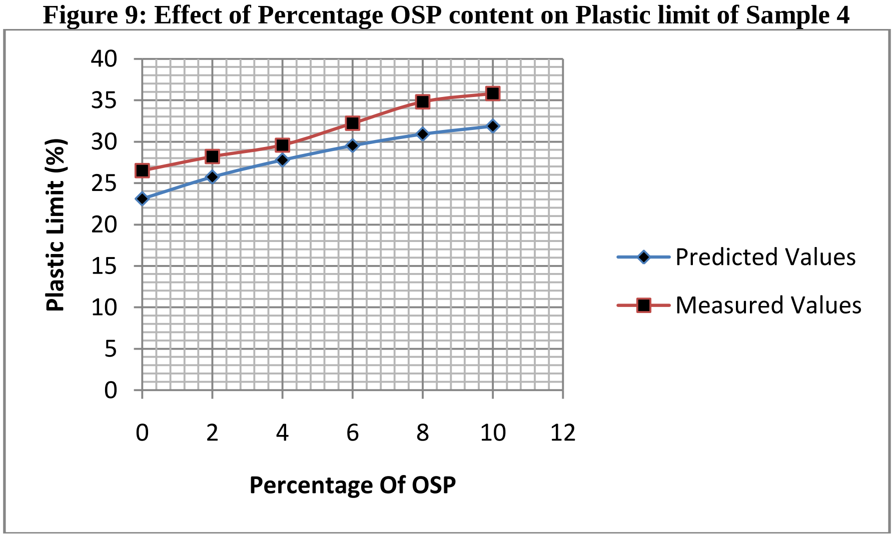

Figure 10: Effect of Percentage OSP content on Plastic limit of Sample 5

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The variation of the plastic limit of lateritic soils and OSP content can be seen in Table 5, at 0% OSP content, the plastic limit (PL) of sample 1 is 20.0%, as the OSP content increased to 2%, the PL also increased to 21.6% and the same trend continues, as the OSP content increases from 2 to 10%, the PL also increases from 21.6 to 30.4%, a 52% increase in plasticity. For lateritic soil sample 2, 3, 4 1nd 5, the plasticity increase was 26%, 36%, 31.3% and 35.1% respectively as OSP content increased from 0 to 10%. This is consistent with the findings by (Ramzi et al., 2001) and (Moses and Afolyan 2011) that increase in cement kiln dust content increases the PL of the soil. since the cement kiln dust and OSP have similar chemical compostion which implies that they will have similar chemical reaction when mixed with soil. Therefore, the addition of lime caused the flocculation and agglomeration of the clay particles through cation exchange at the surface of the clay particles and the highly plastic nature of lime which caused the plastic limits to increase.The linear relationship between the PL of lateritic soil and percentage OSP content can be seen in Figures 6 to 10. In Figure 6, it can be seen that as the graph moves upward to the right indicating the linear relationship that as the OSP content of sample 1 increases, its PL also increases. The same trend is observed for other graphs (Figure 6 to 10) showing the relationship between PL and OSP content of lateritic soil sample 6 to 10. The shapes of the graphs conformto the tabulated result.

The Microsoft excel program was used to develop equation 2, which relates the OSP content and PL of lateritic soil.

$$S = -0.049p^2 + 1.3672p + 23.096 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ 2$$

Where:
S = Plastic limit
p = Percentage of OSP

Equation 2 was used to predict the PL values, see Figures 6 – 10, equation 2 has a R^2 value of 97.32% which indicates a close approximation between the predicted and measured values. The predicted PL value of lateritic soil sample was plotted against percentage OSP content. The resulting graph showed a linear relationship between the two parameters which was similar to the measured PL values and it can be seen that the predicted and measured values are close. This finding verifies the model and as a result, the model can be used to predict PL of OSP stabilized lateritic soil.

