UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 2(2), September (2023), 392-403
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Assessment of Corn-Cob Ash Stabilised Soil for Infrastructure Development in a Sprawled City

Ugwu .N. Juliet[1*]; Ikeagwuonu Arinze[2] and Chiwetalu .U. Jenice[3]
[1,2]Department of Civil Engineering, Enugu State University of Science and Technology, Enugu.
[3]Department of Agricultural & Bioresources Engineering, Enugu State University of Science and Technology, Enugu, Nigeria
[*]Corresponding author; juliet.ugwu@esut.edu.ng

Abstract
This work elucidates the assessment of corn-cob ash stabilised soil for a sustainable infrastructural development in urban sprawled areas. Corn-cob (agricultural waste) was recycled into corn-cob ash (CCA) as a partial replacement with laterite soil at five different levels, 0%, 2.5%, 5%, 7.5% and 10% replacement by weight. Geotechnical laboratory tests were performed on the soil material and a non-linear regression model that can predict the impact of corn-cob ash on the soil for infrastructure sustainability was developed. The laboratory result showed at 2.5 and 5.0 CBR that 2.5% and 5% CCA replacement yielded improved CBR values of 75.40 and 73.53 respectively before soaking and CBR values of 17.01 and 21.97 after soaking. The optimum value gotten at 5% CCA level. The model results predicted the results properly with coefficient of correlation of 0.79 and 0.91 for CBR results of 2.5 and 5 respectively. This study showed that recycling corn-cob waste as stabilizing agent for road infrastructural development helps in waste and environmental management which will result to a stable, friendly and sustainable built environment.

Keywords: Corn-cob, Green-Infrastructure, Stabilization, Urban-sprawl, Waste-Management

1. Introduction

Population in urban cities continues to be on the increase because of availability of amenities which improves one's living. The urban cities are most times planned, designed and well equipped with beautiful built infrastructure to improve man's standard of living. The infrastructural developments and social amenities in the metropolis are the major attraction to everyone wanting to reside there hence the high population density in the urban and (United Nations, 2018). This high population make urban areas less attractive to people that want to live a quiet and relaxed life away from the hostile nature of this urban life and relocating to low areas with low property values (Mosammam et al., 2017; Xu et al. 2019b). Again, the influx of people in the urban makes cost of living very expensive for low-income earners. Some people because of their rising income and financial stability, relocates to the outskirts of metropolitan areas away from the hustles of urban areas. Here, the housing options are less expensive and lower property values which they can decide to buy and build their own houses and these areas are not initially planned (Fenta et al. 2017; Tanveer et al. 2019). As time goes by, these outskirts start experiencing great population growth thereby giving rise to urban sprawl a situation of outward spreading of urban development to unplanned areas around the city. In essence, economic growth, increased affluence, attractive land, housing prices, even weak planning laws all play significant role in urban sprawl.

The sprawled area is borne from the outward spreading of urban development to unplanned areas around the city. These areas are not planned. As time goes by, these unplanned areas now becomes highly populated and they are not well equipped to engage any natural disaster and they are also prone to health disasters and other negative impacts (Sumari et al. 2017; Tanveer et al. 2019).As a result of influx of people, these areas tend to develop fast in commercial activities, agricultural activities, as well as human activities bringing about increase in waste generation, pollution (air, land), reduction of open spaces, loss of natural habitats, increased crime, etc. Urban sprawl is becoming a major issue in many cities. The tendency of population growth in these outskirts, gives rise to houses springing up everywhere without proper planning and infrastructural designs. Naturally, human activities will commence and continually increase. Such activities like agricultural (animal rearing and planting), commercial (establishing markets, business ventures), manufacturing/productions, etc. These human activities in one way or the other come with consequences like; waste generation, pollution (air, land), reduction of open spaces by dumping wastes, loss of natural habitats etc (Wilson and Chakraborty, 2013). These problems increase the overall reduction of man's quality of life because of unplanned nature of such place. The high human population density in these sprawled areas has consequently led to need for increase in development of infrastructures like roads which can technically impact on the built environment enhancing improvement to man's life.

