Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Using artificial neural networks to predict the compressive strength of cement and sawdust ash-treated lateritic soil

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HIGHLIGHTS

- Machine learning (ANN) predicted the compressive strength of lateritic soil treated with cement and sawdust ash.
- Maximum compressive strength of 1345.66 kN/m² was achieved with 8% cement and 30% sawdust ash treatment.
- The machine learning model showed high accuracy and effectively handled non-linearity in predictions.
- At 7 days, CBR and UCS rose by up to 1965.46% and 989.25% with 8% cement and 30% SDA additions respectively.

Keywords:
Cement
Compressive strength
Machine learning
Lateritic soil and Sawdust ash

ABSTRACT

Sawdust industrial residue could be hazardous to the environment, but it becomes pozzolanic when incinerated. Thus, harnessing sawdust ash (SDA) and lateritic soil as road construction materials for low-cost roads is apt. However, modeling and prediction of the properties of soils treated with SDA have received very little attention. This study predicted the compressive strength of lateritic soil treated with cement and SDA using an Artificial Neural Network (ANN). The soil was found to belong to A-2-4(0) in the AASHTO rating and clayey sand (SC) in the Unified Soil Classification System. The soil minerals composition was conducted using an x-ray diffraction technique, which comprises non-clay minerals such as quartz, albite, orthoclase, goethite, and muscovite, as well as clay minerals like clinochlore. The tests carried out on the treated soil were compaction tests, California Bearing Ratio (CBR), unconfined compressive strength (UCS), and durability tests. The maximum dry density of the reinforced soil was reduced, whereas the optimum moisture content increased with an increase in SDA content. At the addition of cement and SDA of up to 8% and 30%, respectively, the strength properties like the CBR and UCS at 7 days of curing increased by up to 1965.46% and 989.25%, respectively. Also, the reinforced soil satisfied the durability requirements. The treated soil could be used as the sub-base of road pavement structures. The ANN modeling dependably predicted the unconfined compressive strength at 7 days of curing of the reinforced soil with coefficients of correlation of 0.989 and 0.996 for training and testing, respectively.

1. Introduction

Sawdust is an industrial waste product obtained while carrying out woodwork operations like sawing, milling, sanding, planning, and routing. Sawdust or wood dust mainly comprises about 40-50% cellulose, polyposis, and other substance compositions, which differ depending on the type of tree that is being processed [1]. There has been a massive generation of sawdust waste all over the world. Nigeria generates about 1.8 million tons of sawdust and 5.2 million tons of wood waste annually [2]. Sawdust has been identified as one of the main causes of lung cancer for workers who are exposed to inhaling sawdust their occupation, such as carpenters, furniture makers, and paper mill workers [1], [3–5]. Consequently, sawdust is hazardous to health and the environment.

Sawdust has been utilized for many purposes to reduce the environmental risk factors posed by sawdust. Firstly, the particulates of sawdust are used for making particle boards [6]. Secondly, sawdust is also used as a source of fuel [7–9]. Consequent upon its potential as a source of fuel, it is used for briquetting techniques with some other biomass materials like palm kernel shells, coconut shells, rice bran, corn cobs, maize stalks, rice husks, and so on. The briquette material is achieved by mixing the sawdust with biomass in a specific percentage of contents and is bound together by materials like starch, tar, pitch, or thermoplastic resin. The mixtures of sawdust, biomass, and binding materials are subsequently molded into small cubes, which are referred to as briquettes.

Sawdust has also been utilized as construction material. In some cases, it was used as a partial replacement for fine aggregates [10–11], [2] while in other circumstances when incinerated into ash, they are used as a partial replacement for cement [12–16].

http://doi.org/10.30684/etj.2025.156269.1873
Received 03 January 2025; Received in revised form 08 March 2025; Accepted 12 March 2025; Available online 23 April 2025
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Furthermore, it has been established that sawdust ash could improve the geotechnical or strength characteristics of soils when treated with sawdust ash alone or combined with binders like cement or lime [17, 18].

Lateritic soils could be regarded as residual or sedentary soil because the parent rock that formed the soil is subjected to consistent leaching in a particular place in a process referred to as laterization. Nigeria is located in the Tropics, which has high temperatures and rainfall that support the laterization process. Also, the basement complex lies beneath Nigeria, where the soils are formed. Consequently, lateritic soils are very prevalent in Nigeria, and it is very common to encounter them or utilize them as fill material for any civil engineering construction work.

The value of natural aggregates in terms of cost has skyrocketed because of the high demand for numerous environmental interests. Therefore, utilizing the lateritic soils as a substitute for natural aggregates has received huge attention in the environs. So many industrial and agricultural waste materials had previously been used with lateritic soils for the construction of civil engineering structures like subgrade soils [19–22], pavements of road-works [23–25], earth embankments for dams [26–28] or waste containment [29–31], foundation soils [31–34] and cement blocks [35–37].

Machine learning could also be referred to as artificial intelligence. Artificial Neural Network (ANN) is a typical example of machine learning. ANN models have particularly shown effectiveness among other machine learning techniques because of their computational power. However, each method performs differently based on the problem or dataset involved [38]. ANN has shown very high accuracy in predicting the properties of construction materials [39–41]. Most of the previous studies on the treatment of soil with sawdust ash and binders did not consider modeling and prediction of the properties of the treated soil. However, [42,43] successfully used geometric and exponential logarithmic models, respectively, to predict the properties of treated soils with binder and other agricultural residues. Therefore, it is necessary to examine and compare the performance of machine learning techniques in predicting real and nonlinear systems like the treated soils with the other mathematical models. Thus, this study focused on the prediction of the unconfined compressive strength of lateritic soil treated with cement and sawdust ash using machine learning (Artificial Neural Network).

2. Materials and methods

The materials used for this study were lateritic soil, sawdust ash, ordinary Portland cement, and clean water. The lateritic soil samples were collected using the disturbed technique at Ovia Amagu Ishiagu in Ivo local government of Ebonyi State in Nigeria, located at latitude and longitude 5.940N and 7.570E, respectively, and the samples were air-dried. The lateritic soil was tested for consistency and gradation in accordance with [44–46] for adequate characterization. The X-ray diffraction technique identified the soil minerals. The sawdust was obtained from Avouzo Ogwor junction timber market, Ishiagu, Ivo Local Government Area of Ebonyi State, which was incinerated into ash in a furnace at a temperature of up to 500 °C, after which it was allowed to cool and thoroughly ground. It was then sieved through a 75 μm sieve to conform to [47] standard. The detectable oxide composition of the sawdust ash was determined using an Atomic Absorption Spectrometer.

The samples of treated soil were prepared by thoroughly mixing the dry soil with constant cement contents of 2, 4, 6, and 8% with varying percentage content of sawdust ash from 2-30%. Subsequently, the optimum moisture content determined for each mix from the compaction test was then used to wet the soil for molding, and all the percentage measurements for the mixes were determined as a percentage of dry soil. The British Standard Light (BSL) was used for the compaction test, which required that the samples would be placed in the 1000 cm^3 mold in 3 equal layers. Then, 2.5 kg rammer was used to give 27 blows evenly on each layer for compaction, after which small samples were taken from the top and bottom of each specimen for moisture content determination. The maximum dry densities were plotted against the moisture contents to find the optimum moisture content.

