Determination of Optimum Blend of NaOH with Pumice Powder in Non-Lateritic Soil Stabilisation for Highway Construction

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Abstract- The role of highways in road transportation cannot be overemphasized as it plays a vital role in socio-economic development of a nation. It facilitates the movement of people, goods, and services, but incessant failure of highways has become a common phenomenon in many parts of Nigeria. The preliminary investigation of the non-lateritic soil collected from Kwa in Quanpan local government council of plateau state shows that it belongs to A-7-6 (0) or CL-ML in AASHTO and unified soil classifications system (USCS) respectively. Soils under these classifications usually fall short of engineering standard for construction use. The soil was treated with pumice powder content (PPC) blend in stepped concentrations 0,2,8 and 14% as well as activated with alkaline (NaOH and KOH) in blend concentration of 80g, 320g, 560g (NaOH) respectively by dry weight of the soil. Compaction was carried out using the British Standard Light (BSL).The liquid limit increased from 15.4% for the natural soil to 27% at 14% PPC (560g NaOH) while the plastic limit increased from 13.75% of natural soil to 26.79% at 2%PPC (560g NaOH).The unconfined compressive strength increases for 2% PPC (80g NaOH) compared to the natural soil from 338.38KN/m2 to 658.99KN/m2 for 7 days curing period. The plasticity index also increases from 1.75% for the natural soil to 7.74% at 14% PPC (560g NaOH). The California bearing ratio (CBR) values for the unsoaked condition of the soil sample increase from 55.89% for the natural soil to a peak value of 57.40% at 2% PPC (NaOH 80g).Statistical analysis of variance (ANOVA) showed that soil characteristics improved due to pumice powder content (PPC) and alkali to treat the soil. The results showed that stabilisation with 2% PPC and 80g NaOH significantly improved the strength properties of the soil.

Indexed Terms- Pumice, NaOH, Stabilization and non- lateritic soil

I. INTRODUCTION

Highway transportation is the dominant mode of carrying people and goods in Nigeria. Most freight and passengers are predominantly transported by road and resulting in repeated failure of existing roadways due to the high volume of heavy goods vehicles (Madu *et al.,* 2016). The role of highways in road transportation cannot be overemphasized as it plays a vital role in the socio-economic development of a country. It facilitates the movement of people goods and services (Olofinyo *et al.,* 2019). Lateritic soils are the underlying course on which all road construction are executed. Therefore, it is necessary to determine the geotechnical properties of lateritic soil before using it for road construction. Selection of locally available lateritic soil that is good and has the adequate required engineering properties which can be sourced at a reasonable distance of haulage or which may need little or complete treatment to obtain the required strength, will be of great importance to highway construction (Abdulwahab *et al.,* 2018).

Lateritic soils are the most common surface deposits occurring in the tropical and subtropical regions of the world, enriched in iron and Aluminum and developed by intensive and prolonged-lasting weathering of the underlying parent rock (Muthusamy *et al.,* 2015).

Laterites serve as the perfect soil materials to solve all construction problems, especially in the construction of earth dams, highways, embankments, airfields and foundation materials to support structures without considering its classification as a problematic or non-problematic type of lateritic soil and the actual field geotechnical performance of the soils. Though, this may seem challenging to the geotechnical engineer, soil stabilisation as a ground improvement technique is the way forward. Stabilisation of soil is the enhancement of soil properties by adding stabilizers (also known as additives), which may be organic or inorganic to modify the existing properties of the soil (Recep *et al.*, 2015). Cohesive clayey soil is a tough challenge for highway engineers due to its swelling and shrinkage characteristics, which are the sole reasons for pavement failures. Stabilisation of such (Kaolinite and Montmorillonite) soils employing mechanical or chemical methods helps in the re-use of these soils instead of road cutting for the complete replacement of the in-situ soil with suitable carted earth materials as subgrade (Divya *et al.*, 2021). The stabilisation method is well known and has been used worldwide for many decades.