In order to reduce risk associated with wastes in our environment like, rice-husk ash, plantain leaf ash, corn-cob ash (CCA) etc, some researchers have envisaged the usefulness of recycling agricultural waste materials like plantain leaf, rice husk, groundnut shells, corn-cobs, saw dust (Ugwu, 2019). These agricultural wastes can be used as partial replacement or full replacement. Ugwu and Ugwuanyi, (2020) in their research used plantain leaf ash as a partial replacement for cement on concrete compressive strength. The analysis showed concrete strength that is very much comparable and sustainable for which there would be significant impact on construction costs and reduction of environmental pollution. Ogbuagu et al., (2018) in their study showed that rice husk ash is a good improvement agent on soil used as sub-grade materials in road construction. More so, Chiwetaluet al., (2021) carried out a study on soil alkalinity control using three different bio-materials (waste) for soil sustainability and productivity. Their studies showed that the waste materials used have significant effect in reducing alkalinity in the soil.

Corn cob, a by-product of corn production, with about 160-180 kg generated for every 1 ton of corn produced (Zhang et al., 2020) are littered around the environment and can be collected, recycled and used for upgrade of the environment. However, most of the corn cobs generated worldwide are still discarded as wastes. The disposal of this enormous waste can constitute environmental pollution either by dumping or burning in open spaces, hence, the need to consider them for recycling into some applications for environmental improvement (Zhang et al., 2020). Corncob has often been considered for heavy metal removal from waste water, bio-fuel production (Zhang et al., 2020; Liu et al., 2012), preparation of high surface area carbons for the adsorption of dyes and phenols from water and for hydrogen storage, composting of swine manure, production of thermally insulated building materials such as particle board or sandwich panel products (Tseng and Hung, 2014; Zhao et al., 2016) with little familiarity for its use as soil stabilizing agent in road infrastructure. Stabilization using corn cob ash (CCA) reduces biomass wastes like corn cob which is an environmental hazard and recycling the corncob wastes will bring about employment of people, reduce cost of using cement as stabilizing material and increase the soil strength.

The knowledge and use of natural pozzolanic materials as partial replacements has increased because the construction cost of infrastructure development reduces. The use of CCA will reduce environmental pollution, climate change, global warming and useful as a stabilizing material in infrastructural development like road. It is considerably available for use. Lateritic soils are good construction materials which are commonly used in road construction, they constitute the sub-grade of most tropical roads, sub base and base courses for low cost roads. Sometimes, there is need to stabilize laterite materials to boost its strength in supporting load. The effects of corn cob ash on the index properties of California bearing ratio (CBR) and unconfined compressive strength (UCS) of a lateritic soil was investigated by Jimoh and Apampa (2014). The result showed that the maximum dry density of the soil reduced as corn cob ash content increases. Owolabi et al., (2015) in their work effects of corn cob ash as partial substitute for cement in concrete, showed an improved result with optimum concrete strength at 5% CCA content and strength reduction as CCA content increased

The goal of this research is to present and assess the application of CCA as stabilizing agent in road infrastructure for sustainability and develop a non-linear regression model that can predict the effects of CCA content on the soil strength. CCA replacements by weight at different percentage levels of 0%, 2.5%, 5%, 7.5%, 10% were considered in order to provide an easy path for its use without experimental work and also suggest on further improvement on the performance of CCA stabilized soil.

2.0 Material and methods

2.1 Materials used for the Study

The material used for this study includes:

- Laterite soil: It was gotten from Ibagwa Nike community layout, Enugu East, Enugu State, Nigeria. It is a reddish brown silty clayey soil material.
- CORNCOB ASH (CCA): This was sourced from a dump site at Ahianku market at Ibagwa Nike community layout, Enugu East, Enugu State, Nigeria. The corn cob was burnt in a muffler furnace at a temperature of 1000 ^{0}C in order to obtain corn cob ash.
- Apparatus used for the study were proctor mould, rammer, weighing balance, triple beam (Ohaus), board tray pan, straight edge, mould spanner, grooving tool, measuring cylinder, CBR Marshall tester (MATEST, S213 model), Muffler furnace, (3B5213C model, Gallenkamp England) and oven (okhard Machine scientific and laboratory Equipment).
- Water: This is for washing and mixing.

