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Performance Masonry Mortar Containing Laterite as Cement Replacement for Civil Infrastructure Development

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Abstract: The performance of laterite-cement based mortar for masonry works with an aim to enhance sustainable civil construction practices was studied. The laboratory tests conducted to analyze the engineering properties of laterite, and sand included specific gravity, particle size distribution, Atterberg limits, strength development and rate of water absorption. The laterite was replaced by weight of cement in percentages that includes 10%, 20% and 30 % and cured for 3 days, 7days and 14 days respectively under control laboratory conditions. The particle size distribution classified laterite as clayey sand and sand as silty sand, while specific gravity values placed all materials within the normal-weight aggregate category. The Atterberg limit tests yielded a liquid limit and plastic limit, for laterite of 37.72% and 48.15.9%, respectively, indicating moderate plasticity. The compressive strength varies with curing days and peaks at 10% replacement, achieving an average strength of 20.657 N/mm² at all curing days. The compressive strength measured revealed that partial replacement of cement with laterite enhances early-age strength development but requires careful percentage control to maintain desired structural integrity. Water absorption tests indicated that 10% laterite replacement produced the least permeable and most chemically stable mortar for masonry works, suggesting that controlled laterite content could improve the engineering properties. The study concludes that laterite, when partially substituted for cement in controlled amounts (10–20%), can improve the strength properties of masonry mortar, making it suitable for civil infrastructure development. it is the view of this paper that future work includes further exploration of laterite’s physical and chemical properties, prolonged curing periods and the addition of supplementary materials to enhance the performance of laterite-based cement mixes.

Keywords: Cement, Laterite durability and Civil Infrastructure

1. Introduction

The increasing price of construction materials, especially in developing countries, has been recognized as one important factor that affects the construction industry. these rises in prices rise has led to a growing recognition that research must be linked to indigenous materials as substitutes to the construction of functional but affordable housing (Krishna, 2002). In this regard, several studies involving the use of new materials that can substitute conventional materials have continued to emerge. These new materials are carefully chosen for research either because they are available in abundance or, in the case of waste, since they are harmful to the environment. Both the above-mentioned reasons are the main motivation for the current study (Krishna, 2002).

Laterite being one among those abundantly available materials has been used for brick production and as a sub-grade material for road construction (Feizbahr and Pourzanjani, 2024). Laterite is a type of soil that is rich in iron and aluminum oxides. These factors include the type of laterite aggregate, the mix design, the environmental conditions, and the construction practices, (Oyelami, 2017). The use of laterites in construction is essentially limited to the manufacture of stabilized laterite-cement based bricks for low cost housing schemes, with optimal savings in cost and environmental sustainability.

According to the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal oxide and precipitation of the oxide with increasing crystallinity and dehydration as the soil is weathered. The major processes of weathering are physical, chemical and biological process. Physical weathering is predominant in the dry climate while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature (Abebaw, 2005). As the disintegration of underlying rock occurs, the primary element is broken down by the process of physical and chemical weathering to simple ionic form. The silica and bases in the weathered material such as sodium, potassium, calcium and magnesium are washed out by the percolated rainwater (verdose water), boxides and hydroxides of sesquioxide accumulated thereby enriching the soil and giving the soil it's characteristic red color, (Aginam, et al., 2004). This process is termed laterization and it depends on the nature and extent of chemical weathering.

Laterization is the weathering process by which the rock is transformed into laterite. After weathering, dehydration occurs. Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich material in a manner which is generally not reversible over wetting (Abebaw, 2005). It leads to the formation of strongly cemented soil with a unique granular soil structure. The topography and drainage of an area also influences the rate of weather because to some extent, it determines the amount of water available for laterization to occur and the rate at which it moves through the weathering zone. The rate at which weathered material is eroded is also controlled.

