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EFFECTS OF LATERITE ON STRENGTH AND DURABILITY OF REINFORCED CONCRETE AS PARTIAL REPLACEMENT OF FINE AGGREGATE

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ABSTRACT

Throughout the world, concrete is widely utilized in buildings, and due to a rise in construction activity, there is a growing requirement for fine aggregate. This study aims to examine how laterite, which replaces some fine aggregate in reinforced concrete, affects the material's strength and durability. The physical properties of materials were investigated. The compressive strength and flexural strength of laterized concrete were determined for each replacement level of 0, 10, 20, 30 and 40% at a mix ratio of 1:2:4 and a water-cement ratio of 0.65, while for the water absorption, the percentages replacement of laterite to fine aggregates was 0, 10, and 20 % with the same mix ratio and water cement ratio. A 100 X 100 X 100 mm cube and 100 X 100 X 350 mm beams were tested for compressive and flexural strength at 7, 14, 21 and 28 days of curing respectively. Water absorption was determined at 28, 56 and 90 days of curing age. The findings show that as the percentage of laterite substitution increases, the laterized concrete's workability declines. However, the strength properties of the concrete partially replaced with laterite increase with curing age and decrease as the laterite content increases. Moreover, the water absorption of laterized concrete is increased by the inclusion of laterite. It was concluded that the use of laterite in the production of concrete should not be more than 10 %.

Keywords: Compressive Strength, Flexural Strength, Laterized Concrete, Water absorption

INTRODUCTION

Currently, the most widely used construction material in the world is concrete (Shuaibu *et al.*, 2014). The demand for these materials constituents has increased significantly as a result of their use in various structures (Muthusamy and Kamaruzaman 2012; Sulaiman *et al*., 2022). The increased demand has also led to an astronomical increase in the price of such materials, which makes it very hard to meet the housing needs of a country as large as Nigeria. Traditionally, river sand has been applied in the manufacture of construction materials in Nigeria as an excellent aggregate. Continued exploitation of our rivers' sand for its purposes has led to a degradation of the environment and undisturbed depletion of nature reserves (Anya 2015). But because of the environmental damage they are causing, for instance by soil erosion or surface water contamination, several sand mining sites have been closed which has resulted in product shortages. In addition, it travels from relatively far locations at high costs because of its scarcity. Therefore, it is clear that there is a need for an economically feasible alternative to fine aggregate material. There have been several attempts to replace river sand with other materials to produce concrete, one of the materials used in this research is lateritic soil. Concrete containing laterites is termed laterized concrete (Osunade and Fajobi 2000). Laterized concrete is defined as concrete in which stable laterite fines replace aggregate (i:e sand) wholly or partially, whole replacement is referred to as terracrete (Olusola 2005). To reduce the cost of production of concrete, the use of laterite as a partial replacement of the fine aggregate is used. However, there are several studies or literature reviews on the partial replacement of fine aggregates with lateritics in concrete production for specific locations where laterite was obtained. Imoni *et al.*, (2016) investigated the flexural strength of latecrete materials. It has been noted that latecrete behaves similarly to concrete. However, the strength characteristics of concretes were more similar to those of latecrete. Furthermore, it was found that the laterized concrete with a 20 % laterite fine ratio when conditioned to a temperature range of 100^0C attained a maximum compressive strength of 12.90N/mm^2. Ambose and Forth (2018) examined the laterized quarry sand concrete workability and compressive strength. The resulting concrete blocks shall be in the range of ordinary cement weight, although later incorporated quarry dust has a low workability which is comparable with conventional construction material's compressive strength. Therefore, if lateritic content is less than 50 %, the use of crushed sand concrete as a base material for Structural Members should be considered. Imoni *et al.*, (2016) examined plasticized laterized concrete workability, compressive strength, and initial surface absorption at water/cement ratios of 0.30, 0.50, and 0.70. Slump, compressive strength at 7, 14, 21 and 28 days and initial surface absorption after 10 minutes (ISA-10) at 28, 60 and 90 days were determined at the laterite contents of 0, 20, 40, 60, 80 and 100 %. The results show that at equal water/cement ratios, compressive strength reduced with increasing content of laterite and ISA-10 increased with increasing content of laterite. The lateritic concrete would nevertheless be resistant to first surface absorption similar to that of the traditional concrete if it is restricted to 40 %. According to Ambose and Forth (2018) evaluation of the strength and durability of laterized concrete using recycled aggregate, the study reports the results of the experiment of a partial aggregate of crushed granite(CG) with recycled coarse aggregate, Akure pit sand (APS) with recycled fine aggregate (RFA), RFA with LS, and APS with LS. In addition, the levels of substitution in step 10 % were 0 to 70 %. The results show that at 28 days of curing, concrete attained optimum compressive strength of 15N/mm^2, 15.1 N/mm^2,13.1 N/mm^2 and 16.8 N/mm^2, respectively for the mixtures produced by partially substituting APS with 70 % RFA, RFA with 40 % LS, APS with 50 % LS, and CG with 50 % RCA. Sulaiman *et al.*, (2019) reported that the addition of Nano silica increases the compressive strength, and workability of concrete, and it minimizes segregation compared to 0 % addition of Nano-silica.