2.2 Methods

2.2.1 Laboratory Method

Various tests were carried out on the samples (soil material) using CCA as a stabilizing agent at varying percentages (0%, 2.5%, 5%, 7.5%, 10%) replacement of laterite soil. These percentage replacements are by weight. Tests conducted include; particle size distribution, specific gravity, Atterberg limit, moisture content, CBR. Thus, mathematical modelling of the experimental data obtained was also done in order to examine, analyse and predict the behaviour of CCA with the lateritic soil for road infrastructure sustainability. The characterization of the laterite soil was done according to particle size distribution, specific gravity and Atterberg limit tests. The tests were carried out according to British Standard (BS) 1377 part 2 and 4, 1990.

2.2.2 Sample Preparation

Laterite Soil

The soil sample in its natural state was collected air dried for about 24 hours. Some unwanted particles were removed from the sample by handpicking and made ready for testing accordingly.

Corncob Ash (CCA)

Corn cobs were obtained from heaps of waste cobs which abound in a dump site at Ahia-Nku market Ibagwa Nike, Enugu. The community is a major corn producing rural community in Agro-ecological zone of Enugu State in South-Eastern Nigeria. The corn-cobs were gathered, washed with water to remove dirty impurities sticking on them as a result of where they were dumped. They were allowed to dry under the sun for four days. This was actually during the dry season so there was enough sunshine for the drying process. These dry corn-cobs were collected and subjected to burning in a muffler furnace and calcined into ash in a make-up container at temperature below 650^{o}C for about 40 minutes so that entire corn cob will burn completely. Thereafter, the burnt ash was allowed to cool for 24 hours and the ash collected. The ash was sieved using 600μm sieve and ashes that passed through the sieve were collected and used for the study while those retained on the sieve were discarded. No further treatment was applied to improve the ash quality as the research wants to utilize simple processes that can be easily applied by locals.

Moisture Content Determination

After soil sample preparations, the natural moisture content of the soil was determined using the gravimetric method of moisture determination and the result obtained.

Sieve Analysis and Atterberg Limit determination

Sieve analysis was conducted to study the particle size distribution of the soil. Plastic limit, liquid limit and plasticity index of the soil were determined from the Atterberg limit test using Casagrande's apparatus.

Specific Gravity Test

Specific gravity of the soil was determined using the density bottle test method. The specific gravity was taken as the ration of soil to the density of water at the same temperature. It was for material characterization.

CBR Test

California Bearing Ratio (CBR) test was conducted on the soil at its natural state and also various proportions of CCA (0%, 2.5%, 5%, 7.5%, 10%) mixture by weight. The shear strength bearing capacity of the soil was determined from the CBR test carried out to study the effects of the various CCA percentage replacements with laterite. This was conducted before and after soaking. The bearing capacity of the soil was measured by conducting the CBR test for the un-soaked and soaked CBR.

2.3 Model Method

Non-linear regression model which will predict the CBR values of the soil at the different CCA percentage replacement was considered. The dependent variable is the strength properties of the soil and the independent variables are the CBR results and the CCA percentage contents. A polynomial function model that will predict the soil strength at various percentages of corncob ash replacements was adopted and the constants determined by applying the multiple regression approach.

3.0 Results and Discussions

3.1 Mathematical Model Development

The strength properties of the soil were modeled using two variables, namely, the CBR results and percentage content of corncob ash (CCA) in the soil. An exponential function model of the form in Equation (1) was assumed and adopted for predicting the CBR values of the soil at various percentages of corncob ash before soaking.

