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ARTICLE

# Comparative Analysis of Curing Methods: Natural and Activated Lateritic Concrete

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ABSTRACT

This work was on *non-activated* and *activated lateritic soil* used in proportions of 0% to 30%, to replace fine sand by wt. %, in the production of lateritic concrete. A mix of 1:2:4 was used, and the cube samples were cured in four (4) curing media of water, sand, polythene, and sawdust. The aim was to evaluate the effects of these curing methods on the mechanical strengths, and other properties of lateritic concrete. The sensitivity of the generated data was characterized statistically and developing linear regression models for predictions. For the Non-Activated Laterite soil (NALS, control mix (0%)), the design strength of 20 MPa was achieved by all the curing methods (standard and non-standard). However, for other replacement levels, water curing was adequate for 10% and 30%, sand at 10%, and sawdust for 20% and 30%, respectively. On the other hand, for the Activated Laterite soil (ALS), the 20 MPa design strength was met only at 0% replacement for all curing methods. Sawdust medium at 10% also satisfied the 20 MPa strength.

## 1. Introduction

Everything in life needs water for survival and is equally true for concrete and all construction works. Global water demand has been projected to increase by 55% in 2050. This is mainly from demands that related to growing urbanization in developing countries. It has also been postulated that the effect of this may cause cities to dig deeper to access water or depend on innovative solutions, or advanced technologies to meet their water demand [1].

The failures of concrete in many of our collapsed structures in Nigeria are due to improper curing. Curing of concrete works assists the hydration process of the cement, and the subsequent gain of adequate strength because of the formation of calcium silicate hydrates (CSH) that imparts strength to concrete. Curing therefore, maintains satisfactory moisture content, and temperature in concrete, for a period which immediately follows placing and finishing, so that

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the desired properties may develop. This process has a strong influence on the properties of hardened concrete. Therefore, proper curing will increase properties such as durability, strength, water tightness, abrasion resistance, and volume stability. However, this problem of proper curing is aggravated by non availability of potable water or, when available, not suitable for curing as stipulated in the code of practice. Research values on water consumption from a study taken from 2012, and projected to 2050, showed that concrete production alone was responsible for 9% of global industrial water withdrawals in 2012. This was estimated to be 1.7% of the total consumption in 2050, which is approximately 75% of the water demand for concrete production and will likely occur in regions that are expected to experience water stress [2].

ASTM C31 [3] requires that standard cured cylinders for concrete acceptance should undergo initial curing between 60 $^{o}$F (16 $^{o}$C) and 80 $^{o}$F (27 $^{o}$C) for up to 48 hours after which they should be transferred to a moist room or water tank. It also defines two different curing conditions to be used for specific purposes. These are the standard curing and field curing.

The effects of non-standard curing on strength of concrete were undertaken by NRMCA [4], as a research project to study how the concrete strength was affected in different medium of curing. Two experiments to study this effect were mounted where test cylinders were exposed to exterior conditions in summer and winter months and compared these results to standard cured specimens. In both cases, concrete cylinders were prepared from a mixture with cement content of 475 lbs./yd$^3$ (282 kg/m$^3$), and fly ash content of 50 lbs./yd$^3$ (30 kg/m$^3$), at a water-cementitious materials (w/cm) ratio of 0.52, and cured for the periods of 3, 7, 28, and 90 days. Four methods of curing were adopted: standard curing, lab-air-dry, outside for 48 hours, moist cured, and outside until time of test. The results of the test are shown in Table 1. Details of the conclusions are contained the work [4].

Nahata et al. [5] worked on the effect of curing methods on cement mortar that were cured for 28 days. He used the findings from the literature review and experimental works carried out as per ASTM standards to evaluate compressive strength of mortar cubes. They used different curing compounds, and a mix ratio of 1:2.75, and water/binder ratio of 0.45 to 0.60, and concluded that using membrane curing compounds achieved an efficiency of 80% – 90% as compared to conventional curing.

Rahman et al. [6] researched on the effect of curing methods on compressive strength of concrete using a concrete mix of 1:2:4, with four different curing methods, dry-air, complete immersion in water, wrapped with gunny bags, and sprinkling with water. They cured the specimens for 7, 14, 21 and 28 days, and concluded that the specimens wrapped with gunny bags gave the highest strength after 28 days of curing.

**Table 1.** Compressive Strength

| Weather Exposure | Age (Days) | Control Strength (Psi/MPa)) | Percent of Control Strength at Same Age (%) | | |
|---|---|---|---|---|---|
| | | | Lab-air-dry | Out 48h, moist) | Outside |
| Cold weather Series D 335 | 1 | 1508 (10.1) | | | |
| | 3 | 2828 (18.9) | | 46 | 14 |
| | 7 | 3852 (25.8) | 95 | 68 | 40 |
| | 28 | 745 (5.0) | 88 | 78 | 66 |
| | 90 | 5374 (36) | 74 | 90 | 82 |
| Hot Weather Series D 338 | 1 | 784 (5.3) | | 180 | 180 |
| | 3 | 2370 (15.9) | | 89 | 86 |
| | 7 | 3176 (19.1) | | 81 | 90 |
| | 28 | 4384 (9.3) | | 78 | 84 |
| | 90 | 5659 (37.9) | | 84 | 80 |

Paulik used five (5) curing methods for works on a bridge construction to arrive at the best strength for the work. The curing methods he adopted and the achieved strengths are shown in Tables 2 and 3. He observed that the differences in compressive strengths at early ages were almost 300% after 48 hours when the specimens cured at 2 °C in air were compared with specimens cured at 20 °C in water. However, these differences gradually diminished after 28 days [7].

