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RESPONSE SURFACE MODELLING OF PERFORMANCE OF CONCRETE WITH BAUXITE LATERITE SOIL AND FLY ASH

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ABSTRACT: The study examined the use of waste materials such as fly ash and bauxite laterite soil in concrete to address waste disposal issues and reduce the cost of concrete products. Bauxite laterite soil is a byproduct of aluminum extraction, while fly ash is a byproduct of coal-fired power plants. To produce bauxite laterite concrete, 20% fly ash was utilized as a partial cement substitute, and 10%, 20%, 30%, and 40% bauxite laterite soil was utilized as a fine aggregate substitute. The mechanical properties of bauxite laterite concrete were studied and compared to those of conventional concrete. The test results indicate that a 10 % substitution of bauxite laterite soil is the optimal amount. After 28 days of curing, the mixture achieved a 58% improvement in compressive strength compared to conventional concrete. In addition, bauxite laterite concrete exhibited high early compressive strength and a unit weight decrease of between 6% and 8%. However, as more bauxite laterite soil was incorporated into the mix, the concrete's workability decreased. Moreover, a Response Surface Model was developed to predict the compressive strength of the bauxite laterite concrete. It can be inferred that both bauxite laterite soil and fly ash are viable alternatives to fine aggregates and cement.

Keywords: Bauxite laterite soil, Fly-ash, Compressive strength, Response surface modeling, Philippines

1. INTRODUCTION

Meyer [1] estimates the annual production of concrete to be 10 billion tons worldwide. The substantial demand for concrete demands massive quantities of raw materials and energy.

Numerous researchers are currently studying the use of alternative materials [2-6] and techniques [7-10] to improve construction materials.

Consider the possibility of cement substitution. Cement is generally composed of limestone, clay, and shale. Silica, alumina, and lime are used as raw materials [11]. They are calcined to make clinker in cement kilns. After that, the clinker is pulverized to an extremely fine powder. Cementitious or pozzolanic materials can be used in place of cement [12]. Fly ash is an example of this, it is abundant in the Philippines [13].

Fine aggregates are another component of concrete that is utilized in considerable quantities. Typically, fine aggregates are acquired through river dredging and, in some instances, rock crushing. Fine aggregates can be replaced with other materials that have comparable particle sizes and surface roughness [14]. Due to its resemblance to sand, bauxite laterite soil could be employed as one of the materials.

To extract bauxite, vast tracts of land must be cleared to reach the material beneath the surface. Following bauxite mining, surrounding ground surfaces are contaminated with mineral waste and made worthless.

In the study, both of the aforementioned materials served as substitutes for components utilized in the production of concrete. Fly ash was used due to its inherent pozzolanic and cementitious characteristics.

This research is working towards a sustainable goal of finding new uses for materials that are currently considered waste. To achieve this, this research is focused on recycling as a means of providing an alternative source of raw materials, specifically cement and fine aggregates. Although the replacement cost of these materials may seem cheap in comparison, when applied to large projects, the cost savings can be significant. Additionally, recycling these materials can also help mitigate concerns surrounding waste disposal, as the amount of waste is reduced. In addition, it may eventually lead to a reduction in the pollution generated by the mining and power generation industries.

Modeling is one technique to establish a connection between the qualities of these wastes and their subsequent impacts [15-17]. In this study, response surface modeling will forecast or predict the causative relationship between the use of fly ash and bauxite laterite waste, notably its compressive strength and curing days.

This study aims to develop a response surface model that predicts the compressive strength of bauxite laterite concrete given its percentage of fly ash, bauxite laterite, and curing days. To create a model [18-20], an equation for the compressive strength of concrete can be established and utilized to estimate the concrete's strength at a certain percent substitution and number of curing days.

2. RESEARCH SIGNIFICANCE

While the Philippine mining industry is still in its development, it is essential to explore and develop ways for waste product utilization. There is minimal research on laterite concrete at present. The purpose of this work is to develop a sustainable material from fly ash and bauxite laterite soil, Utilizing the complementing properties of the two waste products. The building industry's innovation is significantly influenced by waste materials, since the utilization of waste materials in concrete decreases the demand for cement and fine aggregates. At an alarming rate, the world's resources are depleting, posing a serious problem, including the construction sector. As a result, it is becoming increasingly clear that sustainable construction methods are the way forward.