$$C_{BR} = \varphi_1 e^{\varphi_2 \beta} \qquad (1)$$

where C_{BR} is the CBR value, β is the corncob ash content (%), $\varphi_1 and \varphi_2$ are the constants. Linearizing Equation (1),

$$lnC_{BR} = ln\varphi_1 + \varphi_2 ln\beta \qquad (2)$$

If $lnC_{BR} = Y$, $ln\varphi_1 = A$, $\varphi_2 = B$ and $ln\beta = x$ then,

$$Y = A + Bx \qquad (3)$$

Through calibration, the constants A and B can be determined. The exponential function models were subsequently developed for 2.5 CBR, 5.0 CBR and AVERAGE CBR before soaking. A polynomial function model of the form in Equation (4) was adopted for predicting the CBR values of the soil at various percentages of corncob ash after soaking.

$$C_{BR} = A + B\beta - C\beta^2 \qquad (4)$$

Let $C_{BR} = Y, \beta = x$ so that

$$Y = A + Bx - Cx^2 \qquad (5)$$

By applying multiple regressions, we can determine the constants A, B and C.

3.1.1 Statistical Assessment

The accuracy and reliability of the models developed was determined using suitable statistical evaluation criteria namely Coefficient of Determination R^2 and Coefficient of Correlation CORR.

The laboratory and model results are presented in tables and graphs.

3.1.2 Model Verification

The non-linear models developed to predict the CBR values of the soil at various corncob ash contents were verified using the CBR data from the laboratory. Also the accuracy of the models was determined by using statistical tools such as coefficient of determination R^2 and coefficient of correlation CORR.

Comparison of the plots of the 2.5 CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (6) are shown in Figure.3.

$$C_{BR} = 83.63e^{-0.04865\beta} \quad (6)$$

3.2 Discussions

The result of particle size distribution, specific gravity and Atterberg limit tests showed that the soil is a fine grained soil with some fractions of gravel and specific gravity of 1.89 as well as liquid limit of 25.8%, plastic limit of 28.8% and a plasticity index of 3.0%. The Maximum Dry Density decreased sharply from the control value of 1.890g/cm^3 to 1.79g/cm^{3}with10% CCA content. This result collaborated with Jimoh and Apampa, (2014) study that showed reduction in dry density as CCA content increases.

One of the ways the CCA effect was assessed was in terms of soil improvement from CBR (California Bearing Ratio).

The soaked CBR tested in this study was to be able to simulate actual site condition and the effect of water on the CBR value of this soil material. The CBR results for 2.5 CBR, 5.0 CBR and Average CBR at of 0%, 2.5%, 5.0%, 7.5% and 10.0% CCA replacements by weight measurement for before and after soaking are given in Table.1

Table.1: CBR values at different CCA% replacement before and after soaking.

CORNCOB	**BEFORE SOAKING CBR**			**AFTER SOAKING CBR**		
ASH (%)	2.5	5.0	AVERAGE	2.5	5.0	AVERAGE
0	87.59	96.57	92.08	8.09	13.93	11.01
2.5	69.91	80.89	75.40	18.48	15.54	17.01
5.0	66.70	80.36	73.53	22.50	21.43	21.97
7.5	55.45	62.68	59.87	15.21	16.61	15.94
10.0	53.54	61.61	57.33	12.05	15.54	13.80

The CBR values before soaking generally had higher values than after soaking. For the soaked CBR, 2.5% and 5% CCA samples gave a very improved result on the soil strength when compared with the control at 0% as shown in Table 1. This can be from the pozzolanic effect CCA on the soil. The chemical composition of corn cob ash is given in Table.2. The pozzolanic property of CCA makes it to behave like cement (with the composition of oxides of calcium, silicon and aluminium) which in the presence of water, reacts chemically with calcium hydroxide to form compounds possessing cementations properties, hence, the improved quality of soaked CBR strength at 2.5% and 5% CCA replacement. 2.5% and in particular 5% CCA replacement is recommended for use.