The strength properties of the treated soil, such as California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and durability tests, which are required to judge the performance of the strengthened soil as a pavement material, were tested. The CBR specimens were prepared using the CBR mold and 2.5 kg rammer to give 62 blows on each layer evenly, which is equivalent to the compaction energy of BSL. The specimens were cured for 6 days before being immersed in water for 24 hours and allowed to drain for 15 minutes before testing as specified by [48]. The results of the UCS specimens were multiplied by 1.04 as a correction factor to satisfy the 2:1 height-to-diameter ratio as stipulated by [49]. The durability was carried out by comparing the UCS of two sets of specimens as specified by [49]. One set was cured for 14 days, whereas the second set was cured for 7 days and soaked in water for another 7 days to determine the loss in strength between the two sets, which was to measure the durability of the specimens. This was done for each mix, and all the curing processes were achieved by membrane curing. The compressive strength of the treated soil was predicted using SPSS 2O [50].

3. Results and discussion

3.1 Characterization of the lateritic soil

The results of the preliminary tests to adequately characterize the soil are presented in Table 1. The liquid limit, plastic limit, plasticity index, and the percentage finer than sieve number 200 (0.075 mm) of the lateritic soil were found to be 12, 7, 5, and 21.20%, respectively. These consistency limits and particle size distribution (associated with the texture of the soil) were necessary for the proper classification of the soil [51], rated the soil to be in the A-2-4(0) group, which is regarded as a group suitable for road construction work. In the [51] classification Table, the soil groups are ranked from better to worse while moving on the table from left to right. The soil group A-2-4(0) is located more to the left, and the numerical value zero in parenthesis shows that the group index was very low. The foregoing reasons confirmed the lateritic soil to be considered suitable for road construction. The Unified Soil Classification System (USCS) [52], regarded the lateritic soil as clayey sand (SC) of low plasticity. The linear shrinkage of the soil was 4%, which indicates the volumetric stability of the soil. The low consistency limits that were determined concerning the lateritic soil could be attributed to the lack of presence of adequate active clay minerals (only 3% of clinochlore, as shown in Table 2). These implied that the volume change in the soil as a result of moisture content changes would be very low. This is a characteristic that favors a material to be used for road construction work because of wetting and drying as a result of rainy and dry seasons, respectively.

Table 1: Results for characterization of the natural lateritic soil

Soil Property	Description
Liquid limit	12%
Plastic limit	7%
Plasticity index	5%
Linear shrinkage	4%
% passing sieve No 200 (0.075 mm)	21.20%
AASHTO (2011) classification	A-2-4(0)
Unified Soil Classification System (USCS) ASTM (2017)	SC (Clayey Sand)
Color	Reddish-brown
Specific gravity	2.72
Optimum Moisture Content (OMC)	10.65%
Maximum Dry Density	1.72 Mg/m^3
California Bearing Ratio (CBR)	11.51%
Unconfined Compressive Strength (UCS) 7 days	101 kN/m^2

Figure 1 and Table 2 presented the X-ray diffraction peaks and the quantitative composition of the soil minerals, respectively. The soil consists of non-clay minerals, which are quartz (59%), albite (6%), orthoclase (5.9%), goethite (14.5%), muscovite (11.7%), and also clay minerals like clinochlore (3%). Quartz is mainly made up of silica (SiO_2), which is a hexagonal crystal system with no cleavage. The shape of the quartz particle looks bulky. Its specific gravity and hardness are 2.65 and 7, respectively [53]. Albite is a common orthoclase feldspar mineral, which is a Potassium Aluminium Silicate. The range of the crystal system is from monoclinic to triclinic, the cleavage is usually 2 planes, and the shape of the particle is bulky-elongate. The range of the specific gravity is 2.62 – 2.76, and the hardness is 6 [53]. Goethite (FeO-OH) is usually stable in wet conditions and gradually transforms to hematite (Fe_2O_3) in desiccation [54]. For Quartz, Young's modulus, shear modulus, and Poisson's ratio are 76 GPa, 29 GPa, and 0.31, respectively, whereas that of hematite is 67-200 GPa, 27-78 GPa, and no Poisson's ratio, respectively [55]. Muscovite is common mica (potash mica). It could also be a hydrated phyllosilicate mineral of aluminum and potassium, which has the formula $KAl_2(AlSi_3O_{10}(FOH)_2)$ or $(KF)(Al_2O_3)_3(SiO_2)_6(H_2O)$ [54]. Therefore, they are rich in silica and aluminum. They possess a highly perfect basal cleavage, which results in remarkably thin laminar sheets that are often very elastic. Clinochlore could also be referred to as chlorite. The structural unit of chlorite is usually made up of regular stacks of one positively charged octahedral sheet linked by hydrogen bonds, which are sandwiched by negatively charged layers. Chlorites are predominantly trioctahedral, in which Mg^{2+}, Al^{3+}, Fe^{3+}, and Fe^{2+} are located around the octahedral [56].

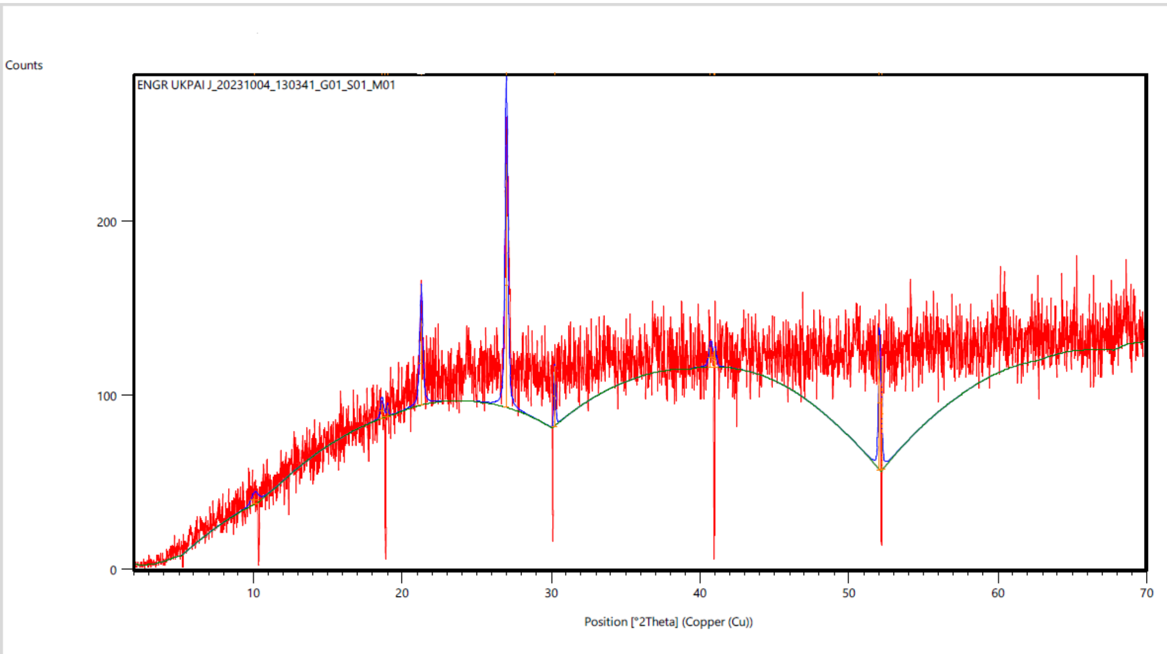

Figure 1: X-Ray diffraction peaks for the lateritic soil

Table 2: Soil mineralogical composition

Soil Mineral	Percentage Composition
Quartz	59
Albite	6
Orthoclase	5.9
Goethite	14.5
Clinochlore	3
Muscovite	11.7