3. METHODOLOGY

3.1 Design of Experiment

The experimental research approach established the causes and effects of partially substituting fly ash for cement and fine aggregates for bauxite laterite soil in the production of concrete on its mechanical properties. The experimental design considers a design mix containing a constant 20% cement replacement for fly ash and varied amounts of fine aggregate in place of bauxite laterite soil.

The compressive strength is the dependent variable in this study, while the amount of bauxite laterite soil used as a partial fine aggregate substitution and the curing days as independent variables. The study's control specimen is with a mix of Portland cement type 1b and fly ash class F (20%) to be used in place of cement.

The percentages of bauxite laterite soil substituted were 10%, 20%, 30%, and 40%, represented as LS0, LS10, LS20, LS30, and LS40. Laterite Soil (LS) and the number following it denotes the percentage replacement of fine particles.

Compressive strength of 25 MPa was used to calculate the design mix, shown in Table 1.

Table 1 Design Mix

Mix (m^3)	LS0	LS10	LS20	LS30	LS40
Water	0.205	0.205	0.205	0.205	0.205
Cement	0.092	0.092	0.092	0.092	0.092
Fly Ash	0.023	0.023	0.023	0.023	0.023
LS	0.000	0.030	0.061	0.091	0.122
Gravel	0.358	0.358	0.358	0.358	0.358
Sand	0.303	0.270	0.240	0.210	0.180

A constant water-cement ratio of 0.57 with a slump of 25mm-50mm was considered. Due to the specific gravity of fly ash class F being identical to that of cement, a partial substitution of cement was made in terms of weight. Due to the varying specific gravity of bauxite laterite soil and river sand, the fine aggregate replacement was done by volume at 10%, 20%, 30%, and 40%. Compressive strength specimens were made in cylindrical molds with a diameter and height of 150mm by 300mm, respectively.

3.2 Index Tests and Scanning Electron Microscope-Energy Dispersive X-ray (SEM-EDX)

The bauxite laterite soil was mined at Samar's aluminum mines. These mining locations are currently undergoing soil explorations, which has identified various layers of laterite soil.

The soil used in the study was extracted two meters below the earth to guarantee that it was free of contaminants. Visual examination revealed that the bauxite laterite soil is red in color and has a particle size distribution that is predominantly fine, shown in Fig. 1.

Fig. 1 Extracted Bauxite Laterite Soil

The soil underwent Atterberg Limit Test to define the boundaries between different states of Bauxite Laterite, Specific Gravity Test as a criterion to distinguish Bauxite Laterite soil type, and Particle Size Distribution Curve to classify Bauxite Laterite based on the proportions of different-sized particles. All procedures were done in accordance with the ASTM Standards.

3.3 Scanning Electron Microscope and Energy Dispersive X-ray (SEM-EDX)

A Scanning Electron Microscope (SEM) was also performed to determine the shape of the particles and their interlocking in soil and to examine the presence voids or micro cracking in the soil and concrete respectively. A magnification of x1000 and x7500 will be used for SEM.

Lastly, an Energy Dispersive X-ray for the

Bauxite Laterite Soil was performed to identify the chemical composition to expound on possible chemical reactions between the various components of the soil.

3.4 Concrete Works and Tests

Concrete was cast and cured according to ASTM C192 specifications, the sample matrix is shown in Table 2.

The concrete mixtures were subjected to the slump test before moulding. The slump test enables us to analyze and quantify the workability of fresh concrete, allowing researchers to determine whether or not the concrete mixture has sufficient water. To establish the slump height, the distance between the top of the mold and the top of the concrete was measured.

Table 2 Number of Specimen

Mix	Days of Curing			
	7	14	21	28
Control	5	5	5	5
LS0	5	5	5	5
LS10	5	5	5	5
LS20	5	5	5	5
LS30	5	5	5	5
LS40	5	5	5	5

On the concrete sample, the Compressive Strength of Concrete Test was performed (based on ASTM C39). The purpose of the test was to evaluate the sample's resistance to compressive forces up to the point of failure.