**Table 2.** Curing regimes of the specimens [7]

| Group | Curing Conditions | Number of Specimens |
|---|---|---|
| Series A | Cured in water at 20 $^{o}$C (± 1 $^{o}$C) | 9 |
| Series B | Sealed and cured at 20 $^{o}$C (± 1 $^{o}$C) | 9 |
| Series C | Cured on air at 20 $^{o}$C (± 1 $^{o}$C) | 9 |
| Series D | Cured on air at 2 $^{o}$C (± 2 $^{o}$C) covered | 9 |
| Series E | Cured on air at 2 $^{o}$C (± 2 $^{o}$C) uncovered | 9 |

Gayarre et al. [8] studied the effect of different curing conditions on the compressive strength of recycled aggregates with water-cement ratio of 0.65, and replacement levels of 0%, 20%, 50%, and 100%, to replace the coarse aggregate. The specimens were cured (standard curing and open-air curing), for 28 days. They concluded that 28 days compressive strengths of both recycled and natural aggregates were almost the same when standard curing environment was considered but differs by 20% when cured in open-air conditions.

The influence of non-standard curing practice on the strengths of specimens and in-situ concrete was evaluated by Arafah et al. [9], using experimental testing methods. They collected samples from construction sites distributed over two areas of distinct climate conditions described as hot and dry (arid), and hot and moist (coastal climates), and tested using cores taken from slab, beam, and column elements. Curing was by water sprinkling twice a day for 7 days with or without burlap cover. They concluded that curing by water sprinkling twice a day and with or without burlap cover was far below the ACI-318 requirements.

**Table 3.** Compressive strength and density of the specimens after 2, 7, and 28 days [7]

| Group | 2 days | | 7 days | | 28 days | |
|---|---|---|---|---|---|---|
| | Density ($g/dm^3$) | Strength ($N/mm^2$) | Density ($g/dm^3$) | Strength ($N/mm^2$) | Density ($g/dm^3$) | Strength ($N/mm^2$) |
| Series A | 2344 | 41.8 | 2358 | 63.4 | 2339 | 81.5 |
| Series B | 2337 | 41.0 | 2355 | 58.3 | 2332 | 71.8 |
| Series C | 2328 | 39.2 | 2316 | 61.4 | 2317 | 68.4 |
| Series D | 2300 | 16.1 | 2344 | 45.2 | 2348 | 66.1 |
| Series E | 2308 | 13.4 | 2318 | 40.5 | 2362 | 67.3 |

Udoeyo et al. [10] used thirty mixes of differing water-binder ratio containing 0%, 10%, 20%, 30%, 40%, and 50% laterite as partial replacements for sand to prepare laterized concrete specimens used to study the effect of non-standard curing methods on the strength of specimen. The results showed that with continuous wetting of the non-standard curing media by sprinkling with water, the strength of concrete obtained was comparable to those cured using the control method. They also opined that the strength of the sand- and sawdust-cured specimen was in some instances the same as or higher than those of the standard cured specimens at an early age (7 days).

The thrust of the present investigation is anchored on the fact that in some parts of Nigeria, water for proper curing for construction works at times becomes difficult for many reasons. Some of these reasons are desertification and arid nature of the environment in the northern part of the country, and some parts in the eastern parts of the country where the water is salty [11]. Therefore, it becomes imperative to explore other methods of curing that would otherwise achieve the desired strength and other impacting properties of the concrete materials. This will add to the existing knowledge on curing methods and their effects on strength development in the area of research, which is lateritic concrete. In furtherance of research works in this area, the importance of documented data on different methods of curing become very important. In this study, four curing methods water, sand, polythene and sawdust, are used to assess the compressive strengths of lateritic soil concrete using experimental methods. The laterite soil was used in proportions of 0%, 10%, 20% and 30% by wt. % of cement to replace part of the sand and cured for 28 days.

## 2. Material

The materials used for this investigation are Ashaka Portland cement, fine and coarse aggregates, lateritic soil, and potable water for mixing. Table 4 shows the physical properties of both the cement, lateritic soil, and the aggregates, while Table 5 is the chemical properties of the cement and lateritic soils (Normal and Activated). The activated lateritic soil was activated to an elevated temperature between 400 °C and 600 °C in a kiln and cooled for 2 hours. The sieve analyses of the lateritic soil, and aggregates are shown in Table 6. The soil material retained by sieve size 150 µm, was used for the investigation.

**Table 4.** Physical Properties of the Aggregates and Lateritic Soil

| Type | Lateritic Soil | Aggregate | |
|---|---|---|---|
| | | Fine | Coarse |
| Specific gravity | 2.52 | 2.61 | 2.7 |
| Impact value (%) | - | - | 7.1 |
| Crushing value (%) | - | - | 22.6 |
| Bulk density ($kg/m^3$) | 1507 | 1501.5 | 1612.5 |

**Table 5.** Chemical Characteristics of Natural and Activated Lateritic Soil

| Compound | Ashaka Cement | Lateritic Type | |
|---|---|---|---|
| | | Natural [5] | Activated |
| | Weight (%) | Weight (%) | Weight (%) |
| $Fe_2O_3$ | 2.90 | 2.38 | 6.80 |
| $TiO_2$ | - | 0.82 | 0.82 |
| $K_2O$ | 0.21 | 0.13 | 0.03 |
| $SiO_2$ | 19.90 | 77.80 | 46.80 |
| MgO | 1.50 | 0.13 | 0.13 |
| $Al_2O_3$ | 5.60 | 18.40 | 28.90 |
| $P_2O_5$ | - | 0.10 | 0.30 |
| $CrO_3$ | - | 0.09 | 0.09 |
| $SO_3$ | 2.30 | 0.09 | 0.09 |
| CaO | 63.70 | 0.04 | 2.40 |
| $ZrO_2$ | - | 0.03 | 1.40 |
| MnO | - | 0.01 | 0.97 |
| ZnO | - | 0.01 | 0.41 |
| $Na_2O$ | 0.21 | - | - |