3.2 Characterization of sawdust ash

Table 3 shows the chemical composition of the sawdust ash. Mineral admixtures are judged using [57] standard. The standard stipulates that for a mineral admixture to be accepted as good pozzolanic material, it must satisfy the condition of containing $SiO_2 + Al_2O_3 + Fe_2O_3$ at a minimum of 70% and SO_3 at a maximum of 4%. Considering the chemical composition of the sawdust ash, the value of $SiO_2 + Al_2O_3 + Fe_2O_3$ was found to be 74.53%, while SO_2 was 1.48%. Therefore, these satisfied the requirements for good pozzolanic material. There are some other essential compounds present in sawdust ash, such as calcium oxide (CaO) and potassium oxide (K_2O), at substantial quantities of 9.42 and 7.39%, respectively. These compounds are also found in cement, which plays a significant role in strength development.

Table 3: Chemical composition of sawdust ash

Chemical Compound	Percentage Composition
Silicon dioxide (SiO_2)	63.31
Aluminium Oxide (Al_2O_3)	7.02
Iron (III) Oxide (Fe_2O_3)	4.20
Calcium Oxide (CaO)	9.42
Magnesium Oxide (MgO)	2.86
Sodium Oxide (Na_2O)	0.62
Potassium Oxide (K_2O)	7.39
Sulfur dioxide (SO_2)	1.48
Phosphorous Pentoxide (P_2O_5)	0.62
Loss on Ignition (LOI)	2.74

3.3 Compaction characteristics of treated soil

The dry density of soil is used to measure the level of compaction achieved at any given moisture content. The dry density attains the peak when the moisture content is at optimum. The peak dry density is referred to as maximum dry density, and the water content at optimum is regarded as optimum moisture content. These two properties were considered while studying the compaction characteristics of treated or untreated soil.

3.3.1 Maximum dry density

Figure 2 presents the relationship between maximum dry densities and sawdust ash (SDA) content. From the results with sawdust ash contents of 0-30%, the maximum dry densities decreased from 1.88-1.61 Mg/m^3, 1.92-1.62 Mg/m^3, 1.96-1.64 Mg/m^3, and 1.99-1.68 Mg/m^3 at cement contents of 2, 4, 6 and 8% respectively. It would be observed that the maximum dry densities plummeted with an increase in sawdust ash content. This could be a result of the gradual replacement of the soil particles in the reinforced soil by the sawdust ash, which is lighter in density in a given volume of the mold. This caused a continuous decrease in maximum dry density. Conversely, the maximum dry densities rose continually with the increase in cement content. This could be caused by the binding effect of cement, which led to the binding of the soil particles, and consequent was the formation of clusters of the soil particles. The bonds of the soil particles became stronger as the cement content increased, and it also behaved like a coarser material rather than being dislodged by the given compaction effort. Coarser materials attain higher levels of densities during compaction than finer particles.

3.3.2 Optimum moisture content

Figure 3 presents the variations in optimum moisture content with changes in sawdust ash content. With the addition of sawdust ash from 0-30%, the optimum moisture content increased from 11.48-13.76%, 16.57-21.04%, 17.51-24.81%, and 18.01-28.82% at 2, 4, 6 and 8% cement content respectively. The rising trend of the optimum moisture content could be a result of an increase in material content as the sawdust ash content increased gradually. Consequently, the moisture content requirement for the lubrication of the entire system of treated soil matrix equally increased for adequate compaction. Similarly, it was also observed from the results that the optimum moisture content also increased with an increase in cement content. This could be associated with the stepping-up of the hydration reaction as the cement content increased. The hydration reaction of cement is an exothermic reaction that requires more water in the system of treated soil matrix as it progresses. Therefore, the optimum moisture content of the mixture increased progressively.