The two bases of the concrete cylinder were covered and positioned vertically within the Universal Testing Machine. Subsequently, the specimen was subjected to an axial compressive load until failure.

3.5 Response Surface Modelling

Lastly, a response surface model was used to create a forecasting model to determine which variables have an impact on the compressive strength of the concrete mixed with Laterite Soil, while providing a graph and an equation, the parameters are shown in Table 3.

Table 3 Parameters used in the Response Surface Modelling

Dependent Variable	Independent Variable
Compressive Strength of Bauxite Laterite Concrete (FC)	Curing Days (days) Amount of Bauxite Laterite Soil (%)

A response surface plot is a useful tool for identifying the parameters that will yield the desired response. An equality line was also used to validate the predicted versus the actual data.

4. RESULTS AND DISCUSSIONS

4.1 Index Tests

To determine the particle size distribution of the oven-dried specimen, sieve analysis was used. The bulk of particles, 96.85%, that passed through the #4 sieve and were retained on the #200 sieve were classed as sand and were used as a substitute for fine aggregate. Fines were identified as a very minor percentage of the 0.97% that passed through the #200 sieve.

The soil is well-graded, as indicated by a uniformity coefficient, Cu, of 9.09. Additionally, the coefficient of curvature, Cc, the value of 0.9, which is close to one, indicates that the delivered soil is well-graded sand. This is great for substituting fine aggregates since it aids in the interlocking of particles, which is necessary for concrete strength.

Bauxite laterite soil has a specific gravity of 2.05, which is lower than the specific gravity of fine particles. The liquid limit is determined to be 50.61% water, whereas the plastic limit is determined to be 35.92% water. The plasticity index for this soil sample is 14.69%, indicating that it is of medium plasticity. The plasticity of the soil can be attributed to the clay particles present in the soil sample. The Atterberg limits was determined to establish the properties of bauxite laterite soil prior to its application as fine aggregate replacement. It has no quantifiable effect on the properties of concrete although it might affect the workability of fresh concrete due to the cohesiveness of bauxite laterite concrete.

4.2 Scanning Electron Microscope and Energy Dispersive X-ray (SEM-EDX)

The physical formation of bauxite laterite soil and bauxite laterite concrete was analyzed with a scanning electron microscope (SEM). It can be seen in the Fig. 2 and Fig. 3 that the soil particle in the specimen that was going to be further examined and magnified does not have any intragranular voids. In addition to this, the soil particle has a densely packed structure with prominently sharp edges.

However, for the SEM analysis of the bauxite laterite concrete revealed a large particle composed of sand, gravel, fly ash, cement, and bauxite laterite soil, as depicted in Fig. 4. The presence of micro cracking in Fig. 4 and voids in Fig. 5 throughout the specimen, which may explain the specimen's relatively low strength compared to that of conventional concrete, is an important feature to note. Fig. 5 depicts a fly ash particle in the foreground that is surrounded by very fine particles that are assumed to be cement hydration products.