**Table 6.** Sieve Analysis of Natural and Activated Lateritic Soil

| Sieve size | Fine Aggregate (%) | | Lateritic Soil (%) [5] | |
|---|---|---|---|---|
| | Retained | Passing | Retained | Passing |
| 5.00 | 0.00 | 100 | - | - |
| 2.63 | 10.73 | 89.27 | - | - |
| 2.00 | 3.37 | 85.54 | - | - |
| 1.18 | 17.23 | 68.31 | 1.90 | 98.10 |
| 600 µm | 33.00 | 35.31 | 27.20 | 70.90 |
| 425 µm | - | - | 18.00 | 52.90 |
| 300 µm | 21.03 | 14.28 | 25.30 | 27.60 |
| 212 µm | - | - | 11.70 | 15.90 |
| 150 µm | 12.13 | 2.15 | 12.40 | 3.50 |
| 75 µm | - | - | 3.50 | 0.00 |
| 63 µm | 1.48 | 0.67 | - | - |
| Pan | 0.67 | 0 | | 0.00 |

## 3. Experimental Procedure

The mix proportion used for this work is approximately a mix of 1:2:4, with a cement content of 318 kg/m$^3$, fine and coarse aggregate contents of 673 kg/m$^3$ and 1234 kg/m$^3$ respectively, and water content of 175 kg/m$^3$. The mix was designed for a concrete strength of 20 MPa at 28 days of curing. The work used two types of lateritic soils. One was in its natural state, and the second was activated to a temperature of 400 °C to 600 °C. Four mixes each were used for both the natural and activated soils at replacement levels of 0%, 10%, 20% and 30%, of the sand by wt. %. The mix with 0% replacement is labeled M-00, as the control mix. The rest of the mixes had attached to them suffices reflecting their different levels of replacement. Curing of the specimens was achieved using different media: water, sand, sawdust and polythene. The curing methods adopted for the sand, sawdust, and polythene were the same as used by Udoeyo et al. [10]. Details of these methods are found in their works. The specimens were cured for 3, 7, 14 and 28 days, before testing to failure.

**Slump and compressive strength of lateritic concrete**

The work was mostly on the compressive strength, and a total of one hundred and sixty (160) cube specimens of dimensions 150 mm were cast and cured as stated earlier. Eighty (80) each were cast for the natural and activated soils. At the end of each curing regimes, three of the cube specimens were tested to failure using an ELE compression machine, and the average recorded. The slump and cube compressive strength are shown in Tables 7 and 8 respectively.

**Table 7.** Slump of Normal and Activated Lateritic Soil Concrete

| Soil Type | M-00 | M-10 | M-20 | M-30 |
|---|---|---|---|---|
| Slump–Normal (mm) | 20 | 30 | 30 | 30 |
| Slump-Activated (mm) | 35 | 30 | 18 | 13 |

**Table 8.** Cube Compressive Strength of Normal and Activated Lateritic Soil Concrete

| Material Type | Mix No | Curing Medium | Compressive Strength (MPa) | | | |
|---|---|---|---|---|---|---|
| | | | 3 d | 7 d | 14 d | 28 d |
| **Lateritic soil** | M-00 | Water | 14.8 | 18.1 | 20.1 | 22.9 |
| | M-10 | | 11.3 | 10.2 | 13.8 | 19.9 |
| | M-20 | | 8.0 | 15.2 | 16.4 | 18.9 |
| | M-30 | | 13.5 | 13.9 | 15.9 | 20.8 |
| | M-00 | Sand | 13.0 | 13.8 | 19.0 | 22.2 |
| | M-10 | | 10.1 | 14.1 | 16.5 | 21.0 |
| | M-20 | | 10.3 | 17.7 | 15.1 | 18.1 |
| | M-30 | | 17.0 | 17.3 | 17.6 | 18.1 |
| | M-00 | Polythene | 6.9 | 14.6 | 13.1 | 20.2 |
| | M-10 | | 14.0 | 13.1 | 15.2 | 17.5 |
| | M-20 | | 10.9 | 14.9 | 13.9 | 16.2 |
| | M-30 | | 12.4 | 16.5 | 16.9 | 17.9 |
| | M-00 | Sawdust | 18.1 | 17.6 | 18.0 | 22.6 |
| | M-10 | | 12.0 | 13.8 | 15.9 | 17.7 |
| | M-20 | | 13.7 | 15.4 | 17.0 | 20.1 |
| | M-30 | | 12.4 | 12.6 | 20.3 | 22.2 |
| **Activated lateritic soil** | M-00 | Water | 18.1 | 14.8 | 19.9 | 24.3 |
| | M-10 | | 11.8 | 14.8 | 19.9 | 17.8 |
| | M-20 | | 12.1 | 11.6 | 11.2 | 12.2 |
| | M-30 | | 8.5 | 12.1 | 12.6 | 13.1 |
| | M-40 | | 9.7 | 13.1 | 12.8 | 15.8 |
| | M-00 | Sand | 13.4 | 13.3 | 18.9 | 23.1 |
| | M-10 | | 10.6 | 15.3 | 15.0 | 17.8 |
| | M-20 | | 7.4 | 7.9 | 13.0 | 13.1 |
| | M-30 | | 8.7 | 8.7 | 11.9 | 13.3 |
| | M-40 | | 9.3 | 8.9 | 12.9 | 10.9 |
| | M-00 | Polythene | 11.6 | 17.6 | 17.9 | 25.5 |
| | M-10 | | 11.3 | 14.5 | 15.4 | 14.5 |
| | M-20 | | 8.0 | 9.0 | 11.6 | 12.9 |
| | M-30 | | 8.3 | 9.2 | 11.4 | 11.6 |
| | M-40 | | 9.3 | 10.0 | 11.7 | 13.6 |
| | M-00 | Sawdust | 14.6 | 6.9 | 13.0 | 20.0 |
| | M-10 | | 10.7 | 14.1 | 15.5 | 21.8 |
| | M-20 | | 9.1 | 6.4 | 10.4 | 11.0 |
| | M-30 | | 9.4 | 8.9 | 11.4 | 10.9 |
| | M-40 | | 9.8 | 10.2 | 12.0 | 11.2 |