Laterite-cement based bricks show that they are likely to be used in construction. The performances developed by this building material would be interesting to be valued in the formulation of concrete for the realization of the frameworks of the works with reduced cost as well not compromising desired quality. This study aims to assess the performance of laterite-based cement for Civil Infrastructural development in an attempt to develop a percentage level of cement replacement with laterite for the formulation of masonry mortar

2. Materials and Methods

Sources of the Lateritic Soil

The lateritic soil was obtained from Millennium City located within Kaduna metropolis with an estimated area of 11.8 Hectare Land size. Kaduna itself is unique amongst Nigerian major cities and situated in between latitudes 10°36′ N and 11°6′ N and longitudes 7°23′ E and 7°31′. The Millennium City is a real estate development in Kaduna that aims to make housing affordable for low-income earners (Joshua, et al., 2014)

Accordingly, Kaduna is the capital city of Kaduna State, and the former political capital of Northern Nigeria. Geopolitically, it is located in north-western Nigeria, on the Kaduna River. It is a trade center and a major transportation hub as the gateway to northern states of Nigeria, with its rail and important road network with a total estimated area of 3,080 km² and an elevation of 250 m (820 ft) (Joshua, et al., 2014)

Materials

Cement

The cement used was obtained from a local distributor at Kaduna in Kaduna State kept in a cool dry place in preparation for use in performing the various laboratory testing. The cement sample satisfies the requirement for use as one of the major components of concrete in that, it was not caked or baked through visual inspection and quick setting time. Table 1 showing the chemical composition of the cement while shown in Table 2 is the physical properties of cement used for the study.

Table 1: Chemical Oxide Composition of cement (Extracted from: Taiwo and Adeboye 2020.)

Oxide	Cement (%)
CaO	63.000
SiO_2	20.000
Al_2O_3	6.000
MgO	4.210
Fe_2O_3	3.000
MnO	0.030-1.110
SO_3	2.0

Table 2: The Physical Properties of PC (Extracted from: Taiwo and Adeboye 2020.)

Description	Physical Properties
Bulk Density	1400.000 (kg/m^3)
Specific Gravity	3.15
Colour	Grey
Insoluble Residue	0.500

Fine Aggregate (Sand)

Natural river sand was used as fine aggregate and obtained from a construction site at National Water Resources Institute Campus in Kaduna, Kaduna State. The sand was sieved on a 5.0 mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. The fine aggregate used for the study will be partially replaced with laterite samples.

Water

The water sample used for this experiment was collected from the soil mechanic Laboratory at the National Water Resources Institute, Kaduna. The sample passed all the necessary requirements for use as ingredient of masonry mortar based on the fact that it is colorless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in three gallons (25 liters each).

Laterite

The laterite samples designated as LAT was obtained from borrow pits at Millennium City located in Kaduna Nigeria. The choice of sites is justified by the fact that it is a borrow pits from where construction companies obtain their materials for road construction, with the aid of a digger and a shovel at a depth of 300 mm (1 foot), which is reddish brown in color. Table 3 shows the chemical composition of lateritic soil samples.

Table 3: Chemical composition of natural lateritic soil samples used for the study (Extracted from: Taiwo and Adeboye 2020)

Constituents (oxides)	Percentages (%)
Silicon Oxide (SiO_2)	68.1210
Aluminium Oxide (Al_2O_3)	19.5280
Iron Oxide (Fe_2O_3)	5.8743
Sodium Oxide (Na_2O)	0.3680
Magnesium Oxide (MgO)	1.2590
Potassium Oxide (K_2O)	1.8219
Calcium Oxide (CaO)	0.1109
Zinc Oxide (ZnO)	0.0045
Sulphur (S)	0. 1134
Manganese Oxide (MnO)	0. 0906
Phosphorus Oxide (P_2O_5)	0.3837
Nickel Oxide (Ni_2O)	0.0014

Methods

Physical Properties Tests on Fine Aggregates

The specific gravity test on the sand was carried out in accordance with ASTM C 67-94 (1995), while the particle size distribution was carried out according to BS 812-103.1 (1985), which is often critical in determining the behavior of the material under serviceability. Mathematically, the Coefficient of uniformity and Coefficient of curvature is outlined below:

Physical properties of the laterite

The liquid limit and plastic limit tests were conducted in accordance with Heathcote, K. (1991), Compressive strength of cement stabilized pressed earth blocks.