Effect of OSP on Maximum Dry density (MDD) of lateritic soil

Table 6: MDD results of varying percentages of OSP stabilized soils

MDD of Lateritic Soil Sample (Kg/m^3)	Percentage of OSP					
	0	**2**	**4**	**6**	**8**	**10**
1	1733	1752	1780	1813	1842	1882
2	1690	1698	1724	1755	1773	1806
3	1641	1660	1682	1695	1715	1752
4	1492	1520	1541	1573	1590	1622
5	1749	1762	1785	1813	1842	1879

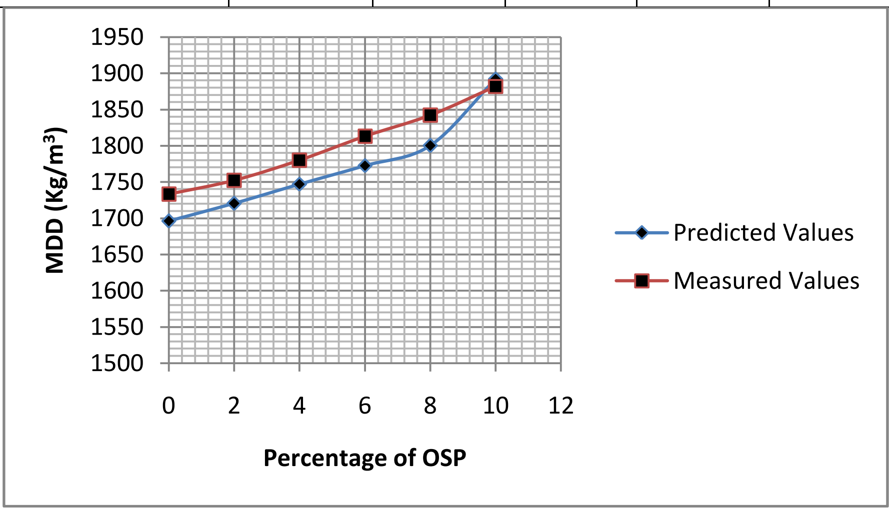

Figure 11: Effect of Percentage OSP content on MDD of Sample 1

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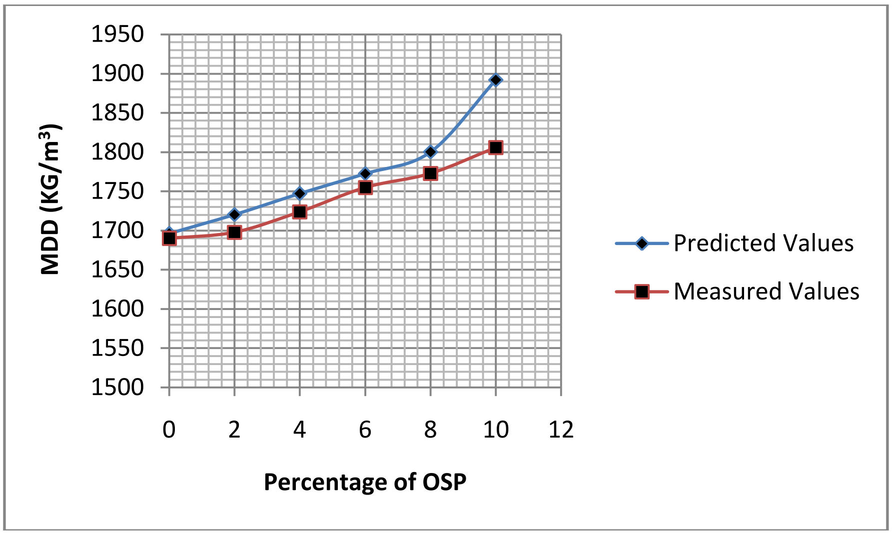