## 4. Discussion

### (i) Characteristics of the natural and activated lateritic soil

From Table 5 the characteristics of the NLS and ALS showed that the totals of $SiO_2 + Fe_2O_3 + Al_2O_3$ are approximately 99% and 83% respectively. These are well above the levels stipulated by ASTM for pozzolanic activity. Therefore, in both conditions the NLS and ALS are pozzolanic and can only go into chemical reaction in the presence of lime and water. The CaO contents are 0.04 and 2.40 respectively, showing they have no cementing values. The $Fe_2O_3$ and $Al_2O_3$ in NLS are 35% and 64% of the ALS, while the $SiO_2$ in the ALS is 60% of the NLS.

**(ii) Basic characteristics of the lateritic concrete**

The statistical Equations (i) - (vi), contained in Minitab 17 Software package were used to derive the values of the Mean, Standard Error of Mean *(SEMean)*, Standard Deviation (*StDev)*, Variance, Coefficient of Variation *(CoefVar)*, and Range (Maximum – Minimum), of both natural and activated lateritic soil are shown below:

$$\bar{x} = \frac{\sum x_i}{n} \quad (i)$$

$$\sigma_M = \frac{\sigma}{\sqrt{n}} \quad (ii)$$

$$\sigma^2 = \frac{\sum (x_i - \bar{x})^2}{n} \quad (iii)$$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{\bar{x}})^2}{n}} \quad (iv)$$

$$CV = \frac{\sigma}{\bar{x}} \quad (v)$$

$$R = (Max. value - Min. value) \quad (vi)$$

Where:

$\bar{x}$ = Population means

$x_i$ = Sum of all the population observations

n = Number of population observation

$\sigma$ = Standard deviation of the population

$\sigma^2$ = Variance

$\sigma_M$ = Standard error of Mean

R = Range of the population observation

The values obtained are shown in Tables 8 and 9 respectively. Table 8 shows the within test results data on the basic characteristics of lateritic soil concrete (Normal and Activated). The within-test is the variation that occurred in the lateritic-cement matrix as curing proceeded within the same mix. Thus, this was for a particular mix measured along the row as curing proceeded. Table 9 is the batch-to-batch data results and is the test results taken down the column. This involved different mixes which are measured at the same age as curing proceeded.

The mean value characterizes the central tendency or location of the data, and the coefficient of variation provid es a general feeling about the performance of a method and its distribution around the mean. It expresses the variation as a percentage of the mean. Thus, the larger the coefficient of variation is, the greater is the spread in the data. These behaviors are reflected in the values obtained in Tables 9 and 10.

The standard error of the mean *(SE Mean)* estimates the variability between sample means, and the standard deviation and thus, establishes a benchmark for estimating the overall variation of a process. Whereas the standard error of the mean estimates the variability between samples, the standard deviation measures the variability within a single sample. The variance (standard deviation squared) measures how spread-out the data are about their mean. A higher standard deviation value indicates greater spread in the data. The greater the variance is the greater the spread in the data. The general observation made on the data as they affect both the mix and age is that the statistical values decreased as the replacement levels

**(iii) Basic Characteristics of the Lateritic –Concrete**

**Table 9.** Basic Statistics for Within-Test for Lateritic-Concrete.

| Type | Medium | Age (Days) | Mean | SE Mean | StDev | Var | CoefVar | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| Normal | Water | 3 | 11.90 | 1.49 | 2.97 | 8.85 | 24.99 | 8.00 | 14.80 | 6.80 |
| | | 7 | 14.35 | 1.64 | 3.28 | 10.74 | 22.83 | 10.20 | 18.10 | 7.90 |
| | | 14 | 16.55 | 1.31 | 2.62 | 6.87 | 15.84 | 13.80 | 20.10 | 6.30 |
| | | 28 | 20.63 | 0.85 | 1.70 | 2.90 | 8.26 | 18.90 | 22.90 | 4.00 |
| Activated | | 3 | 12.04 | 1.66 | 3.70 | 13.70 | 30.74 | 8.50 | 18.10 | 9.60 |
| | | 7 | 13.58 | 0.77 | 1.54 | 2.38 | 11.35 | 11.60 | 14.80 | 3.20 |
| | | 14 | 15.28 | 1.91 | 4.26 | 18.17 | 27.89 | 11.20 | 19.90 | 8.70 |
| | | 28 | 16.64 | 2.16 | 4.82 | 23.24 | 28.97 | 12.20 | 24.30 | 12.10 |
| Normal | Sand | 3 | 12.60 | 1.61 | 3.22 | 10.35 | 25.54 | 10.10 | 17.00 | 6.90 |
| | | 7 | 15.72 | 1.03 | 2.06 | 4.24 | 13.10 | 13.80 | 17.70 | 3.90 |
| | | 14 | 17.05 | 0.83 | 1.65 | 2.74 | 9.70 | 15.10 | 19.00 | 3.90 |
| | | 28 | 19.85 | 1.04 | 2.08 | 4.32 | 10.47 | 18.10 | 22.20 | 4.10 |
| Activated | | 3 | 9.88 | 1.02 | 2.28 | 5.20 | 23.07 | 7.40 | 13.40 | 6.00 |
| | | 7 | 10.82 | 1.47 | 3.28 | 10.73 | 30.28 | 7.90 | 15.30 | 7.40 |
| | | 14 | 14.34 | 1.25 | 2.79 | 7.76 | 19.43 | 11.90 | 18.90 | 7.00 |
| | | 28 | 15.64 | 2.18 | 4.87 | 23.68 | 31.11 | 10.90 | 23.10 | 12.20 |