This study examines how laterite, which replaces some fine aggregate in reinforced concrete, affects the material strength and durability and determines the optimum percentage of laterite content that can be used to produce better strength and durability of the concrete.

MATERIALS AND METHODS

Cement

Portland limestone cement (PLC) which has a specific gravity of 3.16 and a moisture content of 1.81 was the cement utilized. It was sourced from Albabello Trading Company in Zaria.

Fine Aggregate

The fine aggregate used was sourced from the River behind Area G of Ahmadu Bello University Zaria.

Coarse Aggregate

The coarse aggregate used was crushed granite with a maximum nominal size of 20 mm, sourced from Abdukwari quarry opposite Nigeria College of Aviation Technology (NCAT), Zaria.

Laterite

Laterite samples were collected at Mil-Goma opposite Ahmadu Bello University Teaching Hospital, (ABUTH) Shika Zaria. It was collected at a depth of 0.5 m below the ground surface, free from tree roots, debris and inorganic materials.

Reinforcement

A high-yield steel reinforcement bar (12 mm diameter) was sourced from an open market in Sabon Gari, Zaria.

Portable Water

The water used was sourced from the Department of Civil Engineering Laboratory of ABU, Zaria, Kaduna State, Nigeria.

Methods

Physical Properties Tests on Fine and Coarse Aggregates

The specific gravity test was carried out in accordance with BS 812, part 2, (1975). The particle size distribution of fine and coarse aggregate was carried out according to BS 812-103.1 (1985). Aggregate impact and crushing value tests were conducted on coarse aggregate according to BS 812-110 (1990) and BS 812-113(1990) respectively.

Physical properties of the laterite

The moisture content test was conducted in accordance with BS 1377 part 2, (1990). The liquid limit and plastic limit tests were conducted in accordance with BS 1377 part 4, (1990) and BS 1377 part 4, (1990) respectively.

Physical Properties of Cement

The consistency, setting times, and soundness of cement were carried out in accordance with BS EN 1097-2 :(2010).

Mix Proportions

Table 1 highlights the mix proportions that were utilized. The proportion of concrete mix for the grade 15 concrete were determined using the design of experiment. The mixing of concrete was done according to BS 1881-125:1986. While the batching was carried out by weight.

Table 1: Mix Proportion of Laterized concrete

Mix	Cement(kg/m^3)	Laterite Content(kg/m^3)	Fine Aggregate(kg/m^3)	Coarse aggregate(kg/m^3)	Water cement ratio
LC@0	340	0	827	1636	0.65
LC@10%	340	85	744	1636	0.65
LC@20%	340	169	611	1636	0.65
LC@30%	340	253	579	1636	0.65
LC@40%	340	337	496	1636	0.65

Workability of Fresh Laterized Concrete

The workability test was carried out on fresh concrete in accordance with BS EN 12350-2: (2009).