Performance of the Laterite-Cement Based Brick

The rate of water absorption and strength of masonry mortar cubes were carried out in accordance with IS: 3495-1992. (1992).

Mix Composition and Sample Preparation

The mix composition adopted for this study was modified, with the modifications based on the result obtained from the few trial mix experiments carried in the laboratory guided by the laboratory technician. The modifications made were the introduction of Lateritic soil as partial replacement material for cement in various percentages ranging from 10%, 20% and 30%, with water cement ratio of 0.5. The mix composition is present in Table 4. Table 5 presents the details of the mix design. The mix parameters used in preparing the individual mixes and the proportions percentage replacement levels is presented in Table 6.

Table 4: Masonry Mortar Mix Composition

Material	Kg/m^3
Water (kg)	191.52
Cement (kg)	383.04
Fine Aggregates (Sand) (kg)	2042.88
Total	**2617.44**

Table 5: Masonry Mortar Mix Design with Laterite Replacement Levels

Mix Code	Cement (Kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Laterite (kg/m^3)
Control	383	2043	192	0
Mix One	345	2043	192	38
Mix Two	306	2043	192	77
Mix Three	268	2043	192	115

Table 6: Design mix with material composition and total production of Masonry Mortar per mix

Mix Title	Material Composition	Number of Bricks
Control	Sand+Cement	9
Mix One	Sand+Cement+10%Laterite	9
Mix Two	Sand+Cement+20% Laterite	9
Mix Three	Sand+Cement+30%Laterite	9

Laboratory Investigation

Water Absorption

Water absorption measures the water tightness and amount of water that penetrates into the molded bricks when submerged in water in accordance with IS: 3495-1992. (1992). Mathematically, the rate of water absorption is calculated using:

$$W_{abs} = \frac{w_{soaked} - w_{dry}}{\mathrm{W_{soaked}}}\ x\ 100 \qquad (1)$$

Where,

W_{abs}% = percentage water absorption, W_{dry} = weight of dry block before immersion in water and W_{soaked} = weight of soaked block

Compressive Strength of Laterite-cement based Masonry Mortar

The compressive strength test was carried out in accordance with Heathcote, K. (1991). The laterite-cement based cubes were cast and cured for 3, 7 and 14 days respectively. Mathematically, the compressive strength is computed as follows:

$$Compressive\ Strenght\ (N/mm^2)\frac{Applied\ Load(N)}{Area\ of\ Cube\ (mm\ x\ mm)} \qquad (2)$$

Where,

Applied load (N) = Force, now conversion of applied load from Ton force to KN or N., 1 Ton force = 10kN or 10,000N, for 220kN = 220× 1000 = 220,000N and Area of cube = 150mm×150mm = 22,500mm^2

3. Results and Discussions

Physical Properties Tests on Fine Aggregates

Specific Gravity of Laterite and Sand

The specific gravity for laterite and sand is presented in figure 1. The comparative inference revealed that laterite sample with a specific gravity of 2.62 recorded the highest specific gravity value. The specific gravity of samples tested was greater than 2.4 and as a result, they are classified as normal weight aggregate.

The classification was done in accordance with the specification given by Joshua, et al., (2014) on weight classification of aggregate based on their respective specific gravity values. Joshua, et al., (2014) stated that aggregate with specific gravity value less than 2.4 are classified as light weight aggregate while aggregate with specific gravity value exceeding 2.4 are classified as normal weight aggregate which correlate with the result obtained by the study.