Pumice is an amorphous foam produced during volcanic eruptions. It is composed mainly of silica and alumina in relative amounts according to the geological area of origin, and it also includes other chemical elements, such as different oxides and water. Alkali-activated materials are usually produced by mixing alkaline activator solutions with solid raw materials. The hydration process is called geopolymerization, which contains a series of chemical reactions, including the dissolution of starting materials, poly-condensation, condensation and finally, the crystallisation of new reaction products.

Commonly alkali-activated materials based on Silica (Si) and Aluminum (Al) types have excellent mechanical properties, enhanced reinforcement steel bonding and fire resistance. However, at the same time, drawbacks such as long setting time, slow strength development, and high curing requirements are obstacles to their practical application. Several researchers have found that adding slag into Si and Al-based geopolymer can improve the compressive strength and decrease the setting time to some degree; also, acceptable strength can be achieved (Susan *et al.*, 2012).

This research is carried out to investigate the effect of pumice powder addition in alkali-activated non-lateritic soil for highway construction. The pumice sample was collected from Kerang Hills Latitude 9°9´´53̓and Longitude 9°11´´59̓in Mangu Local Government Area of Plateau State.

II. RESEARCH ELABORATIONS

Natural Non-Lateritic Soil

The soil sample used for the study was obtained from a borrow pit at Kwa, Quanpan Local Government Council of Plateau State. The soil sample was collected at a depth between 1.3 - 1.5 m to avoid top soil and ensure the non-inclusion of organic matter. The plate showing the soil excavation is shown in Figure 2 below.

Pumice Sample

The Pumice sample for this study was obtained from Kerang Hills in Mangu, Local Government Council of Plateau State. The Pumice samples were crushed and graded.

Alkaline Samples

The NaOH sample was procured as factory products (finished products) from the Jos, Plateau state Open market.

Water

Potable water was used for all the tests.

Figure 1 Pumice sample region

Figure 2: Soil sample collection region

Design Expert

Design Export 13 software package was used for designing the experiment (DOE) and for conducting multivariate data analysis to allow for planning and conducting efficient experiments to determine the optimal settings for different variables affecting a process or product to reduce cost, improve quality and maximized designed outcomes.

The software enables users to design experiments where the ingredients of a product are mixed in different proportions. It helps identify the optimal combination of ingredients to achieve the designed properties or characteristics of the product.

III. RESULTS/FINDINGS

Table 1: below summarises the general properties exhibited by the soil and the Pumice used for the stabilisation.

Oxide Composition of Non-Lateritic Soil Sample

The elemental composition of the natural non-lateritic soil was determined using X-ray fluorescence (XRF) found the significant compounds of the soil as silicon oxide, SiO2, 54.63%, Iron oxide Fe_2O_3, 20.01% and Potassium oxide, K_2O, 12.90% as shown in Table 4, However, Al_2O_3 was not detected in the soil sample. The test was carried out at the National Steel Raw Materials Exploration Agency Malali, Kaduna State, using the Genius IF Xenemetrix Machine.

TABLE 1: PROPERTIES OF THE NATURAL NON-LATERITIC SOIL AND PUMICE POWDER SAMPLE

Property	Quantity
Percentage passing No. 200 sieve (%)	0.33
Natural moisture content (%)	15.4
Liquid limit (%)	15.4
Plastic limit (%)	13.65
Plasticity index (%)	1.75
Linear shrinkage	-
Specific gravity	2.20
AASHTO Classification	A-7-6 (0)
USCS	CL-ML
Group index	0
Percentage fine sand fraction	2.4
Percentage medium sand fraction	20.0
Percentage coarse sand fraction	60.8
Percentage fine gravel fraction	16.8
Maximum Dry Density (Mg/m^3)	1.82
Optimum moisture content (%)	13.8
Unsoaked California bearing ratio (%)	38.6
Soaked California bearing ratio (%)	13.1
Unconfined compressive strength 7 Days cured (kN/m^2)	n.a
Colour	Reddish brown

Table 4: XRF Results of the Natural Non-Lateritic Soil Sample

Oxide Compositions	Concentration (%)
SiO_2	54.63
K_2O	12.90
Ti_2O	2.80
V_2O_5	0.11
Cr_2O_3	0.18
MnO	0.30
Fe_2O_3	20.01
NiO	0.04
CuO	0.10
ZnO	0.009
BaO	0.55
ZrO_2	0.74
Eu_2O_3	0.15
Total	92.52