Compressive Strength of Laterized-Concrete

The compressive strength test was carried out in accordance with BS EN 12390-2: (2009). Concrete cubes were cast and cured for 7, 14, 21 and 28 days, and a set of 3 cubes was considered for an average for each curing age using the Avery-Denison Universal testing machine.

Flexural Strength of Laterized-Concrete

The flexural strength test on laterized-concrete beams was conducted according to BS EN 12390-5:2019. Beams were cast and cured in water, and 3 samples were tested for a mean for each curing age 7, 14, 21 and 28 days. The flexural strength of laterized concrete was calculated using three (3) point bending test using the equation (1)

$$f_f = \frac{1.5\ FL}{Wd} \qquad (1)$$

Where: f_f = flexural strength of concrete (N/mm^2), wd = cross sectional dimension, L = span of the beam F = failure load

Water Absorption

Water absorption measures the water tightness of concrete and the amount of water that penetrates into the concrete when submerged in water. The test was carried out in accordance with BS EN 1097-6:2013. The water absorption of the laterized concrete was calculated using equation (2)

$$W = \frac{W_W - W_d}{W_d}\ X\ 100 \qquad (2)$$

W =Water absorption (%) Ww =mass of submerged concrete Wd =mass of dry concrete

RESULTS AND DISCUSSIONS

Physical Properties of Cement

The results of the physical properties of cement are presented in Table 2. It was observed from Table 2 that the consistency, initial and final setting time of cement were found to be 29.67 %, 156 and 198 minutes respectively. Moreover, the soundness is 3 mm. However, all the values obtained fall within the limits specified by BS EN 196-3: (1983)

Table 2: Properties of Cement

S/No	Test	Value	Code Limits	Remark
1	Initial Setting time	156 min	≥45mins	Satisfactory
2	Final Setting time	198 min	≤600mins	Satisfactory
3	Soundness	3mm	≤10mm	Satisfactory
4	Consistency	29.67%	26 ≤ consistency ≤ 33	Satisfactory

Properties of Fine and Coarse Aggregate

The results of the physical properties of fine aggregate and coarse aggregate are presented in Table 3. It was observed that all the values obtained were within the acceptable limit as specified by their standard codes. This indicated that the materials are suitable for use in the production of concrete.

Table 3: Properties of the Aggregate

Properties	Fine Aggregates	Coarse aggregates
Specific gravity	2.60	2.63
Aggregate crushing value (ACV)	-	21.11%
Aggregate impact value (AIV)	-	22.2%
Silt content (%)	2	

Sieve Analysis of Fine and Coarse Aggregate

The results of the particle size distributions of fine and coarse aggregate used in this study are shown in Fig. 1 and Fig. 2 respectively. Based on the BS 882(1992) for grading limit of the fine aggregate, Fig. 1 demonstrated that the used fine aggregate was classified as zone 1, indicating that the fine aggregate is appropriate for use in the production of concrete. Similarly, Fig. 2, shows the particle size distribution of coarse aggregate used for the research and it was discovered that the aggregate is uniformly distributed and therefore will be good for achieving the required workability for better concrete production.