The range of specific gravity values (2.61 -2.62) obtained for sand and laterite satisfied ASTM D854-14 requirements which state that the specific gravity of aggregate used for masonry mortar should lie between 2.55 to 2.9 and therefore, the result obtained justifies the use of laterite for soil cement stabilization purposes. This finding is consistent with the works of Geroge et al., (2019).

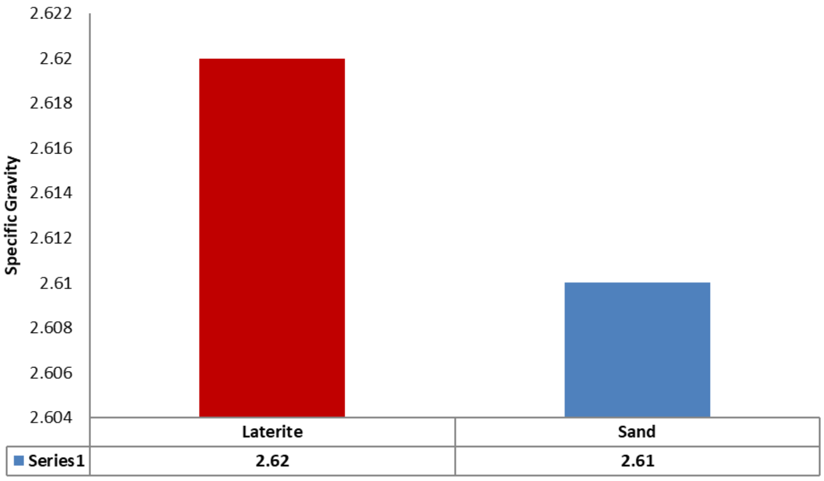

Figure 1: Specific gravity graph for laterite and sand

Particle Size Distribution

Presented in Table 7 is the particle size distribution outcome from soil, while the result from the particle size distribution for the laterite soil for the sand is presented in Table 8.

Table 7: Cumulative Particle Size Distribution Test for Laterite Soil

Particle size distribution test for laterite soil						
S/No.	**Sieve Number**	**Sieve Sizes**	**Weight Retained (g)**	**Percentage Weight Retained (%)**	**Cumulative Percentage Weight Retained (%)**	**Percentage Passing %**
1	4	4.75mm	59.41	29.99	29.99	70.01
2	8	2.36mm	42.81	21.61	51.61	48.39
3	12	1.70mm	38.61	19.49	71.10	28.90
4	16	1.18mm	8	4.04	75.14	24.86
5	30	600mic	24.73	12.48	87.62	12.38
6	40	425µm	5.62	2.84	90.46	9.54
7	50	300mic	2.26	1.14	91.60	8.40

8	70	212µm	5.28	2.67	94.26	5.74
9	200	75µm	4.6	2.32	96.59	3.41
10		Pan	6.76	3.41	100.00	0.00
		Total	**198.08**	**100.00**		

Table 8: Cumulative Particle Size Distribution Test for sand

Particle Size Distribution Test for Sand						
S/No.	**Sieve Number**	**Sieve Sizes**	**Weight Retained (g)**	**Percentage Weight Retained (%)**	**Cumulative Percentage Weight Retained (%)**	**Percentage Passing %**
1	4	4.75mm	1.08	0.54	0.54	99.46
2	8	2.36mm	3.11	1.57	2.11	97.89
3	12	1.70mm	14.76	7.44	9.55	90.45
4	16	1.18mm	9.15	4.61	14.16	85.84
5	30	600mic	69.42	34.98	49.13	50.87
6	40	425µm	40.01	20.16	69.29	30.71
7	50	300mic	16.98	8.56	77.85	22.15
8	70	212µm	33.23	16.74	94.59	5.41
9	200	75µm	0.47	0.24	94.83	5.17
10		Pan	10.27	5.17	100.00	0.00
		Total	**198.48**	**100.00**		