Sesqueoxide Ratio (S.S. Ratio) = $SiO_2/(Fe_2O_3 + Al_2O_3)$

S. S.Ratio = 54.63/(20.01 + 0)

S.S. Ratio =2.73

2.73>2.00; hence, the sample is non-lateritic soil

Particle size distribution

The results of classification tests on the natural soil are summarised in Table 3. Physical observation showed that the soil is reddish brown. The liquid, and plastic limits were observed to be 15.40 and 13.65 %, respectively, and the corresponding plasticity index of 1.75% confirmed that the soil is low plastic. The soil was classified as A - 7 - 6 (0) and CL-ML using the American Association of State Highway and Transportation Officials (AASHTO) ASTM D3282-09 soil classification system and Unified Soil Classification System (USCS) ASTM D2487-11, respectively. These classification systems show that the soil is coarse sand with low plasticity. Detailed test results are given in Table 4

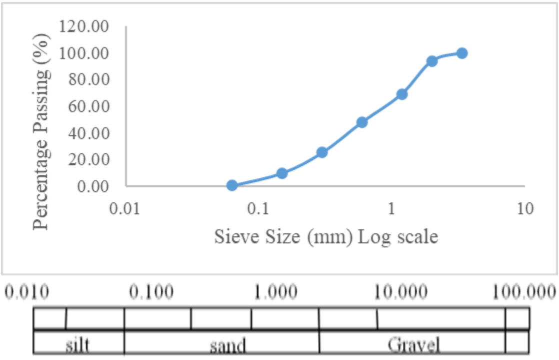


Figure 3: Particle size distribution curve for the natural lateritic soil sample

4.2.4 Particle Seize Distribution of Pumice Powder Sample

The Pumice sample was prepared in powder form, as such, the particle size distribution allows for 100% passing the sieve No. 200 (0.063 mm).

ATTERBERG LIMITS

The water content at which soil changes from one state to the other is known as Consistency or Atterberg's limit. The Atterberg limits are primary measure of the critical water contents of fine grained soil its shrinkage, plastic limit and liquid limits. The Atterberg limits are used to distinguish between Silt and Clay and to distinguish between different types of silt and clays.

Depending on its water content, soil may appear in one of the four states: Solid, Semi-solid, Plastic and Liquid. In each state the Consistency and behaviour of soil are different, and consequently so are its Engineering properties.

4.3.1 Liquid Limit of NaOH-activated Non-Lateritic Soil Stabilized with PPC

The variation of the liquid limit of NaOH activated non-lateritic soil with Pumice Powder content (PPC) is shown in Figure 3. Generally, the liquid limit of the natural non-lateritic soil increases from 15.4% to 27% at 14% PPC. The increase in liquid limit values can be attributed to the fact that PPC has a significant water absorption capacity and increases the volume of the mixture as an additive, thus increasing the minimum water content at which the soil could flow. The results are shown in Table 7.

Table 7: Liquid Limit Test Results of NaOH activated Non-Lateritic Soil with Pumice Powder Additive

Liquid Limit (NaOH Activated Non-Lateritic Soil at Dosage (g))			
PPC (%)	80	320	560
2	25	27	28
8	26	28	18
14	19.1	16.2	27

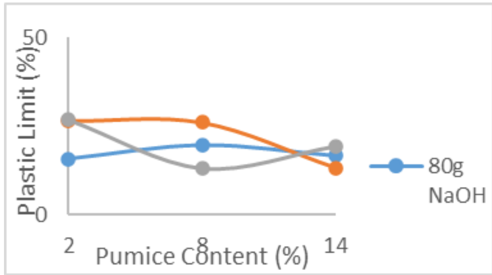


Figure 2: Variation of Liquid Limit Vs Pumice Content in NaOH Activated Non-Lateritic Soil