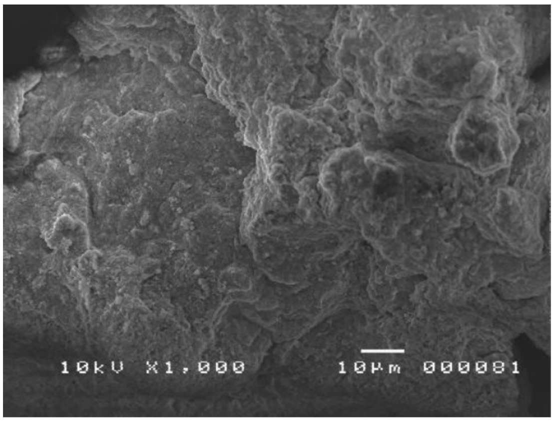

Fig. 2 Soil Micrograph at x1000 Magnification of Bauxite Laterite soil

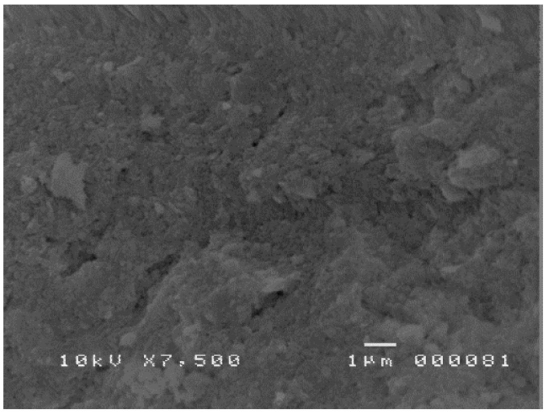

Fig. 3 Soil Micrograph at x7500 Magnification of Bauxite Laterite soil

Observing Fig. 5, it was determined that the bonding between particles was insufficient, as concrete materials such as fly ash did not properly combine with cement, as evidenced by the presence of voids surrounding the fly ash particle. In Fig. 5 revealed that the fly ash particle in the modified bauxite laterite concrete did not mix and bond effectively with the other concrete materials, whereas the fly ash particle in the fly ash concrete did mix and bond effectively with the other concrete materials. This analysis revealed that poor mixing and bonding between concrete particles may have contributed to the decrease in the bauxite laterite concrete samples' strength properties.

Energy Dispersive X-Ray Analysis was utilized to examine the Bauxite Laterite soil and this analysis was conducted to determine the elemental composition of the soil, which was then used to describe the soil's properties. Table 4 displays the mineral composition of the Bauxite Laterite soil, where it was determined that the Bauxite Laterite soil sample contained four major mineral compounds: Aluminum (Al), Silica (Si), Iron (Fe), and Dysprosium (Dy), with Aluminum (Al) and Iron (Fe) accounting for the majority of the composition based on their atomic percentages.

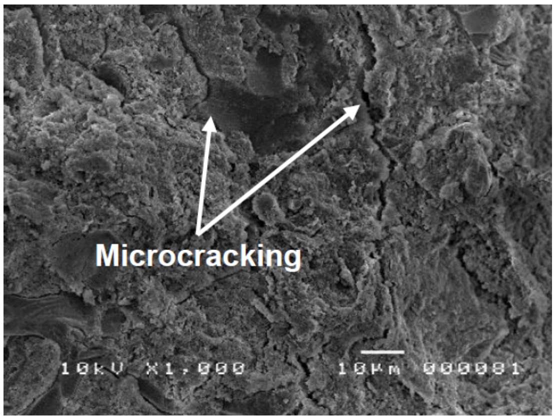

Fig. 4 Concrete Micrograph at x1000 Magnification of Bauxite Laterite Concrete depicting micro cracks

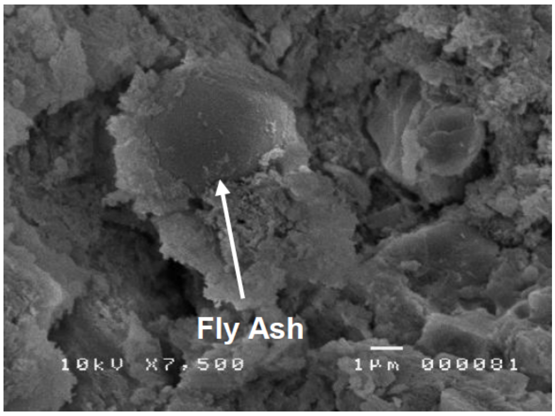

Fig. 5 Concrete Micrograph at x7500 Magnification of Bauxite Laterite Concrete depicting micro cracks

Due to the fuzziness of weight percentages, the atomic percentage was utilized in the analysis. Aluminum had the highest atomic percentage of the four mineral compounds, with a value of 64.21 %, indicating that this element made up the majority of the soil. It should be noted that aluminum reacts chemically with the alkalis present in concrete to generate hydrogen bubbles and ultimately cause cracking. The soil sample was also found to be rich in Iron, which was the second-most abundant element at 15.03%. Iron is already present in cement and contributes to its increased strength and hardness.

It was discovered that the laterite soil contained trace amounts of dysprosium (Dy), which was dispersed throughout the particles of soil. It was discovered that dysprosium did not have any discernible impact on the characteristics of the laterite soil and the bauxite laterite concrete.