Table.2: Chemical composition of corn cob ash (Owolabi et al., 2015)

Chemical contents	Percentage composition
CaO	10.24
SiO_2	64.90
MgO	2.08
Na_2O	0.43
Al_2O_3	10.79
Fe_2O_3	4.75
SO_3	2.53
K_2O	4.23

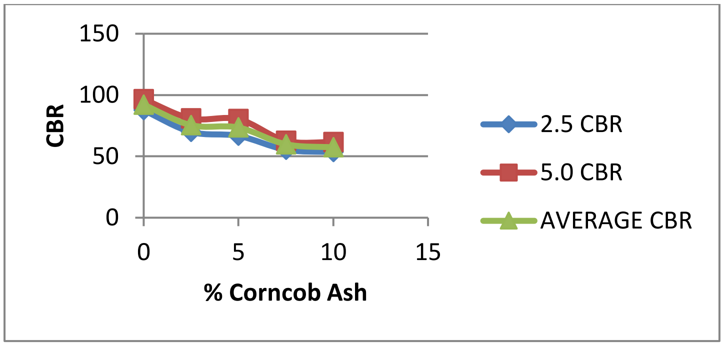

Figure.1: CBR results against Corncob ash content before soaking

The plots of 2.5 CBR, 5.0 CBR and AVERAGE CBR against corncob ash content before soaking are depicted graphically in Figure.1. The highest CBR values for all the plots occurred at 0% corncob ash content with CBR values of 87.59, 96.57 and 92.08 for 2.5 CBR, 5.0CBR and AVERAGE CBR respectively while the lowest CBR values for the plots occurred at 10% corncob ash content.

The plots of 2.5 CBR, 5.0 CBR and AVERAGE CBR against corncob ash content after soaking are depicted graphically in Figure.2. The optimum CBR values for all the plots occurred at 5.0% corncob ash content with CBR values of 22.50, 21.43 and 21.97 for 2.5 CBR, 5.0CBR and AVERAGE CBR respectively.

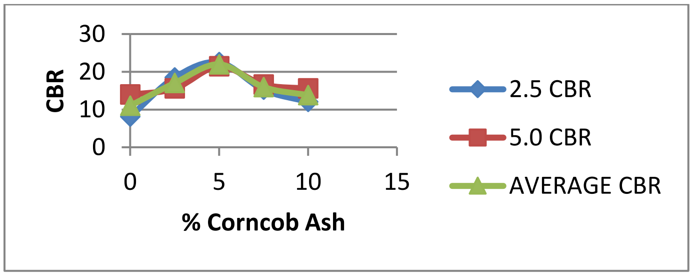

Figure.2: CBR against Corncob ash content after soaking

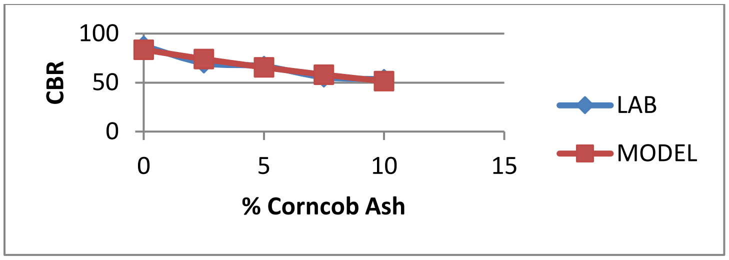

Figure.3: 2.5 CBR against corncob ash content before soaking

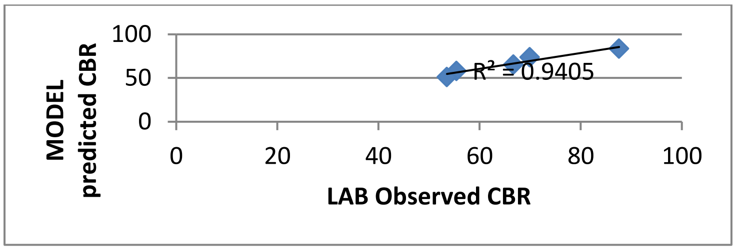

Figure.4: Coefficient of determination for model at 2.5 CBR before soaking

It can be seen that the model developed made a fairly accurate prediction of the 2.5 CBR. The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.940 as shown in Figure.4, resulting to coefficient of correlation CORR value of 0.97.Comparison of the plots of the 5.0 CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (7) are shown in Figure.5