Table 9 continued

| Type | Medium | Age (Days) | Mean | SE Mean | StDev | Var | CoefVar | Min | Max | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| Normal | Sawdust | 3 | 12.43 | 0.46 | 0.91 | 0.83 | 7.33 | 11.60 | 13.70 | 2.10 |
| | | 7 | 14.85 | 1.08 | 2.16 | 4.68 | 14.56 | 12.60 | 17.60 | 5.00 |
| | | 14 | 17.80 | 0.94 | 1.87 | 3.51 | 10.53 | 15.90 | 20.30 | 4.40 |
| | | 28 | 20.65 | 1.13 | 2.25 | 5.07 | 10.90 | 17.70 | 22.60 | 4.90 |
| Activated | | 3 | 10.72 | 1.01 | 2.25 | 5.07 | 21.00 | 9.10 | 14.60 | 5.50 |
| | | 7 | 9.30 | 1.38 | 3.09 | 9.54 | 33.22 | 6.40 | 14.10 | 7.70 |
| | | 14 | 11.66 | 0.42 | 0.95 | 0.90 | 8.13 | 10.40 | 13.00 | 2.60 |
| | | 28 | 14.98 | 2.43 | 5.44 | 29.62 | 36.33 | 10.90 | 21.80 | 10.90 |
| Normal | Polythene | 3 | 11.05 | 1.52 | 3.04 | 9.26 | 27.53 | 6.90 | 14.00 | 7.10 |
| | | 7 | 14.78 | 0.70 | 1.39 | 1.94 | 9.43 | 13.10 | 16.50 | 3.40 |
| | | 14 | 14.78 | 0.83 | 1.66 | 2.76 | 11.24 | 13.10 | 16.90 | 3.80 |
| | | 28 | 17.95 | 0.83 | 1.67 | 2.78 | 9.28 | 16.20 | 20.20 | 4.00 |
| Activated | | 3 | 10.72 | 1.01 | 2.25 | 5.07 | 21.00 | 9.10 | 14.60 | 5.50 |
| | | 7 | 9.30 | 1.38 | 3.09 | 9.54 | 33.22 | 6.40 | 14.10 | 7.70 |
| | | 14 | 11.66 | 0.42 | 0.95 | 0.90 | 8.13 | 10.40 | 13.00 | 2.60 |
| | | 28 | 14.98 | 2.43 | 5.44 | 29.62 | 36.33 | 10.90 | 21.80 | 10.90 |