Table 4 Elemental Composition of Bauxite Laterite Soil

Element	Atomic %
Al	64.21
Si	9.91
Fe	15.03
Dy	10.85

The findings of the EDX analysis performed on the soil sample demonstrated the presence of the fundamental elements of aluminum (Al) and iron (Fe), which justified its name of Bauxite Laterite soil. It has been established that laterite soil almost always contains aluminum and iron, albeit in varying percentages depending on the type of parent rock. Silica (Si) was another element that was prevalent in the laterite soils, and it was discovered in the Bauxite Laterite soil that was used for the research, as well. It is well known that silica is an important element that can be found in cement, and this significance is related to the properties of silica that can induce bonding and strength in concrete.

The composition of the Bauxite Laterite soil and the effects of Iron, Aluminum, and Silica allowed for the interpretation of the effect of the Bauxite Laterite soil on the properties of Concrete. Iron has properties that increase the strength of concrete, whereas aluminum decreases its strength. The presence of silica in cement is essential for the development of concrete's strength. Aluminum dominates the elemental composition of Bauxite Laterite soil, which explains the relatively weaker strength properties of Bauxite Laterite concrete in comparison to conventional concrete.

4.3 Concrete Tests

Compressive tests were performed on concrete samples to investigate the effect of bauxite laterite soil as a partial substitution for fine aggregates and fly ash as a 20% substitute for cement. Compressive strength development was determined on concrete samples after 7, 14, 21, and 28 days of curing, sample testing is shown in Fig. 6.

The strength of concrete depends on many variables such as its design mix, mixing proper and overall handling. Losses should be anticipated and accounted for since mechanical and human errors are expected to occur along the way. During the mixing proper, it is expected that there are components losses such as those inside the concrete mixer. It may affect the overall strength of the concrete specimen due to the disproportion of the sand, gravel, cement and water. Loss of capillary water in hardening concrete results in dry shrinkage occurs in which there is the contraction of concrete that ultimately increases the tensile stress within the specimen. The internal tensile stress may cause cracking, warping and deflection even before loading. The standard dimensions for the concrete specimens have small discrepancies of a few millimeters which can be attributed to human error and shrinkage. Outliers are identified and removed if the data have deviations that go too far from the behavioral trend.

The workability of bauxite laterite concrete decreases in direct proportion to the percentage substitution, as measured by the slump value, shown in Table 5. The concrete mix LS0 has the maximum slump due to the addition of fly ash as a plasticizer. On LS40, the lowest slump value was obtained. Due to the decreased workability of the concrete sample, shown in Fig. 7, the researchers mixed fresh concrete manually. During the mixing process, it became apparent that the workability decreased due to the cohesiveness of the fresh concrete.

Table 5 Slump Test Results

Specimen	Slump (mm)
Control	29
LS0	37
LS10	23
LS20	20
LS30	15
LS40	12

Clay is a form of soil that has a greater capacity for water retention than sandy soils [21]; this attribute of clay relates to the ability of laterite soil, which is rich in clay minerals, to retain more water than the ordinary sand used as fine aggregates in concrete. It was learned during the mixing process that water is progressively absorbed by the bauxite laterite soil, drying portions of the concrete mix.

The control specimen failed in failure categories I and II, and this is due to the concrete's brittleness. The failure modes observed for LS0 and bauxite laterite concrete are Type II and IV.

The average compressive strength of concrete specimens was determined at various curing times. The control specimen has an average strength of 24.24 MPa, which meets the structural concrete minimum standards. The increased use of fine particles weakens the concrete specimen. LS0 has the maximum compressive strength when compared to bauxite laterite concrete, which has a compressive strength of 16.52 MPa. LS0 had a compressive strength of just 68% of that of the control specimen. The compressive strength of the LS10 specimen was marginally lower at 13.42 MPa.

While the compressive strengths of LS20, LS30, and LS40 are decreasing at 12.65 MPa, 9.08 MPa, and 7.70 MPa, respectively, as shown in Fig. 8. Additionally, it is worth noting that the early strength of LS10 and LS20 is greater than that of LS0, which increased strength through subsequent curing periods.