$$C_{BR} = 94.87e^{-0.04616\beta} \quad (7)$$

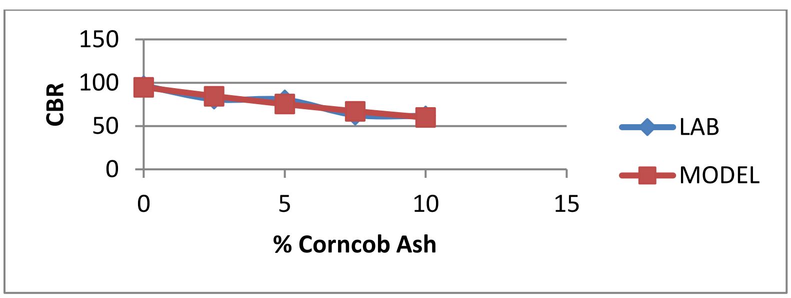

Figure.5: 5.0 CBR against corncob ash content before soaking

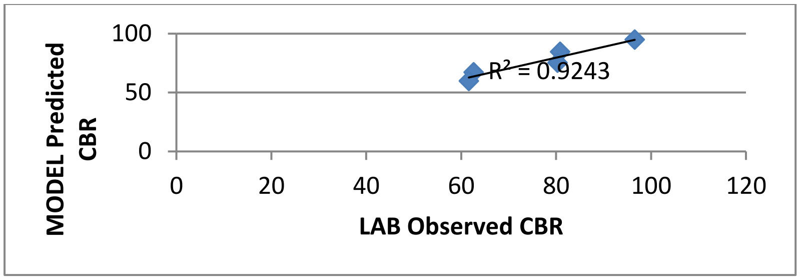

Figure.6: Coefficient of determination for model at 5.0 CBR before soaking

.It can be seen that the model developed made a fairly accurate prediction of the 5.0 CBR. The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.924 as shown in Figure.6, resulting to coefficient of correlation CORR value of 0.96. Comparison of the plots of the AVERAGE CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (8) are shown in Figure.7. It can be seen that the model developed made a fairly accurate prediction of the AVERAGE CBR. The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.945 as shown in Figure.8, resulting to coefficient of correlation CORR value of 0.97.

$$C_{BR} = 89.347e^{-0.04713\beta} \quad (8)$$

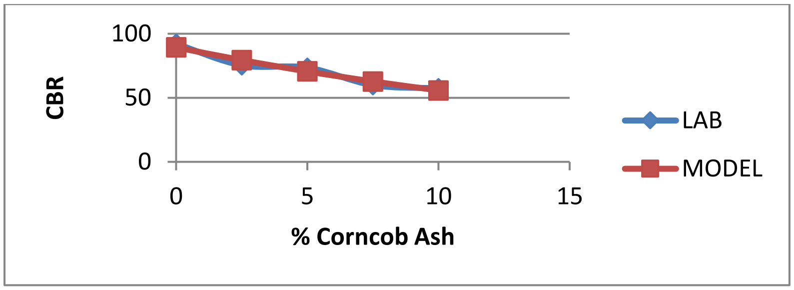

Figure.7: AVERAGE CBR against corncob ash content before soaking

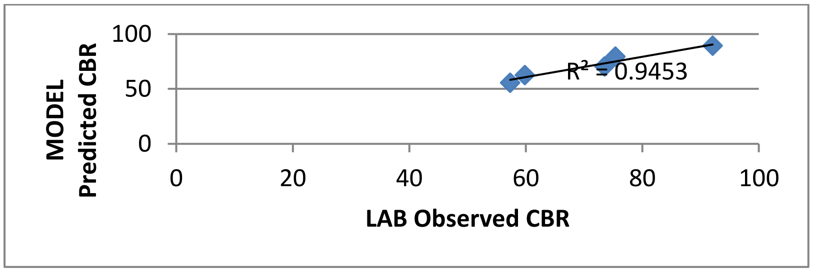

Figure.8: Coefficient of determination for model at AVERAGE CBR before soaking

Comparison of the plots of the 2.5 CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (9) are shown in Figure.9. It can be seen that the model developed made a fairly accurate prediction of the 2.5 CBR. The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.863 as shown in Figure.10, resulting to coefficient of correlation CORR value of 0.93.