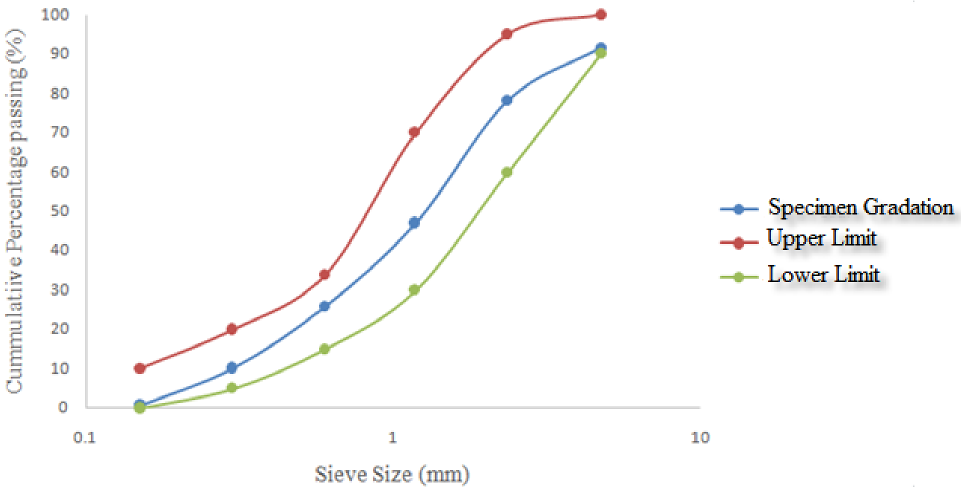

Figure 1: Particle Size Distribution of Fine Aggregate

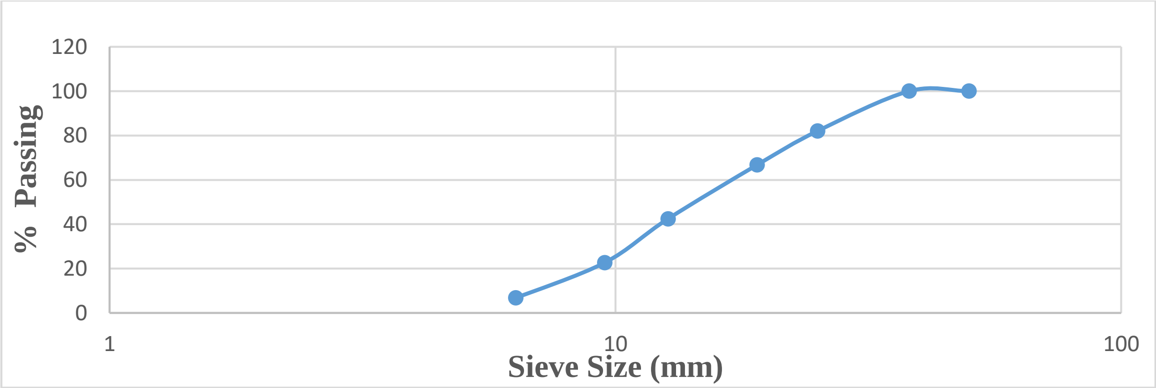

Figure 2: Particle Size Distribution of Coarse Aggregate

Properties of Laterite

The results of the physical properties of laterite are shown in Table 4. It was found that the natural moisture content of the laterite was 16.3 %, and the liquid limit was 46.27 %. The laterite has 58.05% fines passing through sieve No.200.It was classified as A-7-6(4) based on the AASHTO standard (1986) and CL based on the Unified Soil Classification System (USCS) (ASTM, (1992).

Table 4: Properties of Laterite

Properties	Quantity
Percentage Passing No. 200 sieve(%)	58.05
Natural Moisture Content (%)	16.30
Liquid Limit (%)	46.27
Plastic Limit (%)	27.37
Plasticity Index (%)	18.90
Linear Shrinkage (%)	11.30
Specific Gravity	2.55
AASHTO Classification	A-7-6(4)
USCS	CL

Sieve Analysis of Laterite

The particle size distribution of laterite is shown in Fig. 3. It was observed that the laterite was well-graded.