4.3.2 Plastic Limit of NaOH-Activated non-Lateritic Soil Stabilised with PPC

The variation of the plastic limit of the non-lateritic soil with PPC is shown in Figure 3. The Plastic limit increase with higher PPC. The value of 19.26% was observed at 14% PPC at 560g NaOH (see Table 4.5). This represents an increase of 28.61 % when compared to the value obtained for the natural soil (i.e. 13.75%). The Plasticity however are more pronounced for 320g NaOH activated Non-Lateritic soil as shown in the Figure 3, and in all cases not progressive. The deterioration in the plastic limit of the stabilised soil is due to the volume increase of soil by PPC which increased the water content of the soil. However, the increase in the plastic limit with the addition of PPC may in part be due to the water absorption characteristic of PPC. It is expected that the plastic limit of the soil will continue to increase with further addition of PPC until it becomes fully plastic because PPC has significant water absorption capacity.

Table 8: Plastic Limit of NaOH activated Non-Lateritic Soil with Pumice Powder additive

Plastic Limit (NaOH Activated Non-Lateritic Soil at Dosage (g))			
PPC (%)	80	320	560
2	15.75	26.53	26.79
8	19.68	26.04	13.03
14	16.61	13.17	19.26

Figure 3: Variation of Plastic Limit Vs Pumice Content in NaOH Activated Non-Lateritic Soil

4.3.3 Plasticity index of NaOH-activated non-lateritic soil stabilized with PPC

The variation of the plasticity index of the non-lateritic soil with PPC is shown in Figure 4. The result showed an increase from 1.75% for the natural soil to 7.74% of the soil stabilised with 14% PPC at 560g NaOH. Generally, the plasticity index of the soil increases significantly with the addition of PPC to the non-lateritic soil for both 320 and 560g dosages of NaOH. It decreases for the 80g dosage as shown in Figure 4 and presented in Table 9.

Table 9: Plasticity Index Test Results of NaOH activated Non-Lateritic Soil with Pumice Powder additive

	Plasticity Index (NaOH Activated Non-Lateritic at Dosage (g))		
PPC (%)	80	320	560
2	9.25	0.47	1.21
8	6.32	1.96	4.97
14	2.49	3.03	7.74

COMPACTION CHARACTERISTICS

The Pumice stabilised natural soil was compacted using WAS compactive effort. Results obtained were based on a comparison of the effect of NaOH activators on 2, 8 and 14% PPC stabilised soil sample with concerning the MDD and OMC.

4.4.1 Effect of the Activators on Maximum Dry Density

The variation of maximum dry density (MDD) of activated non-lateritic soil with PPC as an additive is depicted in Figure 8 for specimens compacted with BSL energy level. Generally, the MDD values decreased with an increase in PPC even as the density of the PPC (2.62) is higher than that of the natural soil (2.20), for a PPC addition level of 14% of NaOH

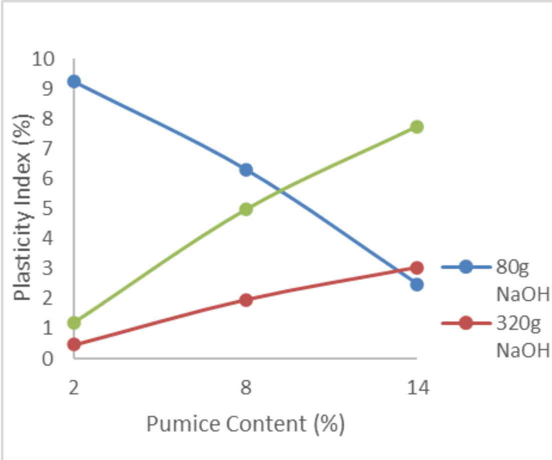
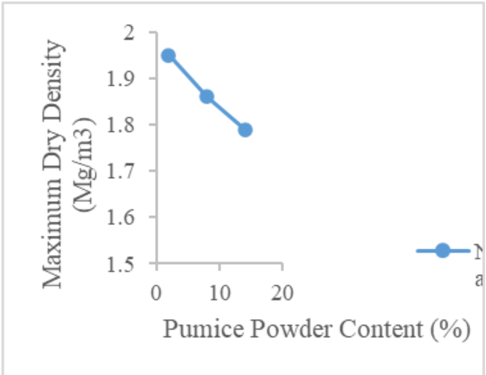


Figure 4: Variation of Plasticity Index of NaOH Activated non-lateritic soil with PPC



Effect of the Activators on Optimum Moisture Content

The variation of optimum moisture content (OMC) of activated natural non-lateritic soil with PPC additive is depicted in Figure 9. For the WAS compaction energy level used, OMC increases an with increased in the PPC additive level. The OMC recorded for the natural soil sample compacted using WAS is -%, while for samples containing 14% additive of PPC for instance, the OMC increases to 10.20 and 16.10% for WAS compactive effort. Detailed test results are given in Appendix A6.