$$C_{BR} = 8.848 + 4.575\beta - 0.439\beta^2 \quad (9)$$

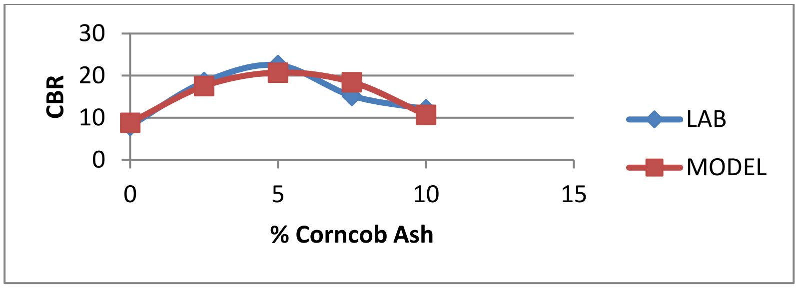

Figure.9: 2.5 CBR against corncob ash content after soaking

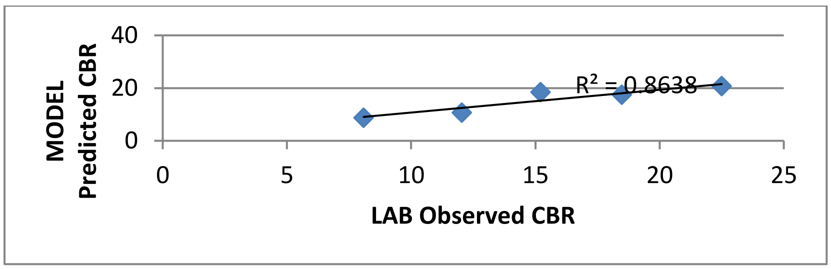

Figure.10: Coefficient of determination for model at 2.5 CBR after soaking

Comparison of the plots of the 5.0 CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (10) are shown in Figure.11. It can be seen that the model developed made a fairly accurate prediction of the 5.0 CBR. The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.620 as shown in Figure.12, resulting to coefficient of correlation CORR value of 0.79.

$$C_{BR} = 13.45 + 2.008\beta - 0.183\beta^2 \qquad (10)$$

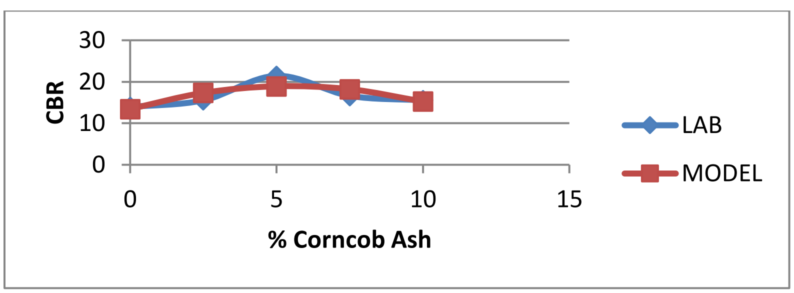

Figure.11: 5.0 CBR against corncob ash content after soaking

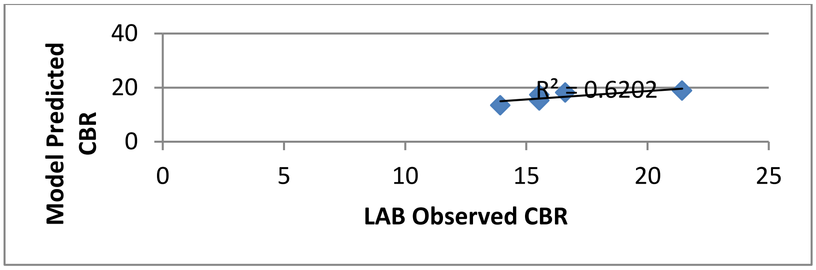

Figure.12: Coefficient of determination for model at 5.0 CBR after soaking

Comparison of the plots of the AVERAGE CBR against the corncob ash content in the laboratory and those predicted using the model in Equation (11) are shown in Figure.13. It can be seen that the model developed made a fairly accurate prediction of the AVERAGE CBR.