Fig. 6 Sample Concrete mixed with Bauxite Laterite Soil Substitution

The control and LS0 specimens gained increasing amounts of strength over time, particularly during the later curing periods. As a result, both control and LS0 specimens demonstrated improved long-term strength. LS10 and LS20 build strength rapidly, attaining 69.37 % and 65.77% strength after 7 days, respectively. Although bauxite laterite concrete demonstrates a linear strength rise, this contributes to the material's low 28-day compressive strength. On bauxite laterite concrete specimens, it is noted that the strength develops slowly.

Long-term strength can be linked to the hydration process, in which water causes concrete to harden by forming cementitious components. The chemical reaction between cement components and water produces hydration products, which are found in concrete [22]. Laterite soils are mainly composed of clay, which has a better water-holding capacity than sandy soils. Due to the low workability of laterite concrete, it is prone to include a large number of voids. While the curing process may have aided in the hydration of the specimen, due to water's incompressibility, it is unable to support loads, which may have resulted in the bauxite laterite concrete's decreased compressive strength.

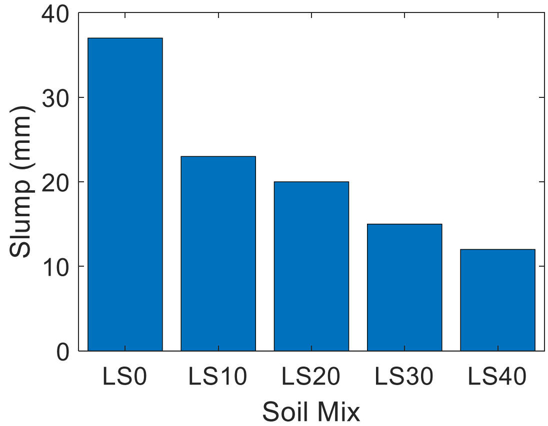

Fig. 7 Workability of the Soil Mix

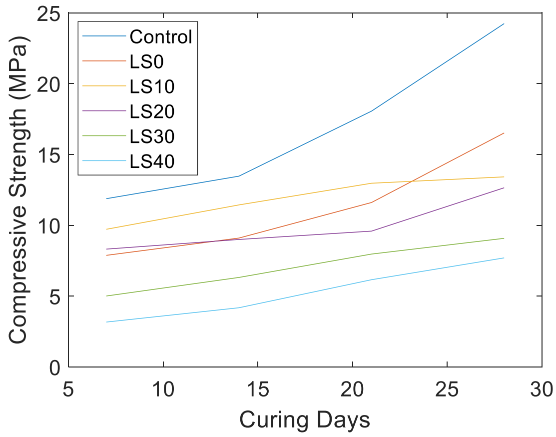

Fig. 8 Compressive Strength vs. Curing Days

The researchers noted that several concrete examples had uneven top and bottom surfaces. It was determined to be caused by air voids, settling, and moisture loss in the concrete. When the specimen was placed on the Universal Testing Machine (UTM), the specimen's uneven surface was seen. The initial focus of the applied force was on the partial cross-sectional region it impacted. Without having to optimize the strength, the top piece eventually failed. Side fractures occurred on either the top or bottom faces of these specimens.

4.4 Response Surface Modelling and Validation

A response surface model for the compressive strength of bauxite laterite concrete was used for estimating the strength at a given percent substitution of the laterite soil and days of curing. A Response surface model graph was used to illustrate the strength development curve for each percent substitution, shown in Fig. 9, and in equation form, shown in Eq. 1.

The response surface model has an R^2 value of 0.7542 which shows an agreement between the model and the observed parameters. An equality line was also used to validate the predicted versus the actual data, shown in Fig. 10.