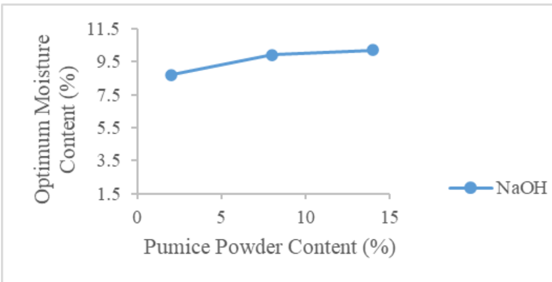


Figure 9: PPC - Optimum Moisture Content Relationship of Non-Lateritic Soil

Regression Analysis and Analysis of Variance for Compaction Characteristics

The regression analysis tests run on the Activated non-lateritic soil compaction characteristic PPC was carried out for the WAS comp active effort. In the case of MDD and OMC, it was considered as the dependent variable (response), while the PPC additive percentages and alkaline dosage (grams) are the independent variable (predictors). The regression equation obtained from the analysis for MDD and OMC WAS Compactive effort can be expressed in Equations 1-2:

$$MDD_{(NaOH)} = 1.9733 - 0.1333P_c - 0A_d \quad \ldots (1)$$
$$OMC_{(NaOH)} = 8.6000 + 0.1250P_c - 0A_d \quad \ldots (2)$$

where;
$MDD_{(NaOH)}$ – Maximum Dry Density with NaOH as an activator

$OMC_{(NaOH)}$– Optimum Moisture Content with NaOH as activator

P_c – Pumice powder content (%)
A_d – Alkaline activator dosage (g)

Figures 10 – 13 are residual plots showing how the observed measurement of MDD and OMC are distributed around the theoretical mean value.

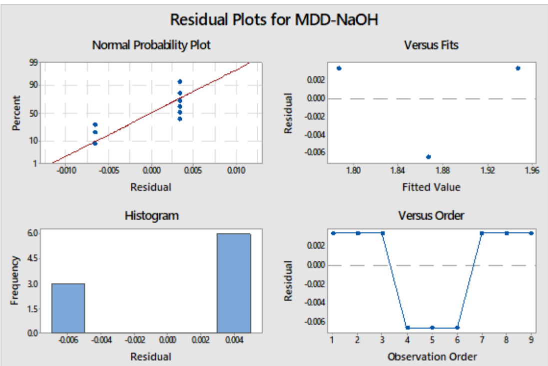


Figure 10: MDD Residual Plots for NaOH activated-PPC stabilized Non-Lateritic Soil

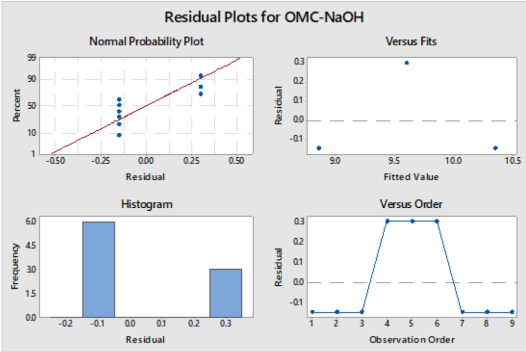
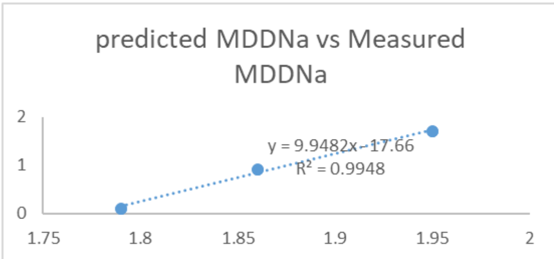


Figure 12: OMC Residual Plots for NaOH activated-PPC stabilised Non-Lateritic Soil

Validation of the Maximum Dry Density and Optimum Moisture Content Models
The measured and predicted values of the stabilised soil compacted at WAS energy levels shows that the residual errors ranges from 0.24 to 1.68 for MDD of NaOH activated soil samples. At the same time, the residual errors ranges from -0.15 to 0.3 for OMC of NaOH activated soil samples respectively. The NaOH activated samples produced a better residual range for OMC test observations.