$$C_{BR} = 11.14 + 3.297\beta - 0.311\beta^2 \quad (11)$$

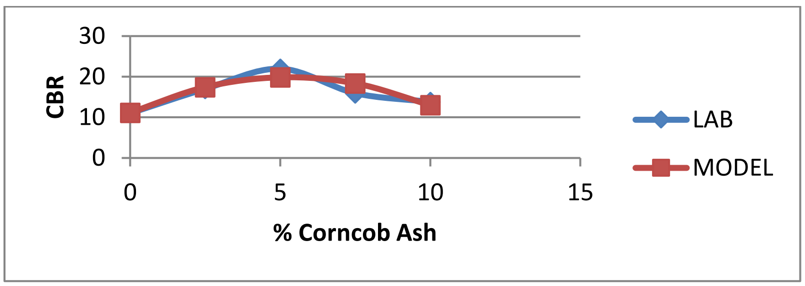

Figure.13: AVERAGE CBR against corncob ash content after soaking

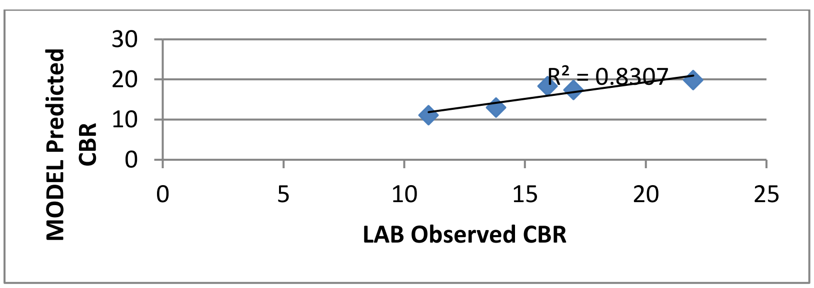

Figure.14: Coefficient of determination for model at AVERAGE CBR after soaking

The statistical assessment of the accuracy of the model gave coefficient of determination R^2 value of 0.830 as shown in Figure.14, resulting to coefficient of correlation CORR value of 0.91. For the CBR test, there was an initial increase from the control value of 11% to 17% at 2.5% CCA and from 17% to 22% at 5.0% on average. This was followed by a decline at increasing levels of CCA additions. For the Unconfined Compression Strength test, the control has CBR value of 92.08kN/m^2 and 75.40kN/m^2 and 73.53 kN/m^2 at 2.5% and 5% respectively which then followed by a decline at increasing levels of CCA. The model results properly predicted the laboratory results with the coefficient of correlation at 2.5 CBR and 5 CBR as 0.79 and 0.91 respectively.

4.0. Conclusion and Recommendation

This paper, assessment of corn-cob ash stabilised soil for infrastructure development in a sprawled city has presented and showed that the addition of CCA content to soil reduced the plasticity, swelling potential and permeability and increased strength of the soil. This natural soil, which only satisfies the requirements for use as a sub-grade material, was improved by CCA contents at 2.5% and most preferably 5% stabilization of which they can be applied for pavement layer. The pozzolanic property of CCA as in Table 2, made it to behave like cement (with the composition of oxides of calcium, silicon and aluminium) which in the presence of water, reacts chemically with calcium hydroxide to form compounds possessing cementations properties that increased the soil strength. These corncob ash are economic and environment friendly. This 5% Corncob ash content can be used to improve soils with similar geotechnical properties to the soil used in this study. In the development of these sprawled cities, considering infrastructures like roads that can technically impact on the built environment and enhance improvement to man's life, the use of biomass wastes like corn cobs and its recycling into useful construction materials can reduce the construction cost, improves waste and environment management. Hence the use of CCA as stabilising agent in road construction can improve the quality of infrastructure development resulting to a well planned sprawled city and is recommended.

Acknowledgements

The authors acknowledge the Department of Civil Engineering, Enugu State University of Science and Technology for providing facilities used in carrying out this research.

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