Shown in Figure 2 is the cumulative particle size distribution test for laterite soil. The particle size distribution curve for laterite indicates that a significant proportion of the material consists of finer particles. The steepness of the curve suggests a limited range of particle sizes, with a dominance of fine aggregates. The cumulative passing percentage reaches approximately 70% at a finer sieve number, indicating that laterite has a substantial number of smaller-sized particles

This particle size distribution is typical of lateritic soils, which often contain a mix of clay and silt fractions in addition to sand-sized particles. This gradation pattern suggests that the laterite may exhibit low permeability and moderate shear strength, characteristics that are generally suitable for subgrade applications in road construction.

Subsequently, the cumulative particle size distribution test for sand is shown in Figure 3. The particle size distribution curve of the sand sample shows a higher proportion of larger particles, with the cumulative passing percentage nearing 100% at coarser sieve numbers. The rapid rise in the curve up to around 90% cumulative passing indicates a more uniformly graded material with fewer fine particles than the laterite. Sand's gradation, as seen here, suggests high permeability and lower cohesion. These properties make the sand sample for this study a suitable material for the production of masonry mortar using a laterite-cement based mixture.

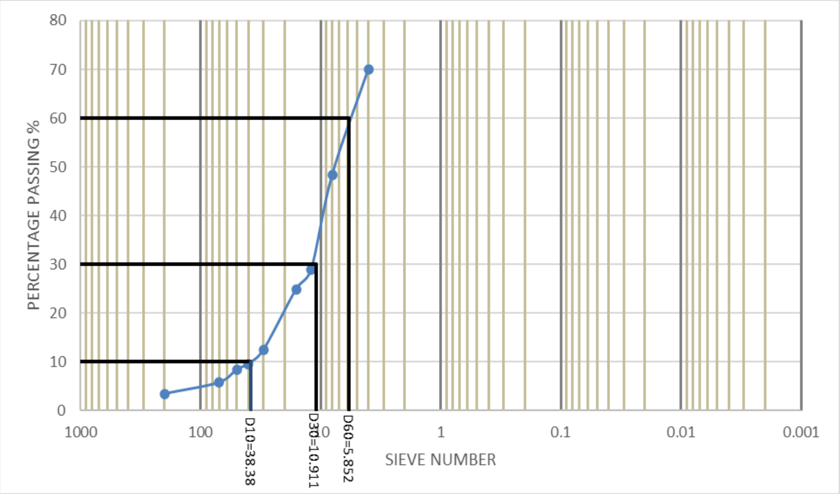

Figure 2: Cumulative Particle Size Distribution Test for Laterite Soil

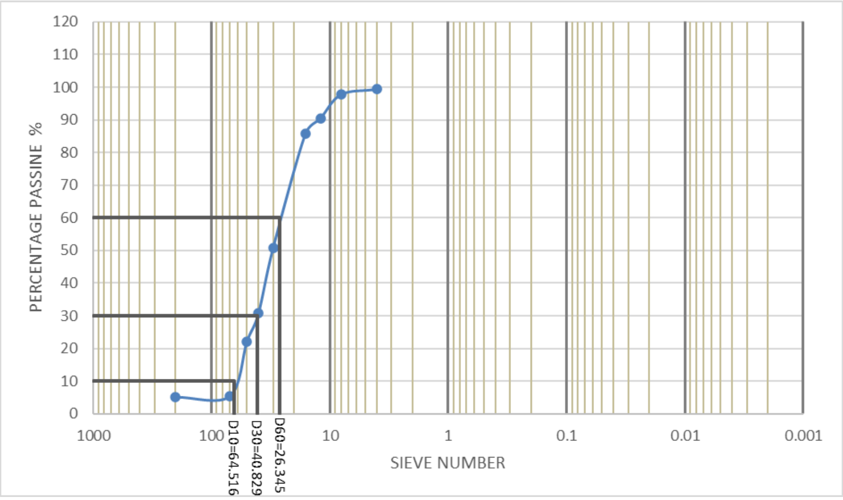

Figure 3: Cumulative Particle Size Distribution Test for Sand

Effect of Variation of Laterite on Specific Gravity of Lateritic-Cement Masonry Mortar