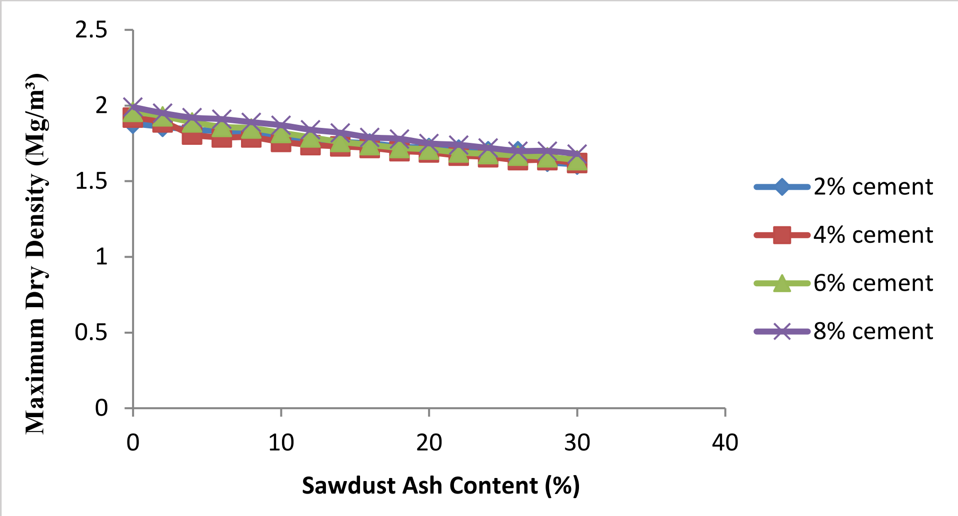

Figure 2: Variations of maximum dry density with increase in SDA content

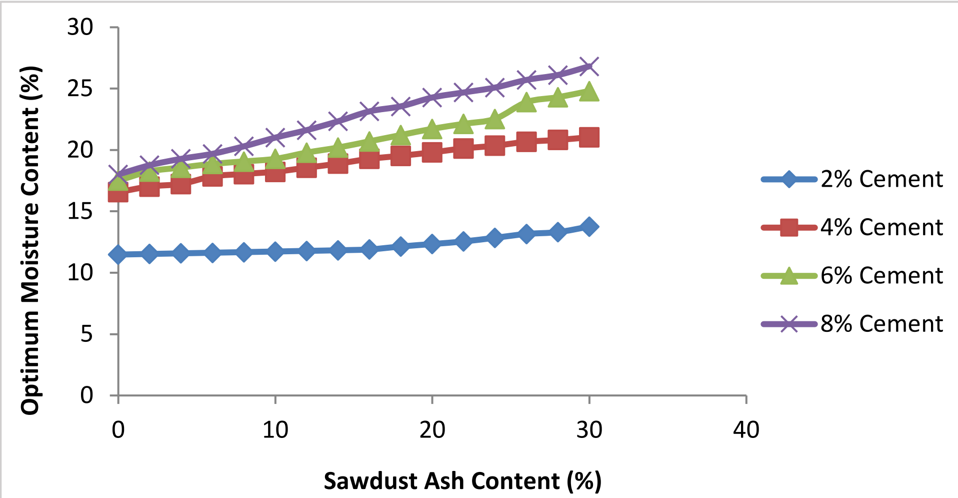

Figure 3: Variations of optimum moisture content with increase in SDA content

3.4 Strength characteristics of reinforced soil

The strength characteristics of stabilized soil are judged by California Bearing Ratio (CBR), unconfined compressive strength (UCS) at 7-day curing period, and the durability test. Figures 4 and 5 presented the variations in California Bearing Ratio and unconfined compressive strength at the 7-day curing period, respectively, with the increase in sawdust ash content. The California Bearing Ratio increased from 13.26-41.07%, 55.08-114.28%, 108.12-178.09%, and 144.84-273.88% at 2, 4, 6, and 8% cement content respectively with rise in sawdust ash content from 0-30% and in a similar manner, unconfined compressive strength at 7 days curing period rose from 123.54-225.02 kN/m^2, 227.22-398.18 kN/m^2, 389.34-611.02 kN/m^2 and 691.58-1345.66 kN/m^2 respectively in the same conditions. The improvement in strength characteristics with the increase in sawdust ash content conforms to the trend of results of [17,18]. However, they focused more on using other binders like lime rather than cement. The improvement in strength characteristics could be attributed to the presence of substantial amounts of Silica, Alumina, Iron oxide, and calcium oxide in sawdust ash, as shown in Table 3. These compounds also play a major role in reacting with calcium hydroxide, which is one of the products of the hydration of cement to produce additional cementitious compounds like hydrates of calcium-silicates and calcium alumino-ferrites, which further improves the strength properties of the reinforced soil, as shown in Equations (1) and (2):

$$Ca(OH)_2 + SiO_2 \rightarrow CaO.SiO_2.H_2O \quad (1)$$

$$Ca(OH)_2 + Al_2O_3 + Fe_2O_3 \rightarrow CaO.Al_2O_3.Fe_2O_3.H_2O \quad (2)$$

The Nigerian General Specification (1997) stipulated a CBR value of 180% for cement-stabilized materials while conventional values of 7 days UCS of 750-1500 kN/m^2, 1500-3000 kN/m^2, and 3000-6000 kN/m^2 for sub-base, base (lightly trafficked roads), and base (heavily trafficked roads), respectively. In view of the foregoing, the reinforced lateritic soil satisfied the requirement for a sub-base with a UCS value of 795.26k N/m^2 at 7 days and a CBR value of 183.60%.

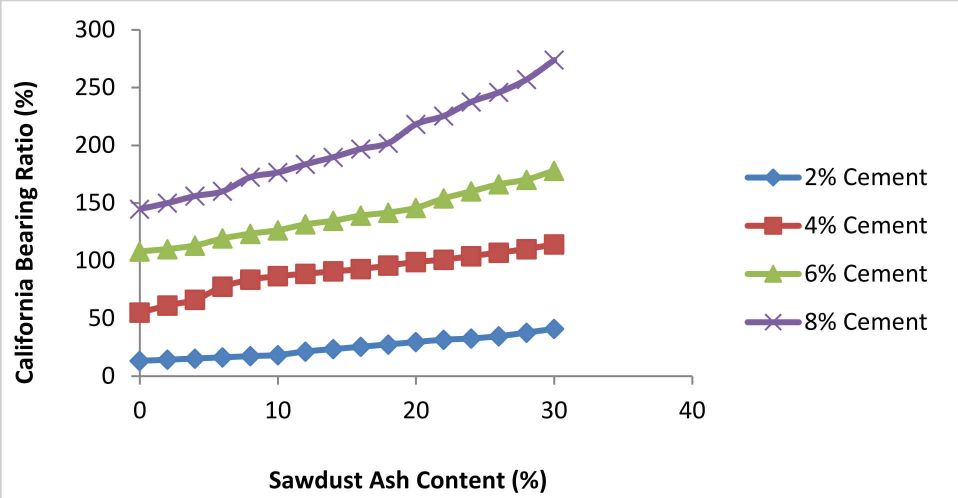

Figure 4: Variations California Bearing Ratio (%) with increase in SDA content (%)

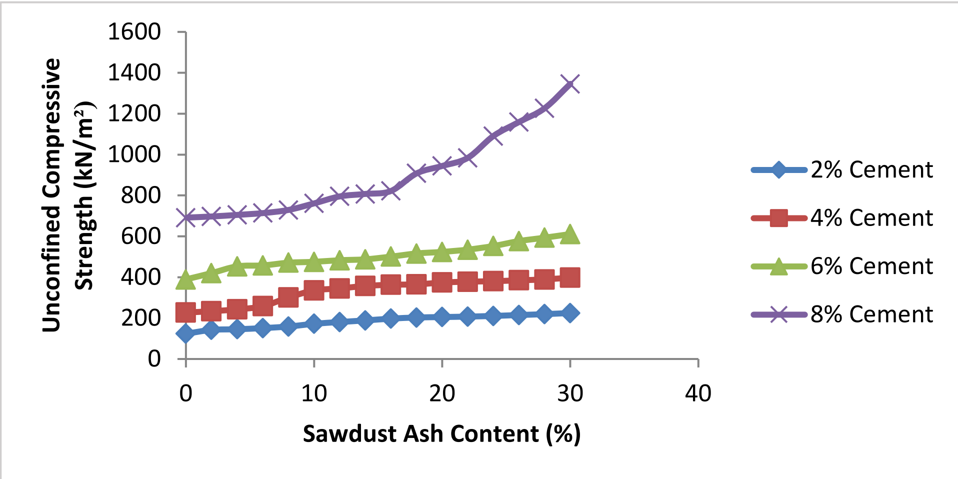

Figure 5: Variations of unconfined compressive strength with increase in SDA content

The judgment criteria for road pavement materials are not limited to California's bearing ratio and unconfined compressive strength of 7 days. The durability test requirement for the stabilized material needs to be satisfied because of periods of high rainfall. The durability results are presented in Figure 6 [49] specified a minimum loss in value of unconfined compressive strength of 20% between specimens cured for 14 days and those cured for 7 days and subsequently immersed or soaked in water for another 7 days. In Figure 6, it was shown that the reinforced soil satisfied the durability requirement because the losses in strength for the specimens were below 20%.

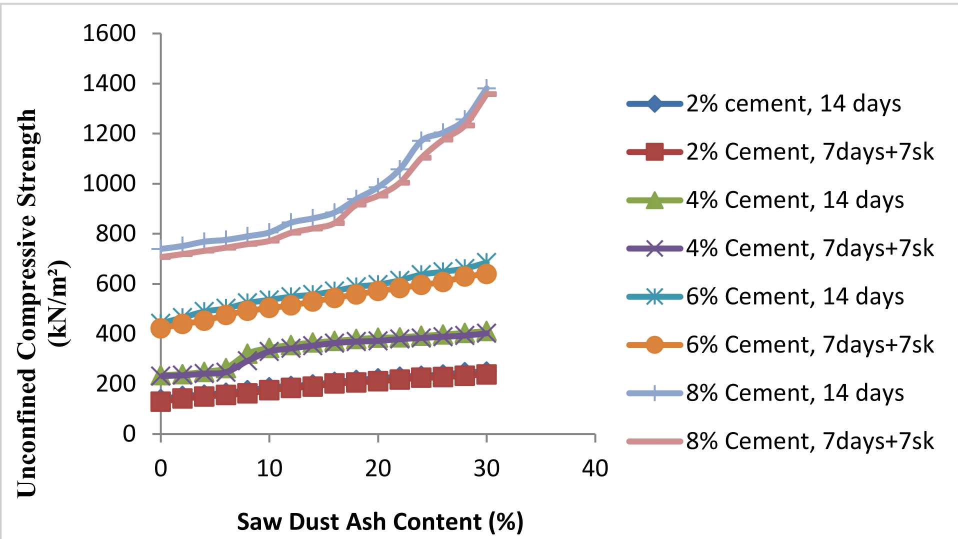

Figure 6: Durability tests for the reinforced soil

3.5 Interpretation of artificial neural network (ANN) output

Table 4 is the case processing summary of the Artificial Neural Network. The multilayer perceptron (MLP) and the feed-forward architectures were used for the network. In the process, 76.7% of the data were used for training, while 23.3% were used for testing, for a total of 60 valid data points.