Figure 12: Effect of Percentage OSP content on MDD of Sample 2

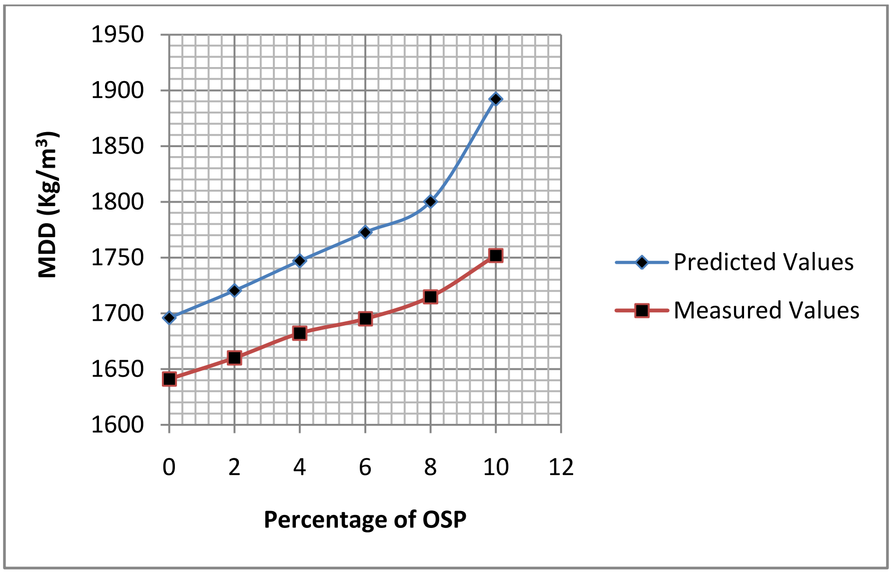

Figure 13: Effect of Percentage OSP content on MDD of Sample 3

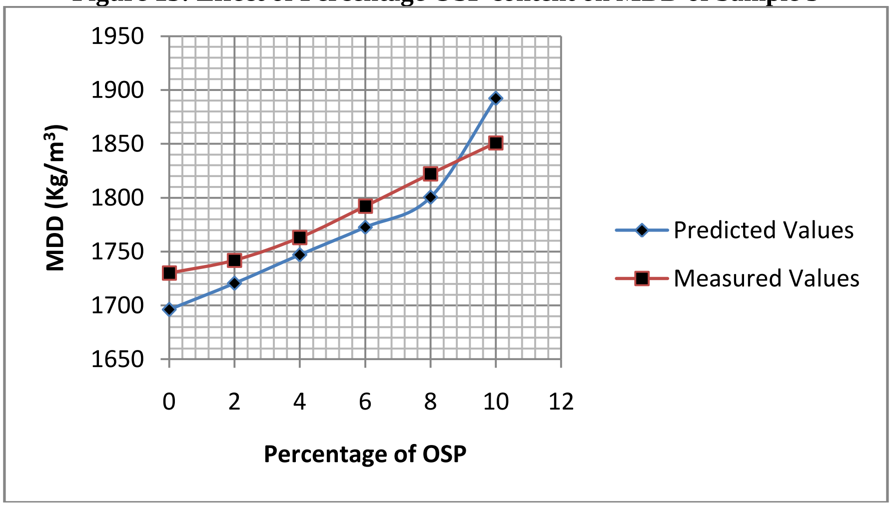

Figure 14: Effect of Percentage OSP content on MDD of Sample 4

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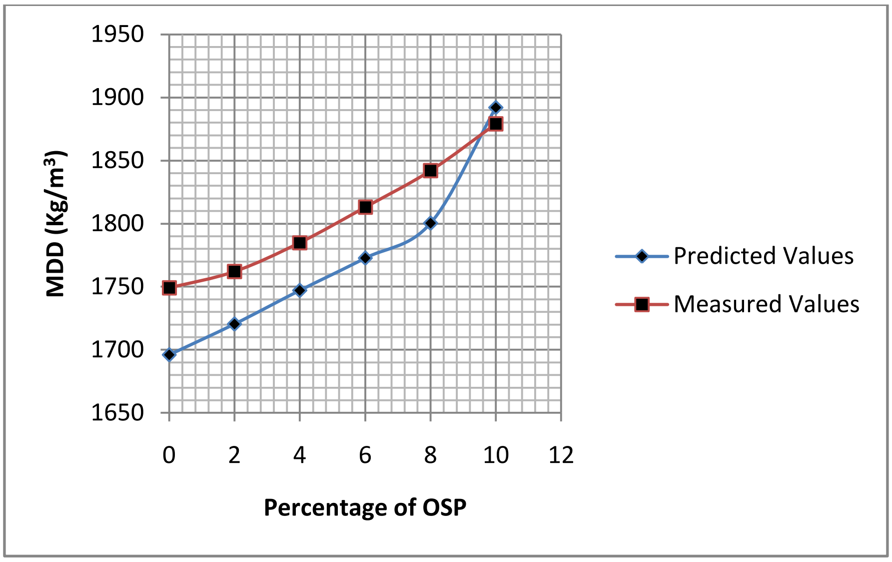

Figure 15: Effect of Percentage OSP content on MDD of Sample 5

The effect of OSP on the maximum dry density (MDD) of lateritic soil – OSP mixtures are shown in Table 6. It can be seen that at 0% OSP, the MDD of Lateritic soil sample 1 is 1733kg/m^3, as the OSP content increases from 2 to 10%, the soil's MDD also increases from 1752 to 1882kg/m^3, an increase of 8.6%. for lateritic soil sample 2, 3, 4 and 5, the percentage increase in MDD was found to be 6.9%, 6.8%, 8.7% and 7.4% respectively. This goes to show that the lateritic soil samples had the same behaviour (increase in MDD) when OSP was added. This is in agreement with similar observation for fly ash – soil – lime mixture. (Sahu, 2001 and Consoli et al., 2001). it is also consistence with (Eltaif and Gharaebeh 2008). This increase in MDD is as a result of the progressive increase in the amount of the sand-size particles in themixture due to flocculation and agglomeration of clay and the consequent reduction ofthe amount of clay-size particles in the lateritic soil. This clusters of clay minerals inthe soil and minerals in the OSP due to ion exchange in the soilresulted in more stable silt-sand-like structures. Figure 11 gives the graphical relationship between percentage OSP and MDD of lateritic soil sample 1. The graph gives a linear relationship between the two parameters as it moves upward to the right indicating that as the OSP content increases, the MDD of the soil also increases. The same trend is noticed for lateritic soil sample 2 to 5 as OSP content increase, see Figures 12 to 15.