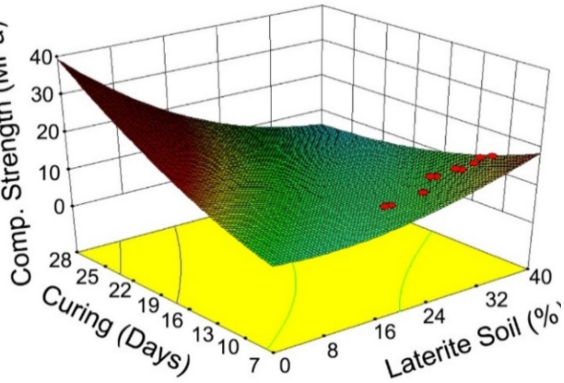

Fig. 9 Response Surface Model Graph

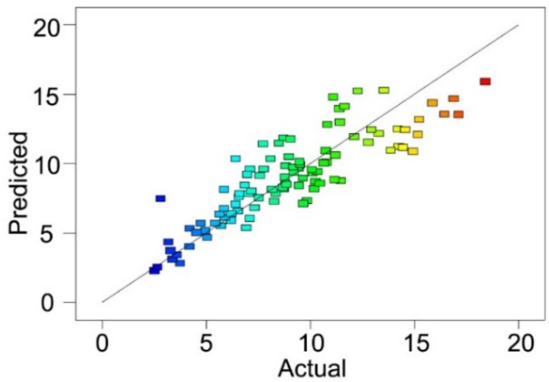

Fig. 10 Equality Line for Validation

$$\boldsymbol{FC = 9.65 - 5.24L + 1.92D - 0.55LD - 1.77L^2 + 0.48D^2 + 1.23L^2D - 0.33LD^2 + 2.55L^3 - 0.11D^3} \quad (1)$$

Where,
FC = Compressive strength (MPa),
L = Amount of Laterite soil (%),
D = Number of curing days (days).

5. CONCLUSIONS

The parameters of the bauxite laterite soil, sand, gravel, fly ash, and cement were determined prior to the production of bauxite laterite concrete. After analyzing the index properties of bauxite laterite soil, it was determined that its sand-sized particles made it a good substitute for fine aggregate. The bauxite laterite soil is found to have uniform particle size distribution with a specific gravity of 2.05.

The chemical properties of the components upon interaction with each other created a reaction that was completely be different from its properties when utilized individually. Aluminum is the biggest contributor due to its reaction to cement that created hydrogen bubbles that ultimately cause micro-cracking within the specimen as affirmed by the micrographs of bauxite laterite soil. Soil micrographs of bauxite laterite soil indicate the presence of angular particles.

Increased partial substitution of bauxite laterite soil resulted in a decrease in the concrete's strength and workability.

LS10 is the preferred substitution due to its superior combination of compressive strength when compared to the other percentage substitution specimens. After seven days of curing, it regained 69.37% of its compressive strength. At 13.42 MPa, the compressive strength of LS10 was 57.80% that of the control sample. Due to the lower specific gravity of bauxite laterite soil compared to river sand, the unit weight of bauxite laterite concrete was up to 8% lighter than traditional concrete.

The study was able to create a response surface model for the compressive strength of bauxite laterite concrete for estimating the strength at a given percent substitution of the laterite soil and days of curing. The response surface model has an R^2 value of 0.7542 which shows an agreement between the model and the observed parameters.

6. REFERENCES

[1] Meyer C., The greening of the concrete industry. Cement and Concrete Composites, Vol. 31, Issue 8, 2009, pp. 601-605.

[2] Kowsura S., Chaiprakaikeow S., Jotisankasa A., Malaikrisanachalee S., Nontananandh S., Nusit K., Sawangsuriya A., Inazumi S., Properties and performances of soil cement modified with concentrated para-rubber, International Journal of GEOMATE, Vol. 24, Issue 102, 2023, pp. 42-49.

[3] Uy E. E. S., & Adajar M. A. Q., Assessment of critical-state shear strength properties of copper tailings, International Journal of GEOMATE, Vol. 12, Issue 32, 2017, pp. 12-18.

[4] Tajaddini A., Saberian M., Kamalzadeh Sirchi V., Li J., Maqsood T., Improvement of mechanical strength of low-plasticity clay soil using geopolymer-based materials synthesized from glass powder and copper slag, Case Studies in Construction Materials, Vol. 18, 2023, pp. 1-15.

[5] Uy E. E. S., Adajar M. A. Q., & Galupino J. G., Utilization of philippine gold mine tailings as a material for geopolymerization, International Journal of GEOMATE, Vol. 21, Issue 83, pp. 28-35.