The variation in laterite percentage shown in Table 9 shows is to assess the effect of the variations in laterite's specific gravity values of each mix. The results showed that Mix Two (10%) has the highest specific gravity, indicating a denser composition, while Mix Three (20%) has the lowest, which might imply a lighter or less compact mix.

Table 9: Variation in specific gravity of laterite

Description	Mixes		
	Mix One	**Mix Two**	**Mix Three**
WEIGHT OF EMPTY DENSITY BOTTLE + COCK (g) W1	32.38	32.5	32.48
WEIGHT OF DENSITY BOTTLE + SOIL (g) W2	62.52	54.37	59.5
WEIGHT OF BOTTLE + SOIL + WATER (g) W3	152.6	147.22	150.56
WEIGHT OF DENSITY BOTTLE + WATER (g) W4	133.87	133.82	133.85
W2-W1	30.14	21.87	27.02
W4-W1	101.49	101.32	101.37
W3-W2	90.08	92.85	91.06
SPECIFIC GRAVITY (W2-W1/(W4-W1) -(W3-W2)	**2.64**	**2.589**	**2.62**

These trends in specific gravity values reveal that each mix (10%, 20% and 30%) may be optimized for different applications, but based on the desired density and stability of the final material. Mix Two (10 %), with its consistently higher specific gravity, is likely to provide enhanced structural stability, making it a preferable choice for bricks in a load-bearing components in this study. Mix Three, with its lower specific gravity, might be more suited for applications especially where reduced weight is essential when utilizing the bricks.

Atterberg Limit

The atterberg limit shows the state of transition of cohesive soils in the presence of water (Joshua, et al., 2014). It is the degree of firmness of the soil in the presence of water. According to George, et al., (2019), atterberg limit is an index of the number of fines present in the soil samples. Accordingly, Soil samples containing significant number of fines are likely to exhibit high liquid and plastic limits than soils with lesser fine content (George, et al., 2019).

The result of the atterberg limit test for the liquid and plastic limit is shown in Figure 4. The results suggest that the laterite sample may exhibit high water absorption capacity due to larger surface area determined by the amount of finer fraction present in the sample. The laterite sample justifies the requirement for use as the liquid limit and plastic limit does not exceed 80 and 55% according to the specification given by George, et al., (2019). Similar results were obtained by Joshua, et al., (2014).