The Microsoft excel program was used to develop a model equation that relates the OSP content and MDD of lateritic soil.

$$m = 0.1375p^2 + 11.944p + 1696.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \quad 3$$

Where:
m = Maximum dry density
p = Percentage of OSP

Equation 3 gave a R^2 value of 99.84% which indicates a strong positive correlation between the predicted and measured values. The predicted MDD value of lateritic soil sample was plotted against percentage OSP content, see Figures 11 - 15. The resulting graph showed a linear relationship between the two parameters which was similar to the measured MDD values.

IV. CONCLUSION

From the laboratory investigation and analysis carried out to determine liquid limit, plastic limit and MDD of the lateritic soil stabilized with OSP, the following conclusions were reached: The lateritic soils used in the study were A-2-6 and A-2-7 soils based on the AASHTO Soil Classification System. The soils are mostly low to medium compressible clay and highly compressible clay.The liquid limit of the soil samples tested decrease linear with the increase inOSP content. The increase in OSP content increase the plastic limit and maximum dry density of the lateritic soils linearly.According to Federal Ministry of Works and Housing (1997) specification, the lateritic soils used in this study in its natural state did not meet the requirement to be used as sub-base material but upon addition of OSP it was reversed (iemeet the Nigeria LL, PL and MDD specification for sub-base material).

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