**Table 10.** Basic Statistics for Batch-to-Batch-Test for Lateritic-Concrete

| Type | Medium | Mix No | Mean | SE Mean | StDev | Variance | CoefVar | Minimum | Maximum | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| Normal | Water | M-00 | 18.98 | 1.70 | 3.41 | 11.62 | 17.97 | 14.80 | 22.90 | 8.10 |
| | | M-10 | 13.80 | 2.17 | 4.34 | 18.81 | 31.43 | 10.20 | 19.90 | 9.70 |
| | | M-20 | 14.62 | 2.34 | 4.68 | 21.88 | 31.99 | 8.00 | 18.90 | 10.90 |
| | | M-30 | 16.02 | 1.68 | 3.35 | 11.24 | 20.92 | 13.50 | 20.80 | 7.30 |
| Activated | | M-00 | 19.28 | 1.98 | 3.96 | 15.68 | 20.55 | 14.80 | 24.30 | 9.50 |
| | | M-10 | 16.07 | 1.77 | 3.54 | 12.50 | 22.00 | 11.80 | 19.90 | 8,10 |
| | | M-20 | 11.85 | 0.23 | 0.45 | 0.20 | 3.81 | 11.20 | 12.20 | 1.00 |
| | | M-30 | 11.58 | 1.05 | 2.09 | 4.37 | 18.06 | 8.50 | 13.10 | 4.60 |
| | | M-40 | 12.85 | 1.25 | 2.50 | 6.23 | 19.42 | 9.70 | 15.80 | 6,10 |
| Normal | Sand | M-00 | 12.60 | 1.61 | 3.22 | 10.35 | 25.54 | 10.10 | 17.00 | 6.90 |
| | | M-10 | 15.72 | 1.03 | 2.06 | 4.24 | 13.10 | 13.80 | 17.70 | 3.90 |
| | | M-20 | 17.05 | 0.83 | 1.65 | 2.74 | 9.70 | 15.10 | 19.00 | 3.90 |
| | | M-30 | 19.85 | 1.04 | 2.08 | 4.32 | 10.47 | 18.10 | 22.20 | 4.10 |
| Activated | | M-00 | 17.18 | 2.37 | 4.74 | 22.45 | 27.59 | 13.30 | 23.10 | 9.80 |
| | | M-10 | 14.68 | 1.50 | 2.99 | 8.96 | 20.39 | 10.60 | 17.80 | 7.20 |
| | | M-20 | 10.35 | 1.56 | 3.12 | 9.76 | 30.19 | 7.40 | 13.10 | 5.70 |
| | | M-30 | 10.65 | 1.16 | 2.32 | 5.40 | 21.81 | 8.70 | 13.30 | 4.60 |
| | | M-40 | 10.50 | 0.91 | 1.82 | 3.31 | 17.32 | 8.90 | 12.90 | 4.00 |
| Normal | Sawdust | M-00 | 12.43 | 0.46 | 0.91 | 0.83 | 7.33 | 11.60 | 13.70 | 2.10 |
| | | M-10 | 14.85 | 1.08 | 2.16 | 4.68 | 14.56 | 12.60 | 17.60 | 5.00 |
| | | M-20 | 17.80 | 0.94 | 1.87 | 3.51 | 10.53 | 15.90 | 20.30 | 4.40 |
| | | M-30 | 20.65 | 1.13 | 2.25 | 5.07 | 10.90 | 17.70 | 22.60 | 4.90 |
| Activated | | M-00 | 13.63 | 2.70 | 5.39 | 29.07 | 39.57 | 6.90 | 20.00 | 13.10 |
| | | M-10 | 14.52 | 2.53 | 5.06 | 25.63 | 34.85 | 10.70 | 21.80 | 11.10 |
| | | M-20 | 9.22 | 1.02 | 2.04 | 4.18 | 22.15 | 6.40 | 11.00 | 4.60 |
| | | M-30 | 10.15 | 0.60 | 1.19 | 1.42 | 11.73 | 8.90 | 11.40 | 2.50 |
| | | M-40 | 10.80 | 0.50 | 0.99 | 0.99 | 9.20 | 9.80 | 12.00 | 2,20 |
| Normal | Polythene | M-00 | 11.05 | 1.52 | 3.04 | 9.26 | 27.53 | 6.90 | 14.00 | 7.10 |
| | | M-10 | 14.78 | 0.70 | 1.29 | 1.94 | 9.43 | 13.10 | 16.50 | 3.40 |
| | | M-20 | 14.78 | 0.83 | 1.66 | 2.76 | 11.24 | 13.10 | 16.90 | 3.80 |
| | | M-30 | 17.95 | 0.83 | 1.67 | 2..78 | 9.28 | 16.20 | 20.20 | 4.00 |
| Activated | | M-00 | 18.15 | 2..85 | 5.69 | 32.43 | 31.38 | 11.60 | 25,50 | 13.90 |
| | | M-10 | 13.93 | 0.90 | 1.80 | 3.24 | 12.93 | 11.30 | 15.40 | 4.10 |
| | | M-20 | 10.38 | 1.13 | 2.27 | 5,14 | 21.84 | 8.00 | 12.90 | 4.90 |
| | | M-30 | 10.13 | 0.82 | 1.63 | 2.66 | 16.12 | 8.30 | 11.60 | 3.30 |
| | | M-40 | 11.15 | 0.96 | 1.92 | 3.68 | 17.21 | 9.30 | 13.60 | 4.30 |

increased and increased as the age of the lateritic concrete increased. The assertion therefore is that in developing the model equations consideration of the material effect is important, and should be integrated into the equation.

**(iv) Slump and Compressive Strength**

The slump is used to measure the workability or consistency of fresh concrete mix. The slump of the lateritic soil concrete in its natural state improved the workability as the replacement of sand by lateritic soil increased. The reverse was the case when the lateritic soil was activated to a higher temperature. This behavior is more pronounced on the development of the compressive strength.

Figure 1 (a-c) gives a general idea on the development of lateritic concrete strength for natural and activated lateritic concrete. The differences in the strength developments and their classifications are shown in Table 11. Curing with water, sand, and polythene improved both the compressive strengths of NLS and ALS. The increase in compressive strengths were approximately 6%, 4% and 26%, respectively. Although, sawdust curing medium registered a decrease for ALT as compared to NLS, it still met the concrete designed strength of 20 MPa. The increase recorded for the polythene curing medium was remarkable and thus recommended as curing medium when both NLS and ALS without any additives are considered. At 10% sawdust replacement by wt. % of sand, curing with water and sand marginally achieved the 20 MPa design strength. This design strength was also achieved for ALS specimens cured with sawdust (21.8 MPa). For other replacements, 20% and 30%, the design strength was achieved for specimens cured with sawdust (20.1 MPa), at 20% replacement, and specimens cured in water (20.8 MPa) and sawdust (22.2 MPa), at 30% replacement. However, they were only for NLS specimens. The conventional 7/28$^{th}$ day strength for specimens cured in water (NLS and ALS) are 79% and 61%, respectively. However, for other mixes, where sawdust was used in various proportions to replace sand by wt. % of sand are 66% (average for NLS), and 91%. For mixes containing proportions of laterite soil by wt. % of sand (average of 10%, 20%, and 30%), the 7/28$^{th}$ day strength (Normal and activated), are 66% and 91% (average for ALS), respectively. The high value recorded for the activated laterite soil-concrete were due to the low strength recorded.