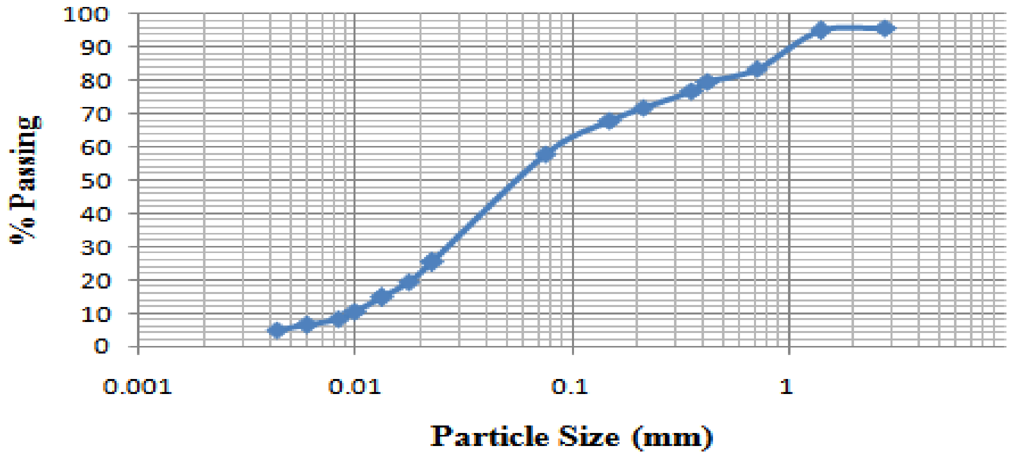

Figure 3: Particle Size Distribution of Laterite

Workability Test

The results of the workability/slump test carried out on fresh laterized concrete are presented in Fig. 4. It was observed that as the proportion of laterite content rise, the workability reduced. The decrease in the workability may be due addition of laterite and also due to the fact that the laterite fines absorb more water than fine aggregate, causing a reduction in the amount of water present in the mix. Similar results were reported by Aliyu *et al*., (2020).

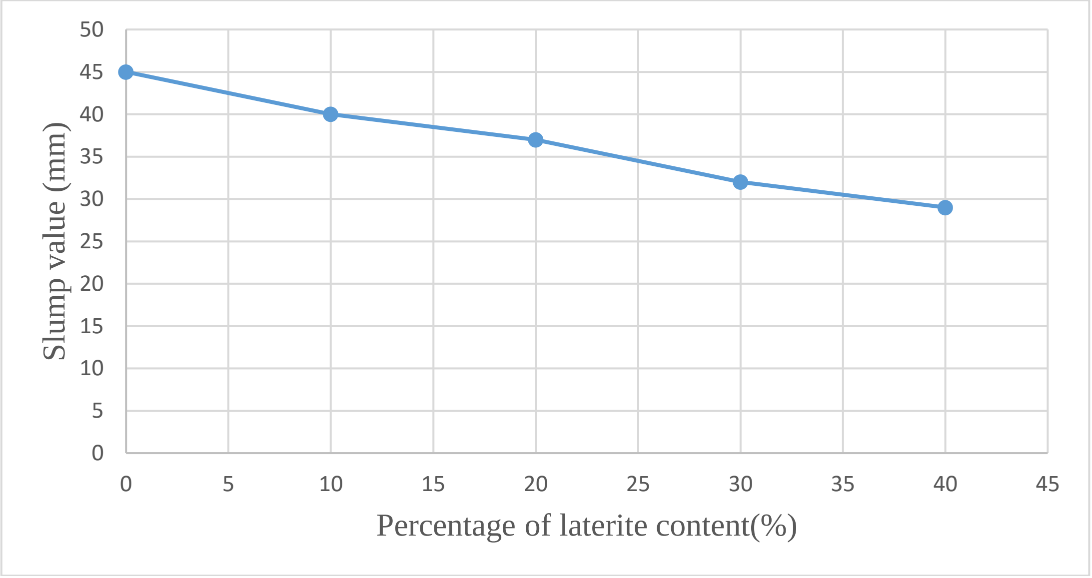

Figure 4: Relationship between slump value and laterite content

Compressive Strength of Laterized Concrete

Fig. 5 presents the results of compressive strength of laterized concrete. It was observed from Fig. 5 that the addition of laterite content decreased the compressive strength. On the other hand, the compressive strength of concrete enhances as the curing age increased. It was also observed that the maximum compressive strength obtained from the control mix of the normal concrete without laterite was found to be 20.43N/mm^2. From the various replacement laterite levels with respect to the fine aggregate, the optimum compressive strength obtained which is closer to the target strength for the mix design was found to be at 10 % replacement level with the compressive strength value of 19.53N/mm^2. It was observed that, by addition of laterite content, the compressive strength at 28 days curing age tends to reduce, this may be due to the large amount of silt, quartz and granular aggregate of kaolinite clay particles in the concrete from the laterite content which tends to reduce the bond between the concrete matrixes.