CALIFORNIA BEARING RATIO
California bearing ratio (CBR) is a penetration test used to evaluate the mechanical strength of natural ground, sub grades and base courses beneath new carriageway construction. The test results are used with empirical curves to determine the pavement thickness and its component layers (Murthy, 2008).

4.5.1 Unsoaked Condition
4.5.1.1 Unsoaked Condition for NaOH Activated Lateritic Soil Stabilized with PPC
The variation of the Unsoaked California bearing ratio (CBR) of the NaOH activated non-lateritic soil with PPC is shown in Figure 14. For the British standard light compaction (bsl) energy level used, the CBR initially peak values at 2% PPC and 80 g NaOH content and then decreased with increased PPC content. The Unsoaked CBR value increased from 55.89% for the natural non-lateritic soil to a peak value of 57.40% corresponding to a 2.6%

increase from the natural soil CBR value. The observed decrease in the Unsoaked CBR values beyond 2% PPC content may be due to the presence of higher quantity of PPC that did not bond with the soil particles thus resulting in high compressibility of the mixture and more so, the CBR value decreases with increased Alkaline activator content, with optimum as 80 g NaOH.

Specimens stabilised with up to 14% PPC, and compacted with the BSL energy level were considered meet the requirement of 30% CBR of the Nigerian General Specification (1997) for soil material to be used as subbase material, however none of stabilised specimens met the requirement of 80% CBR for soil to be used as base materials for road construction.

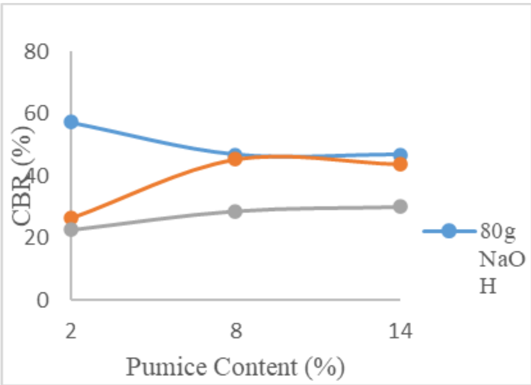


Figure 14: BSL Unsoaked CBR- NaOH activated non-lateritic soil with PPC

requirement of 80% CBR for soil to be used as base materials for road construction.

4.5.2 Soaked Condition

4.5.2.1 Soaked Condition for NaOH Activated Non-Lateritic Soil

The variation of the soaked CBR of NaOH non-lateritic soil with PPC is depicted in Figure 16. For the BSL compaction energy levels used, the soaked CBR decreases up to 80% PPC for both 80 g and 320 g dosage but however increased at 80% PPC for 560g dosage. For the BSL, compaction effort, the CBR values increased from 55.89% for the natural non-lateritic soil to a peak value of 13.6% for 2% PPC and 320g NaOH respectively. Generally, the soaked CBR of non-lateritic soil is less than that of unsoaked condition, since under soaked condition the surface tension forces (offering additional resistance to penetration under the unsoaked condition) are destroyed (Sellaf *et al.*, 2014).

Regression analysis and analysis of variance for unconfined compressive strength (UCS)

The regression analysis tests on the unconfined compressive strength test results were analyzed with using PPC and Alkaline dosage as parameters. The regression equation obtained from the analysis for unconfined compressive strength 7 days for BSL Compactive effort is expressed in Equations 9:

$$UCS_{(NaOH)} = 438.0 - 4.46P_c - 0.1360A_d \quad \dots (9)$$

where;

$UCS_{(NaOH)}$ – Unconfined compressive strength-NaOH as activator

P_c – Pumice powder content (%)

A_d – Alkaline activator dosage (g)

Figure 24 shows residual plots showing how the observed measurements of UCS are distributed around the theoretical mean value.