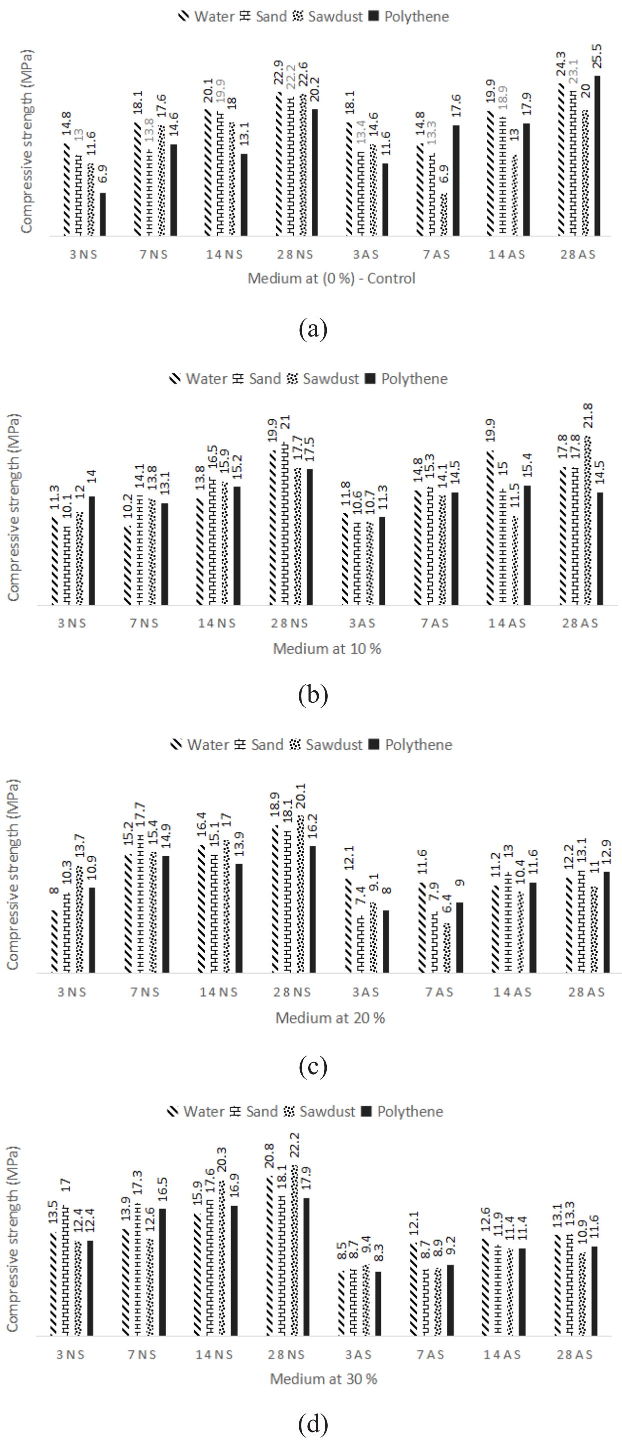


**Figure 1.** Compressive Strength of Lateritic Concrete in Different Medium of Curing

Table 12 is a classification table for the concrete grades, based on the compressive strengths achieved by the different curing methods, and how they met the strength of 20 MPa as the design strength. It showed that the specimens without sawdust (control) cured in standard and non-standard medium, met the 20 MPa design strength for both the NLS and ALS-concrete. However, it was observed that the ALS cured with sawdust reduced in strength by approximately 12% when compared with NLS (Table 11). It therefore showed that at 0% replacement the standard and non-standard methods gave a normal reinforced concrete grade of 19.9 MPa – 24.3 MPa. The lateritic concrete strengths (normal and activated) at 10%, 20%, and 30% replacements respectively, fell below the design strength of 20 MPa, and therefore could be used for other grades of concretes (Table 12). These are designated as lateritic-concrete lintels strength (14.5 MPa to 18.9 MPa) and blinding lateritic-concrete (10.9 MPa to 13.3 MPa).

**Table 11.** Compressive Strength of Lateritic Concrete: Comparison in Different Curing Medium

| Repl (%) | Medium | Lateritic Concrete | | | |
|---|---|---|---|---|---|
| | | Non-activated | Activated | Diff. (MPa) | Diff (%) |
| 0 | Water | 22.9 | 24.3 | +1.4 | +6.1 |
| | Sand | 22.2 | 23.1 | +0.9 | +4.1 |
| | Polythene | 20.2 | 25.5 | +5.3 | +26.2 |
| | Sawdust | 22.6 | 20.0 | –2.6 | –11.5 |
| 10 | Water | 19.9 | 17.8 | –2.1 | –10.6 |
| | Sand | 21.0 | 17.8 | –3.2 | –15.2 |
| | Polythene | 17.5 | 14.5 | –3.0 | –17.1 |
| | Sawdust | 17.7 | 21.8 | +4.1 | +23.2 |
| 20 | Water | 18.9 | 12.2 | –6.7 | –35.4 |
| | Sand | 18.1 | 13.1 | –5.0 | –27.6 |
| | Polythene | 16.2 | 12.9 | –3.3 | –20.4 |
| | Sawdust | 20.1 | 11.0 | –9.1 | –45.3 |
| 30 | Water | 20.8 | 13.1 | –7.7 | –37.0 |
| | Sand | 18.1 | 13.3 | –4.8 | –26.5 |
| | Polythene | 17.9 | 11.6 | –6.3 | –35.2 |
| | Sawdust | 22.2 | 10.9 | –11.3 | –50.9 |

**Table 12.** Classification of Strength Levels

| Strength level (MPa) | Mix (%) | Curing Medium | Soil texture | Application |
|---|---|---|---|---|
| 19.9 - 24.3 | 0 | Polythene, Water, | Normal, | |
| | 10 | Sawdust, Sand | Activated | |
| | 10 | Water, Sand | Normal | |
| | 20 | Sawdust | Activated | Slab |
| | 30 | Sawdust | Normal | Beam |
| | 30 | Water | Normal | Column |
| | | Sawdust | Normal | |

Table 12 continued

| Strength level (MPa) | Mix (%) | Curing Medium | Soil texture | Application |
|---|---|---|---|---|
| 14.5 – 18.9 | 10 | Polythene | Normal | Lintel |
| | 10 | Sawdust | Normal | |
| | 10 | Water | Activated | |
| | 10 | Sand | Activated | |
| 10.9 – 13.3 | 20 & 30 | Water<br>Sand<br>Sawdust<br>Polythene | Activated | Blinding |

**(vi) Linear Regression Analysis of Lateritic Concrete**

The statistical analysis was carried out on the compressive strength of lateritic concrete (NLS and ALS), using the Minitab 19 Statistical Software, on the conventional and non-standard methods of curing. The relevant linear regression equations in the study are from Equations (vii) to (ix).