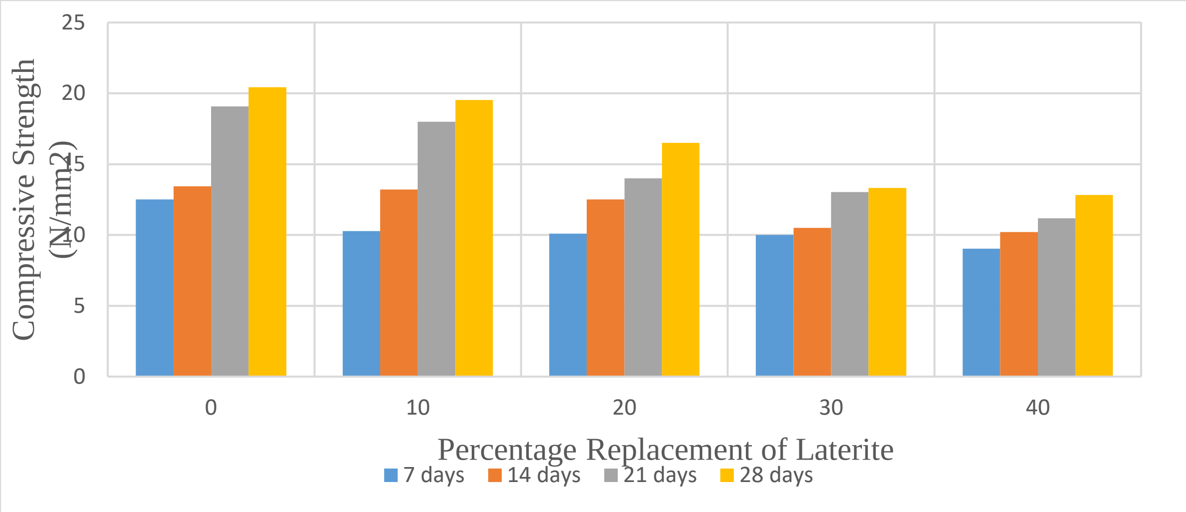

Figure 5: Relationship between Compressive Strength and of Laterite content

Flexural Strength of Reinforced Laterized Concrete

The results of the flexural strength of concrete are presented in Fig. 6. It was observed that the flexural strength of laterized concrete decreased as the percentage of laterite content increased, it increased as the curing age increased. It is seen that the maximum Flexural strength obtained from the reinforced laterized concrete beam from the control mix of the normal concrete without laterite was found to be 29.1 N/mm^2. While from the various replacement laterite level with respect to the fine aggregate, the optimum flexural strength obtained which is closer to the control mix of normal concrete was found to be at 10 % replacement levels with a flexural strength of 28.78 N/mm^2. It was observed that, by an increase in the laterite content, the flexural strength at 28 days curing age tends to decrease as a result of a large amount of silt, quartz and granular aggregate of kaolinite clay particles in the concrete from the laterite content which tends to reduce the bond between the concrete matrixes.