Table 4: Case processing summary

	N	Percent
Sample Training	46	76.7%
Testing	14	23.3%
Valid	60	100.0%
Excluded	3	
Total	63	

Figure 7 presents the network architecture of the Artificial Neural Network (ANN). The var00002, var00003, var00004, and var00005 represent the 4 predictor variables, which are cement content, sawdust ash content, optimum moisture content, and California Bearing Ratio, respectively. These four variables are the dependent variables and are also known as covariates. The four dependent variables were placed at the output layer as the predictors. The network architecture also had 1 hidden layer of 3 units, which gave the predicted variable var00001, which was the unconfined compressive strength found in the output layer. All the mathematical processes for the prediction took place in the hidden layers.

Table 5, Figures 8, and 9 show the summary of model properties, predictability performance of the ANN model, and residuals versus the predicted values, respectively. The sum of square error for training was 0.247 and 0.034 in testing, which implies that the coefficients of determination (R2) were 0.753 and 0.966 for training and testing, respectively. The relative error for training was 0.011, while in testing, it was 0.004, which could be translated as the coefficient of correlation (R) of values 0.989 and 0.996, respectively. From the output, the Artificial Neural Network, which is a machine learning approach, showed very high accuracy in prediction more than the exponential, logarithmic models in which the latter had a coefficient of correlation (R) of 0.972 and 0.985 [43]. The two modeling tools showed a very high level of dependability. Still, it appears that the ANN model handled the non-linearity of data more efficiently than the exponential logarithmic model. Another advantage of ANN is that it is flexible and less rigorous to apply. However, there are also some limitations of ANN; it requires an idea of the pattern of data distribution before choosing network architecture for the modeling. Another disadvantage is that it cannot be used to predict data points that were not used for the training or testing. This is because the mathematical processes for the prediction were all enclosed in the hidden layer.

Figure 10 presented the sensitivity analysis for the independent variables, which showed how important each variable was in predicting the unconfined compressive strength. The level of normalized importance ranged from 11.5 to 9.6, 36.5, and 100% for cement content, sawdust ash content, optimum moisture content, and California Bearing Ratio, respectively. This implies that the California Bearing Ratio played the highest role while sawdust ash content played the least role in predicting the unconfined compressive strength in the ANN model.

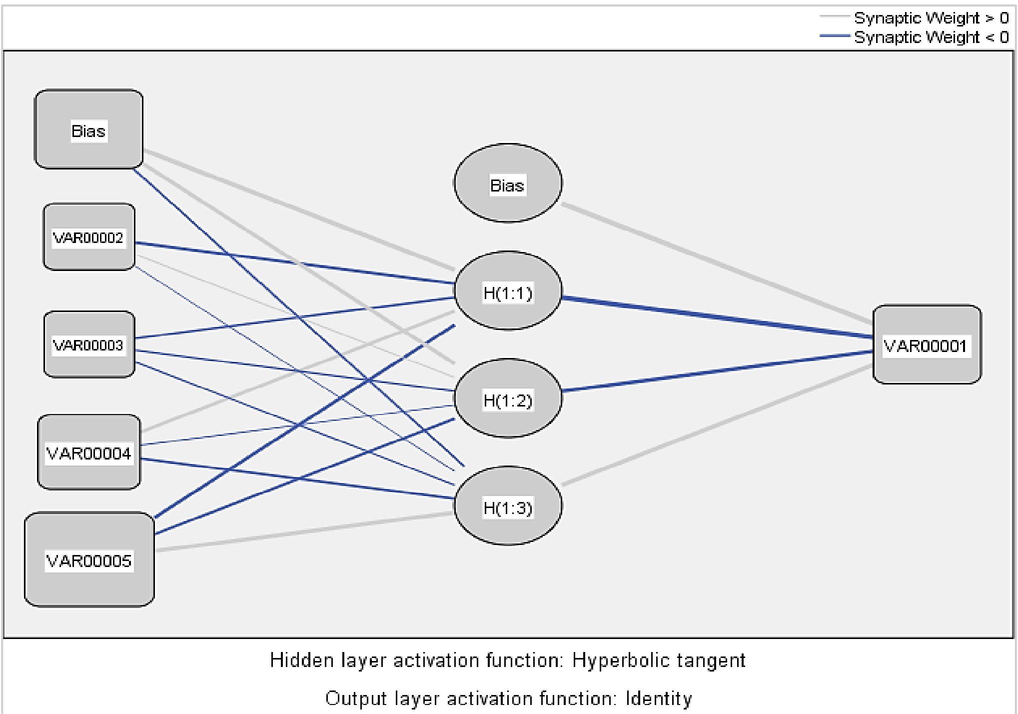

Figure 7: Network architecture of the predictor and predicted variables of the ANN

Table 5: Model summary

Training	Sum of Squares Error	0.247
	Relative Error	0.011
	Stopping Rule Used	1 consecutive step (s) with no decrease in error[a]
	Training Time	0:00:00.00
Testing	Sum of Squares Error	0.034
	Relative Error	0.004
Dependent Variable: VAR00001		
a. Error computations are based on the testing sample.		