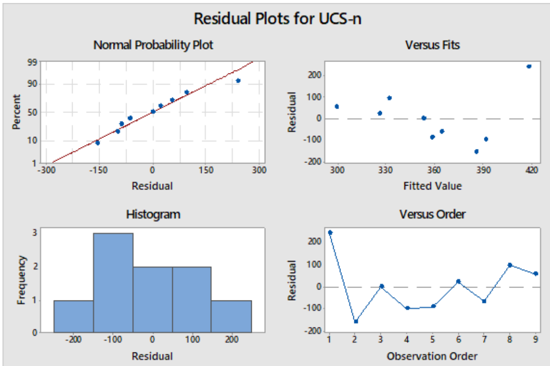
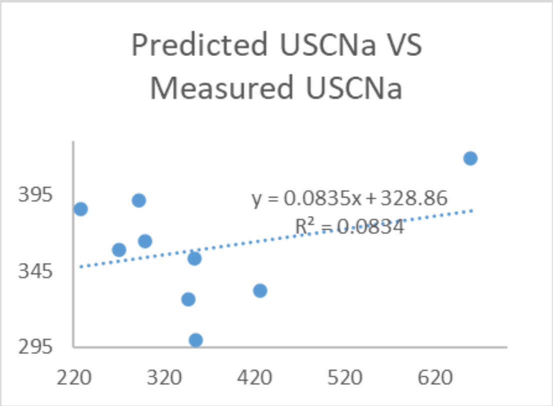


Figure 24: UCS Residual Plots for NaOH activated-PPC stabilised Non-Lateritic Soil

4.6.4 Validation of the Unconfined Compressive Strength Models for 7 days Curing

The measured and predicted values of the stabilised soil compacted at energy levels of BSL, show that the residual errors ranges from -147 to 240.79 for unconfined compressive strength 7 days curing for NaOH activated- PPC stabilised models.

The NaOH activated –PPC stabilised samples produced better residual errors as observed from the UCS measurements, indicating a better predicting model.



CONCLUSION

From the result of the investigation carried out within the scope of the study, the following inference in the context of utilising PPC in soil stabilisation can be drawn;

i. The soil sample used for this study is classified as A - 7 – 6 (0) and CL using the American Association of State Highway and Transportation Officials (AASHTO) ASTM D3282-09 soil classification system and Unified Soil Classification System (USCS) ASTM D2487-11, respectively. The liquid and plastic limits were 15.4 and 13.65 %, respectively, and the corresponding plasticity index of 1.75 % confirmed that the soil is low plastic soil. However, NaOH and KOH activated samples' liquid and plastic limits increases with increase in PPC.

ii. The Optimum blend of NaOH and KOH activators required for 2, 8, and 14% PPC to be used a stabilisers were obtained as (80, 320, and 560)g NaOH and (112, 448, and 560)g KOH respectively

iii. Generally, there was an increase in OMC with increase in PPC, and a corresponding decrease in MDD as the PPC increased.

iv. The Unsoaked CBR value increased from 55.89% for the natural lateritic soil to peak values of 57.40% and 50.60% corresponding to a 2.6% increase and decrease of 9.5% from the natural soil CBR value respectively at 2% PPC for the NaOH and KOH activated samples respectively. However, the soaked CBR for the NaOH activated sample peaked at 13.6% for 2% PPC and 49.85% for 14% PPC for KOH activated samples. Generally the CBR shows slight signs of improvement with increases in PPC. There was an enormous increase in UCS with an increase in PPC up to 2%, i.e. 658.99 kN/m^2 was recorded for 80 g NaOH at 2 % PPC and 325.81 kN/m^2 peak value was recorded for 112 g KOH at 2% PPC when the specimen was compacted with BSL energy, indicating a drop from the 338.38 kN/m^2 obtained for the control.

v. It can thus be safely concluded that regression analysis provides a sound background for predicting the geotechnical properties of soil samples for preliminary assessment in the absence of experiment data.

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