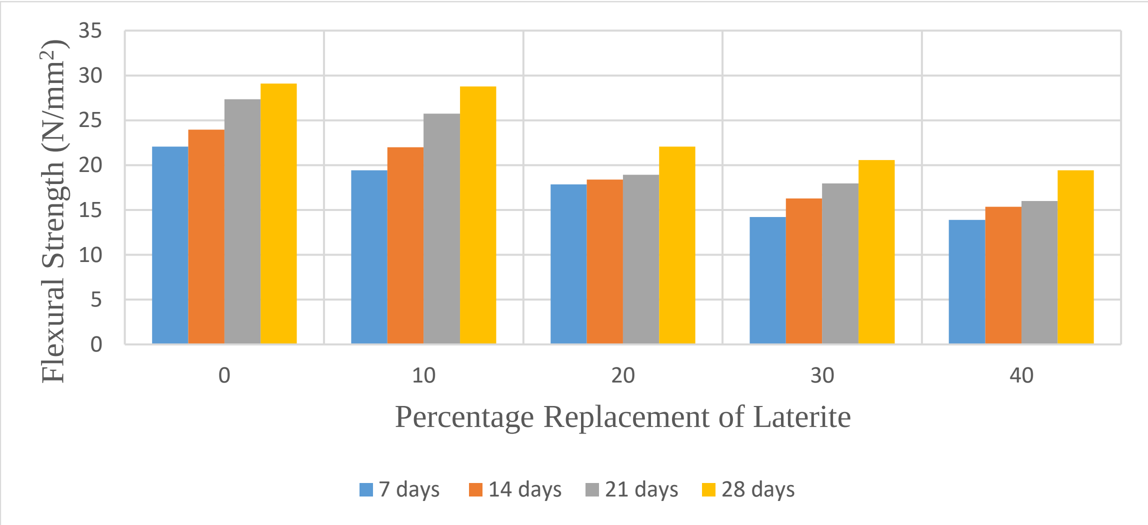

Figure 6: Relationship between Flexural Strength and laterite content

Water Absorption of Laterized Concrete

The results of water absorption carried out on laterized concrete are presented in Fig. 7, it was observed that as the age of curing increases the absorption rate of concrete increased. The water absorption for the control at 90 days is 3.98 % while for the different replacement levels of fine aggregate with the laterite were obtained to be 4.39% and 4.97 % for 10 % and 20 % replacement respectively.

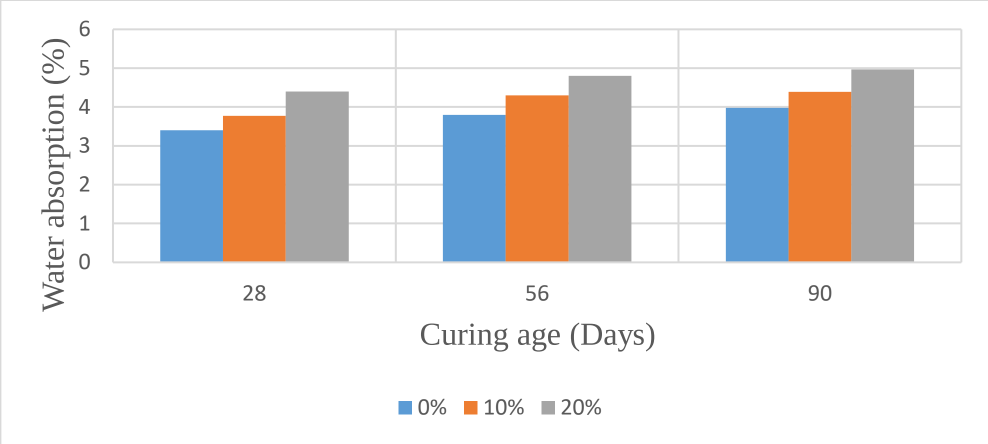

Figure 7: Relationship between Water Absorption against Curing Age

CONCLUSIONS

These conclusions were in light of the of the tests were conducted;

i. The materials used met the minimum requirements specified in various standards for concrete production.
ii. The laterite used for this study was classified and found to be A-7-6(4) based on the AASHTO standard and CL based on the Unified Soil Classification System (USCS).
iii. The compressive and flexural strengths of laterized concrete were reduced by the addition of laterite.
iv.
v. The addition of laterite enhances the water absorption of the laterized concrete.
vi. The optimum laterite content to produce the best strength was found to be not more than 10%.

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