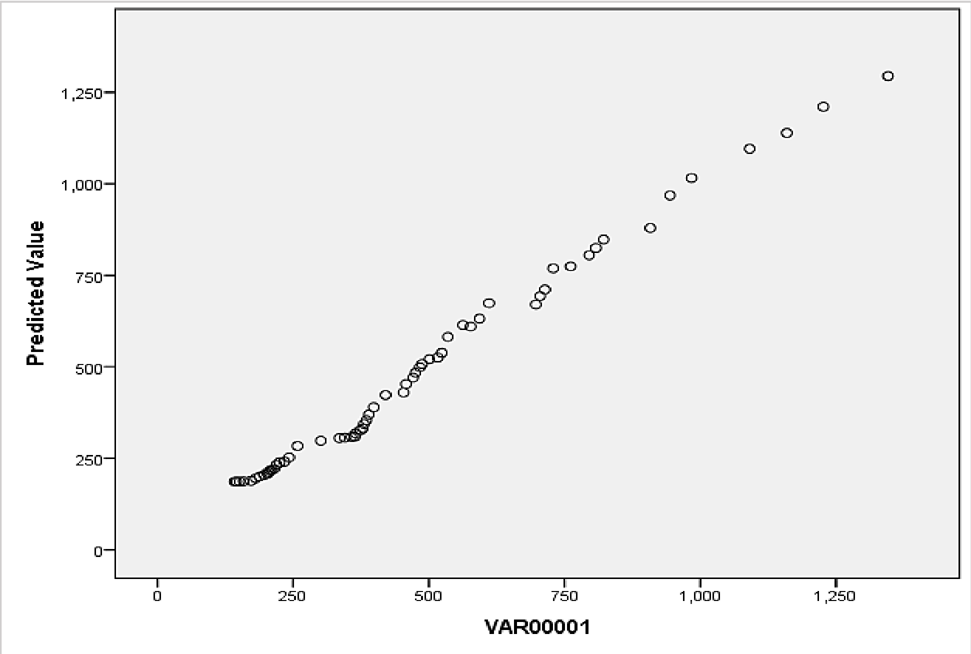

Figure 8: Performance predictability of the ANN

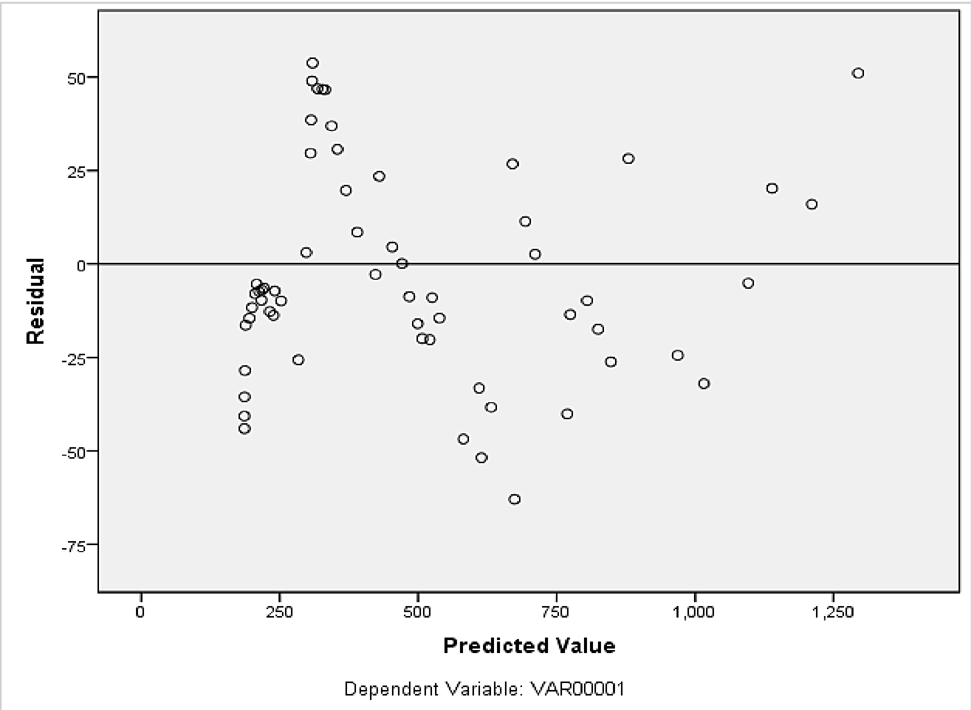

Figure 9: Residuals for the predicted values

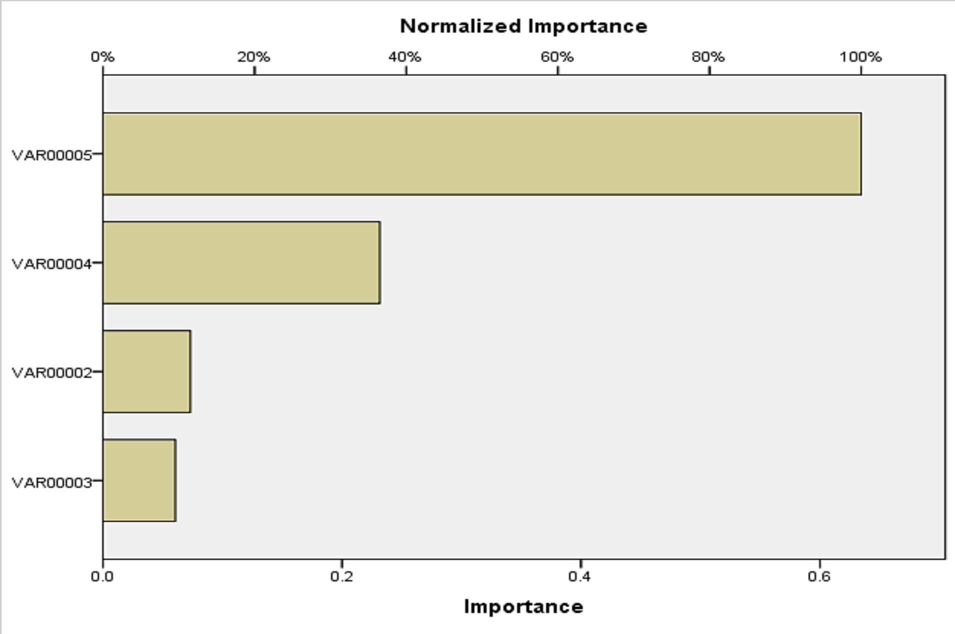

Figure 10: Sensitivity analysis for the variables

4. Conclusion

This study used a machine learning approach (Artificial Neural Network) to predict the unconfined compressive of reinforced lateritic soil at Ovia Amagu Ishiagu in Ivo local government of Ebonyi State in Nigeria reinforced with cement and sawdust ash for pavement structures. At the end of the study, the following conclusions were drawn:

1. The soil was found to belong to A-2-4(0) in the AASHTO rating and clayey sand (SC) in the Unified Soil Classification System. These groups of soil were found to be suitable for road construction work.
2. The soil mineralogy consists of non-clay minerals: quartz (59%), albite (6%), orthoclase (5.9%), goethite (14.5%), and muscovite (11.7%), and clay minerals like clinochlore (3%).
3. It was confirmed that sawdust ash contained some essential compounds, which made it a good pozzolanic material.
4. The maximum dry density of the reinforced soil reduced with the increase in sawdust ash content but increased with the increase in cement content. Also, the optimum moisture content increased with the increase in sawdust ash content and cement content.
5. When cement and sawdust ash were added up to 8% and 30%, respectively, strength properties like the California Bearing Ratio and unconfined compressive strength at 7 days of curing increased by up to 1965.46% and 989.25%, respectively. Furthermore, the reinforced soil also satisfied the durability requirements.
6. The reinforced soil only satisfied the requirements to be used as the sub-base of road pavement structures.
7. The artificial neural network modeling dependably predicted the unconfined compressive strength at 7 days of curing of the reinforced soil, with coefficients of correlation of 0.989 and 0.996 for training and testing, respectively.

Author contributions

Conceptualization, **J. Ukpai,** and **U. Okonkwo**; data curation, **J. Ukpai**; formal analysis, **J. Ukpai**; investigation, **J. Ukpai**; methodology, **J. Ukpai,** and **U. Okonkwo**; project administration, **J. Ukpai**; resources, **J. Ukpai**; software, **J. Ukpai**; supervision, **U. Okonkwo**; validation, **J. Ukpai,** and **U. Okonkwo**; visualization, **U. Okonkwo**; writing—original draft preparation **J. Ukpai**; writing—review and editing, **U. Okonkwo**. All authors have read and agreed to the published version of the manuscript.