$$Y = \beta_0 + \beta_1 x + \varepsilon \qquad (vii)$$

Where

$\varepsilon$ = the random error

$\beta_0$ = least square estimates of the intercept

$\beta_1$ = slope of model

$$\widehat{\beta}_0 = \bar{y} - \widehat{\beta}_1 \bar{x} \qquad (viii)$$

$$\widehat{\beta}_1 = \frac{\sum_{i1}^{n} y_i x_i - \frac{\left(\sum_i^n y_i\right)\left(\sum_1^n x_i\right)}{n}}{\sum_1^n x_i^2 - \frac{\left(\sum_1^n x_i\right)^2}{n}} \qquad (ix)$$

Where

$$\bar{y} = \left(\frac{1}{n}\right) \sum_1^n y_i \text{ , and } \bar{x} = \left(\frac{1}{n}\right) \sum_1^n x_i \,. \qquad \text{(x)}$$

The two (2) factors considered were the percentage lateritic soil content (Mix), and the Age of the lateritic concrete samples (curing). Table 13 showed the linear regression models obtained for the different conditions of the lateritic soil, mix, and methods of curing the specimens. The linear regression models for the lateritic concrete (NLS and ALS), can be generally represented by: $f_c = A \mp Bx + Cx_1$ ,

Where

$f_c$ = the compressive strength of the lateritic concrete (NLS and ALS),

*A*, *x*, and *x1,* are constant, mix, and age, respectively, of the lateritic concrete.

The analysis of variance (ANOVA) showed that the regression models, mix and age, are significant with p-values < 0.005, except for NLC mixes for non-standard method of curing (sand, polythene, and sawdust). The other characteristics of these models are also shown in the table. The standard deviations of the samples vary from 2.449 to 3.478. The interactions between the mix and age

**Table 13.** Linear Regression Data for Lateritic Concrete

| Curing Medium | LatConc Type | Stat. Term | Coef | St.Coef | T-Value | P-Value | Signif | St.Dev | $R^2$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| Water | NLC | Const | 10.99 | 1.43 | 7.66 | 0.000 | Significant | 3.018 | 55.35 |
| | | Mix | -0.879 | 0.39 | -2.26 | 0.029 | Significant | | |
| | | Age | 2.796 | 0.39 | 7.17 | 0.000 | Significant | | |
| | ALC | Const | 18.48 | 1.44 | 12.83 | 0.000 | Significant | 3.032 | 58.52 |
| | | Mix | –2.874 | 0.392 | –7.34 | 0.000 | Significant | | |
| | | Age | 1.287 | 0.392 | 3.28 | 0.002 | Significant | | |
| Sand | NLC | Const | 10.27 | 1.16 | 8.82 | 0.000 | Significant | 2.449 | 54.95 |
| | | Mix | 0.072 | 0.32 | 0.23 | 0.822 | NSignificant | | |
| | | Age | 2.340 | 0.32 | 7.40 | 0.000 | Significant | | |
| | ALC | Const | 13.44 | 1.13 | 11.90 | 0.000 | Significant | 2.378 | 72.63 |
| | | Mix | –2.439 | 0.307 | –7.94 | 0.000 | Significant | | |
| | | Age | 2.367 | 0.307 | 7.70 | 0.000 | Significant | | |
| Polythene | NLC | Const | 8.23 | 1.19 | 6.91 | 0.000 | Significant | 2.507 | 49.61 |
| | | Mix | 0.469 | 0.324 | 1.45 | 0.154 | NSignificant | | |
| | | Age | 2.091 | 0.324 | 6.46 | 0.000 | Significant | | |
| | ALC | Const | 11.79 | 1.38 | 8.55 | 0.000 | Significant | 2.902 | 40.62 |
| | | Mix | –1.449 | 0.375 | –3.87 | 0.000 | Significant | | |
| | | Age | 1.527 | 0.375 | 4.07 | 0.000 | Significant | | |
| Sawdust | NLC | Const | 9.52 | 1.30 | 7.34 | 0.000 | Significant | 2.728 | 57.02 |
| | | Mix | –0.022 | 0.352 | –0.06 | 0.950 | NSignificant | | |
| | | Age | 2.722 | 0.352 | 7.72 | 0.000 | Significant | | |
| | ALC | Const | 14.85 | 1.65 | 8.98 | 0.000 | Significant | 3.478 | 60.08 |
| | | Mix | –2.99 | 0.449 | –6.67 | 0.000 | Significant | | |
| | | Age | 2.24 | 0.449 | 4.99 | 0.000 | Significant | | |

of the lateritic concrete, ranged from 49.61% to 72.63%, and the residual plots models showed that there were few residuals [12], and hence apparent limited outliers [13].

## 5. Conclusions

The effect of curing methods used in the evaluation of the compressive strength, and other characteristics of NALS and ALS have been studied. The conclusions on the findings are that, the material properties of the lateritic soils are important in considering model developments and their performances for lateritic soils. The slumps of the NALS and ALS, the statistical characteristics of the data, and the values of the compressive strengths achieved on the work, testify to the fact of the importance of the material characteristics in the performance of lateritic soils for engineering purposes.

The work also showed that the various methods of curing studied assisted in the classifications of grades of NALS and ALS-concrete. The four (4) methods of curing adopted (water, sand, polythene, and sawdust), for this work are suitable both for NALC and ALS-concrete. However, when SDA was used to replace part of the sand by wt. %, the curing medium can become sensitive to the state in which the laterite soil is in, either in the normal or activated state. This becomes a determining factor for strength classification.

## Conflict of Interest

Author declares that there is no conflict of interest.

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