[6] Tan J. F., & Adajar M. A. Q., Recycled gypsum and rice husk ash as additives in the stabilization of expansive soil, International Journal of GEOMATE, Vol. 17, 2020, pp 197-202.

[7] Olabode O.P., San L.H., Analysis of soil electrical resistivity and hydraulic conductivity relationship for characterisation of lithology inducing slope instability in residual soil, International Journal of Geo-Engineering, Vol. 14, Issue 1, 2023, pp. 1-16.

[8] Qader Z.B., Karabash Z., Cabalar A.F., Analyzing Geotechnical Characteristics of Soils in Erbil via GIS and ANNs, Sustainability (Switzerland), Vol. 15, Issue 5, 2023, pp. 1-40.

[9] Mohamed M.H., Ahmed M., Mallick J., AlQadhi S., Finite Element Modeling of the Soil-Nailing Process in Nailed-Soil Slopes, Applied Sciences (Switzerland), Vol. 13, Issue 4, 2023, pp 1-27.

[10] Pasternak G., Zaczek-Peplinska J., Pasternak K., Jóźwiak J., Pasik M., Koda E., Vaverková M.D., Surface Monitoring of an MSW Landfill Based on Linear and Angular Measurements, TLS, and LIDAR UAV, Sensors, Vol. 23, Issue 4, 2023, pp 1-16.

[11] Pöllmann H., Composition of cement, Structure and Performance of Cements, Vol. 1981, 2001, pp. 25–56.

[12] Zhang D., Zhao J., Wang D., Wang Y., & Ma X., Influence of pozzolanic materials on the properties of natural hydraulic lime-based mortars, Construction and Building Materials, 2020, pp. 244.

[13] Galupino J., Adajar M. A., Uy E. E., Koa N. C., Lao A. L., Lao R. N., & Tan J. C. M., Performance of concrete mixed with fly ash and plastic when exposed to fire. International Journal of GEOMATE, Vol. 19, Issue 74, 2020, pp. 44-51.

[14] Cadersa A. S., & Auckburally I., Use of Unprocessed Coal Bottom Ash as Partial Fine Aggregate Replacement in Concrete, University of Mauritius Research Journal, Vol. 20, 2016, pp. 62–84.

[15] Hameed M. M., Alomar M. K., Baniya W. J., & AlSaadi M. A., Prediction of high-strength concrete: high-order response surface methodology modeling approach. Engineering with Computers, Vol. 38, 2022, pp. 1655–1668.

[16] Amiri H., Azadi S., Karimaei M., Sadeghi H., & Farshad D., Multi-objective optimization of coal waste recycling in concrete using response surface methodology. Journal of Building Engineering, 2022, pp. 45.

[17] Nwose S. A., Edoziuno F. O., & Osuji S. O., Statistical analysis and Response Surface Modelling of the compressive strength inhibition of crude oil in concrete test cubes, Algerian Journal of Engineering and Technology, Vol. 4, 2021, pp. 99–107.

[18] Wu Y., & Crawford J. E., Numerical Modeling of Concrete Using a Partially Associative Plasticity Model, Journal of Engineering Mechanics, Vol. 141, Issue 12, 2015, pp.1-24.

[19] Aziminezhad M., Mahdikhani M., & Memarpour M. M., RSM-based modeling and optimization of self-consolidating mortar to predict acceptable ranges of rheological properties, Construction and Building Materials, Vol. 189, 2018, pp. 1200–1213.

[20] Ai D., Lin C., Luo H., & Zhu H., Temperature effect on electromechanical admittance–based concrete structural health monitoring, Structural Health Monitoring, Vol. 19, Issue 3, 2020, pp. 661–692.

[21] Tzu-Hsing Ko, Nature and Properties of Lateritic Soils Derived from Different Parent Materials in Taiwan, The Scientific World Journal, vol. 2014, 2014, pp. 1-4.

[22] Kakali G., Tsivilis S., Aggeli E., & Bati M., Hydration products of C3A, C3S and Portland cement in the presence of CaCO3. Cement and Concrete Research, Vol. 30, Issue 7, 2000, pp. 1073–1077.