Funding

The authors declare that no information on funding for the study could affect the manuscript submitted for consideration. Therefore, there is no competing interest.

Data availability statement

The authors declare that this manuscript is their original work, and the data for this study will be made available on request.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] E. Vallières, J. Pintos, M. E. Parent, J. Siemiatycki, Occupational exposure to wood dust and risk of lung cancer in two population-based case-control studies in Montreal, Canada. Environ. Health, 14 (2015)1-9. https://doi.org/10.1186/1476-069x-14-1

[2] B. C. Olaiya, M. M. Lawan, K. A. Olonade, Utilization of sawdust composites in construction- A review, SN Appl. Sci., 5 (2023)1-25.https://doi.org/10.1007/s42452-023-05361-4

[3] P. Bhatti, L. Newcomer, L. Onstad, K. Teschke, J. Camp, M. Morgan, T. L. Vaughan, Wood dust exposure and risk of lung cancer, Occup. Environ. Med., 68 (2011) 599-604. http://dx.doi.org/10.1136/oem.2010.060004

[4] IARC (2012): Monographs on the evaluation of carcinogenic risks to humans: A review of human carcinogens; arsenic, metals, fibres and dusts. International Agency for Research on Cancer, Lyon, Vol. 100, Part C.

[5] K. K. Kasangana, M. Chadyiwa, D. Masekameni, T. Makonese ,Exposure to wood dust and health effects: A review of epidemiological evidences from developing countries, Proceedings of National Association for Clean Air, Johannesburg, South Africa, 2017,1-7.

[6] H. Orelma, A. Tanaka, M. Vuoriluoto, A. Khakalo, A. Korpela , Manufacture of all – wood sawdust – based particle board using ionic liquid – facilitated fusion process, Wood Sci. Technol., 55 (2021) 331-349. https://doi.org/10.1007/s00226-021-01265-x

[7] B. O. Bolaji, The use of sawdust as an alternative source of energy for domestic cooking and as a means of reducing deforestation, Global, J. Environ. Sci., 4 (2005) 73-76. http://dx.doi.org/10.4314/gjes.v4i1.2444

[8] M. Brown, V. Kearley, Role of wood waste as source of biomass fuel in the U K. Energy Materials, Taylor and Francis, 4 (2009) 162-165. https://doi.org/10.1179/174892312X13269692038815

[9] O. L. Rominiyi, B. A. Adaramola, O. M. Ikumapayi, O. T. Oginni, S. A .Akinola, Potential utilization of sawdust in energy, manufacturing and agricultural industry; waste to wealth, World J. Eng. Technol., 5 (2017) 526-539, https://doi.org/10.4236/wjet.2017.53045

[10] A. Mwango, C. Kambole, Engineering characteristics and potential increased utilization of sawdust composites in construction – A review, J. Build. Constr. Plann. Res., 7 (2019) 59-68. https://doi.org/10.4236/jbcpr.2019.73005

[11] N. Dwivedi, A. P. Khare, S. Haq, Wood plastic composite: Emerging material for an environmental safety- A review, Proceeding of Advances in Clean Energy Technologies, Springer Nature, 2021, 85-99. https://doi.org/10.1007/978-981-16-0235-1_7

[12] F. F. Udoeyo, P. U. Dashibil, Sawdust ash as concrete material, J. Mater. Civ. Eng., 14 (2002) 173. https://doi.org/10.1061/(ASCE)0899-1561(2002)14:2(173)

[13] S. Chowdhury, M. Mishra, O. Suganya, The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview, Ain Shams Eng. J., 6 (2015) 429-437. https://doi.org/10.1016/j.asej.2014.11.005

[14] S. Assiamah, S. Agyeman, K. Adinkrah-Appiah, H. Danso, Utilization of sawdust ash as cement replacement for landcrete interlocking blocks production and mortarless construction, Case Stud. Constr. Mater., 16 (2022) e00945. https://doi.org/10.1016/j.cscm.2022e00945

[15] R. Wang, P. Haller , Applications of wood ash as a construction material in civil engineering: A review, Biomass Conv. Bioref., 2022. https://doi.org/10.1007/s13399-022-03580-0

[16] V. Mehta, S. Mondal, N. Kumar, .S Kumar ,Use of wood sawdust ash as effective raw material for clay bricks, IOP Conference Series: Earth and Environmental Science, 1110, 2023, 1-16. https://doi.org/10.1088/1755-1315/1110/1/012081

[17] C. C. Ikeagwuani, I. N. Obeta, J. C. Agunwamba, Stabilization of black cotton soil subgrade using sawdust ash and lime, Soils and Foundations, 59 (2019) 162-175. https://doi.org/10.1016/j.sandf.2018.10004

[18] W. A. Butt, K. Gupta, J. N. Jha, Strength behaviour of clayey soil stabilized with sawdust ash, Int. J. Geo-Eng., 7 (2016) 1-9. https://doi.org/10.1186/s40703-016-0032-9

[19] U. N. Okonkwo, Compressibility of lateritic soil strengthened with palm kernel husk ash for sub-grade soil, Electron. J. Geotech. Eng., 23 (2018) 249-260.

[20] C. Kennedy, U. N. Okonkwo, The effectiveness of residual soil, Orashi River sand and Sombrero River sand as stabilizing agents for subgrade soil of highway pavement, Sch. J. Eng. Tech., 11 (2023) 91-107. https://doi.org/10.36347/sjet.2023.v11i04.001

[21] U. N. Okonkwo, C. Kennedy Effectiveness of cement and lime as stabilizers for subgrade soils with high plasticity and swelling potential, Saudi J. Civ. Eng., 7 (2023) 40-60. https://doi.org/10.36348/sjce.2023.v07i03.001

[22] C. P. Enyinnia, U. N. Okonklwo, C. D. Nwa-David, Critical state characteristics of lateritic soils treated with rice husk ash as subgrade soil, Eng. Technol. J., 42 (2024) 1355-1366. https://doi.org/1030684/etj.2024.149978.1754

[23] R. K. Etim, I. C. Attah, P. Yohanna, Experimental study on potential of oyster shell ash in structural strength improvement of lateritic soil for road construction, Int. J. Pavement Res. Tech., 13 (2020) 341-351. https://doi.org/10.1007/s42947-020-0290-y

[24] J. E. Sani, P. Yohanna, I. A. Chukwujama, Effects of rice husk ash admixed with treated sisal fibre on properties of lateritic soil as a road construction material, J. King Saud Univ. Eng. Sci., 32 (2020) 11-18. https://doi.org/10.1016/j.jksues.2018.11.001

[25] U. N. Okonkwo, E. C. Ekeoma, L. O. Eleke , Polynomial models for predicting time limits for compaction after mixing operation of lateritic soil reinforced using cement or lime, J. Civ. Eng. Sci. Technol., 14 (2023) 26-34. https://doi.org/10.33736/jcest.4918.2023

[26] U. N. Okonkwo, Lateritic soil and calcined kaolin for earth embankments, Environ. Geotech., 4 (2017) 384-389. http://dx.doi.org/10.1680/jenge.16.00011

[27] J. R. Oluremi, S. T. Ijimdiya, A. O. Eberemu, K. J. Osinubi, Reliability evaluation of hydraulic conductivity characteristics of waste wood ash treated lateritic soil, Geotech. Geol. Eng., 37 (2019) 533-547. https://doi.org/10.1007/s10706-018-0625-5

[28] O. Onakunle, D. O. Omole, A. S. Ogbiye, Stabilization of lateritic soil from Agbara Nigeria with ceramic waste dust, Cogent Eng., 6 (2019) 1-10. https://doi.org/10.1080/23311916.2019.1710087

[29] U. N. Okonkwo, E. E. Arinze, E. I. Ugwu, Lateritic soil treated with polyvinyl and waste powder as a potential material for liners and cover in waste containment, J. Solid Waste Technol. Manag., 44 (2018) 173-179 https://doi.org/10.5276/JSWTM.2018.173

[30] K. J. Osinubi, A. O. Eberemu, T. S. Ijimdiya, P. Yohanna, Interaction of landfill leachate with compacted lateritic soil treated with Bacilllius coagulans using microbial-induced calcite precipitation approach, J. Hazard. Toxic Radioact. Waste, 24 (2020)1-9. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000465

[31] R. K. Etim, T. S. Ijimdiya, A. O. Eberemu, K. J. Osinubi, Compatibility interaction of landfill leachate with lateritic soil bio-treated with Bacillus Magaterium, criterion for barrier material in municipal solid waste containment, Clean. Mater., 5 (2022) 100110. https://doi.org/10.1016/j.clema.2022.100110

[32] K. Ishola, T. S. Ijimdiya, P. Yohanna, K. J. Osinubi, Evaluation of shear strength of compacted iron ore tailings treated lateritic soil, Platform: J. Eng., 4 (2020) 48-58. https://doi.org/10.61762/pajevol4iss3art8814

[33] I. I. Obianyo, A. P. Onwualu, A. B. O. Soboyejo, Mechanical behavior of lateritic soil stabilized with bone ash and hydrated lime for sustainable building applications, Case Stud. Constr. Mater., 12 (2020) e00331.https://doi.org/10.1016/j.cscm.2020.e00331

[34] U. N. Okonkwo, C. P. Enyinnia, U. C. Ajah, C. D. Nwa-David, U. N. Tobby, Geotechnical and mineralogical characteristics of lateritic soil and locust bean (Parkia Biglobosa) Pod ash as construction soil, J. Civ. Eng. Sci. Technol., 15 (2024) 78-79. https://doi.org/10.33736/jcest.6076.2024

[35] A. G. Mimboe, M. T. Abo, J. N. Y. Djobo, S. Tome, Lateritic soil based-compressed earth bricks stabilized with phosphate binder, J. Build. Eng., 31 (2020) 101465. https://doi.org/10.1016/j.jobe.2020.101465

[36] B. A. Akinyemi, A. Elijah, A. Oluwaseun, D. T. Akpenpuun, O. Glory, The use of red earth, lateritic soils and quarry dust as an alternative building material in sandcrete block, Sci. African, 7 (2020) e00263. https://doi.org/10.1016/j.sciaf.2020.e00263

[37] K. E. Ibedu, P. P. Duru, O. O. Akin, E. A. Egwa, Compressive strength and water absorption of cement-locust bean waste ash blend for latcrete blocks production, J. Civ. Eng. Sci. Technol., 14 (2023) 6-13. https://doi.org/10.33736/jcest.4362.2023

[38] K. C. Onyelowe, M. Iqbal, F. E. Jalal, M. E. Onyia, Application of 3 algorithm ANN programming to predict the strength performance of hydrated-lime activated rice husk ash treated soil, Multiscale Multidiscip. Model. Exp. Des., 4 (2021) 259-274. https://doi.org/10.1007/s41939-021-00093-7

[39] K. Thirumalai Raja, N. Jayanthi, J. Leta Tesfaye, N. Nagaprasad, R. Krishnaraj, V. S. Kaushik, Using an artificial neural network to validate and predict the physical properties of self-compacting concrete, Adv. Mater. Sci. Eng., 2022 (2022) 1-10. https://doi.org/10.1155/2022/1206512

[40] A. A. Ali, U. Heneash, A. Hussein, S. Khan, Application of artificial neural network technique for pavement roughness as a performance indicator, J. King Saud Univ. Eng. Sci., 36 (2024) 128-139. https://doi.org/10.1016/j.jksues.2023.01.001

[41] S. A. Ahmad, H. U. Ahmed, S. K. Rafiq, D. A. Ahmad, Machine learning approach for predicting compressive strength in foam concrete under varying mix designs and curing periods, Smart Constr. Sustain. Cities, 1 (2023) 1-17. https://doi.org/10.1007/s44268-023-00021-3

[42] U. N. Okonkwo, E. E. Arinze, S. U. Ubochi, Predictive model for elapsed time between mixing operation and compaction of lateritic soil treated with lime and quarry dust for sub-base of low-cost roads, Int. J. Pavement Res. Technol., 15 (2022) 243-255. https://doi.org/10.1007/s42947-021-00022-4

[43] U. N. Okonkwo, E. C. Ekeoma, H. E. Ndem, Exponential logarithmic for strength properties of lateritic soil treated with cement and rice husk ash as pavements of low-cost roads, Int. J. Pavement Res. Technol., 16 (2023) 333-342. https://doi.org/10.1007/s42947-021-00134-x

[44] ASTM D4318-17 (2018), Standard test methods for liquid limit, plastic limit and plasticity index. American Society for Testing and Materials International, West Conshocken, P A, USA.

[45] ASTM D6913-04 (2017) Standard test methods for particle-size distribution (gradation) of soils using sieve analysis. American Society for Testing and Materials, International, West Conshocken P A, USA.

[46] BS 1377-1 (2016) Methods of test for soils for civil engineering purposes: General requirements and sample preparation, British Standard Institute, London, United Kingdom

[47] BS 12 (1991), Specification for portland cement. British Standard Institute, London, United Kingdom

[48] Nigerian General Specification (1997): *"*Bridges and Roadworks*"* Vol.11, Federal Ministry of Works, Abuja.

[49] BS 1924 (1990), Methods of test for stabilized soils. British Standard Institute, London, United Kingdom.

[50] IBM Corporation (2020). SPSS Statistics. International Business Machines Corporation, New York, USA.

[51] Standard specifications for transportation, materials, and methods of sampling and testing, The New AASHTO Green Book, American Association of State Highway and Transportation Officials, (2011) Washington DC, USA.

[52] ASTM D2487-17 (2020) Standard practice for classification of soils for engineering purposes (Unified Soil Classification System), American Society for Testing and Materials International, West Conshocken, P A, USA.

[53] Hurlbut, C. S. Dana's manual of mineralogy; 16th Edition, Wiley New York,1957.

[54] Mitchel J. K. and Soga K. Fundamentals of Soil Behaviour; 3rd Edition, Wiley, Hoboken, N J, USA, 2005.

[55] Santamarina J. C., Klein K. A. and Fam M. A. Soils and Waves: Particulate materials behaviour; Wiley, New York, 2001.

[56] M. F. Brigatti, E. Galan, B. K. G. Theng, Structure and Mineralogy of Clay Minerals, Developments in Clay Science, 5 (2013) 21-81. https://doi.org/10.1016/B978-0-08-098258-8.00002-X

[57] ASTM C618 (2001), Standard specification for coal fly ash and raw or calcined natural pozzolana for use as mineral admixture, American Society for Testing and Materials, International, West Conshocken, PA, USA.