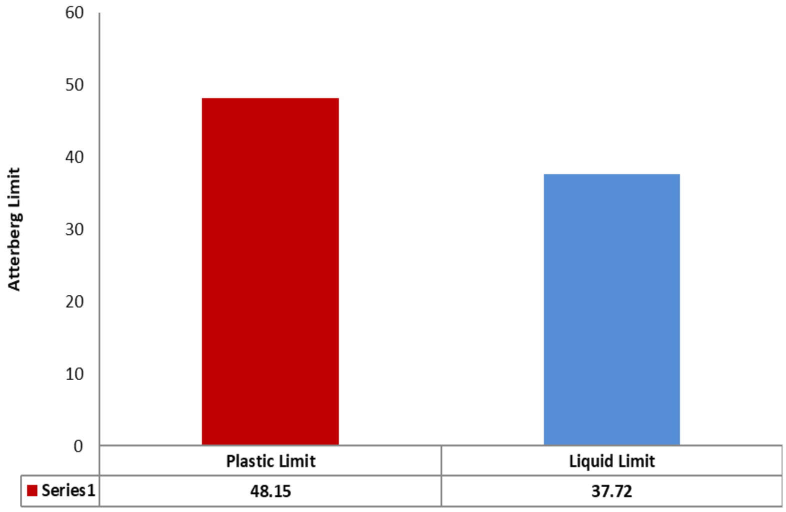

Figure 4: Liquid and Plastic Limit Value of Laterite Sample

Variation in Rate of Water Absorption

The variation in the rate of water absorption is shown in Figure 5, 6 and 7 respectively for the control masonry mortar bricks at different laterite replacement percentages of 10 %, 20 % and 30 % at different curing ages. This rate of water absorption is the masonry mortar's capacity of water intake which can result to swelling by absorption onto the particles surface due to voids present within the mortar micro-structure (Joshua, et al., 2014). Therefore, the level of water absorption is critical when specifying masonry mortar for a particular application. The results showed that 10 % laterite replacement percentages performed best at all curing ages, for before and after insertion in water. Subsequently, the percentage of water absorption increase after 10 % replacement percentages up to 30%. This can inform policy that masonry mortar with 10 % laterite replacement is less permeable and chemically more stable than normal control masonry mortar. According to George, et al., (2019), rate water absorption in masonry mortar slows down as the percentage of cement increases. Despite the increasing trend of water absorption, all the laterite cement based masonry bricks satisfied the maximum water absorption of less 12% specified by the Nigerian Industrial Standard (2004).

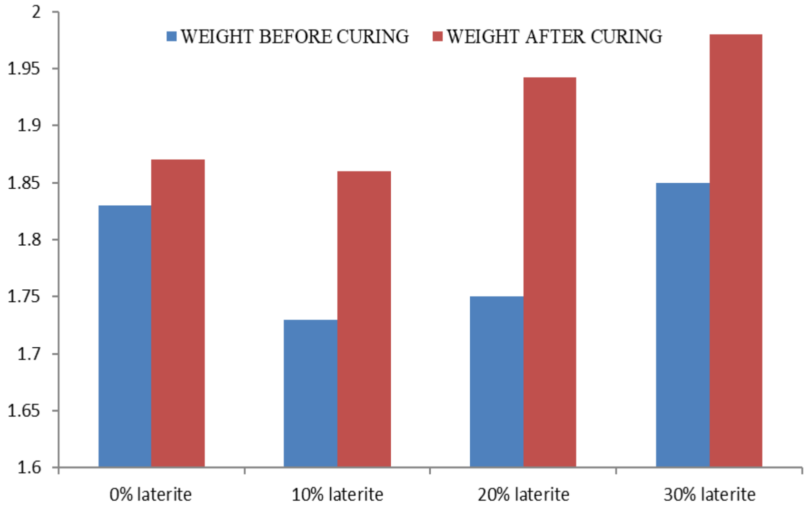

Figure 5: Absorption of Control before and after 3 days curing

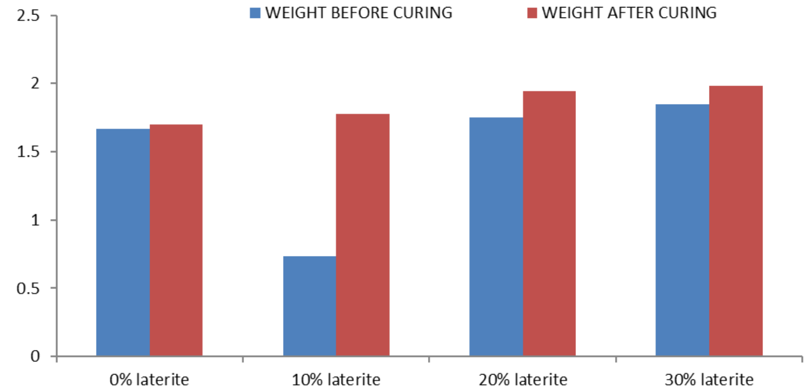

Figure 6: Absorption of Control before and after 7 days curing

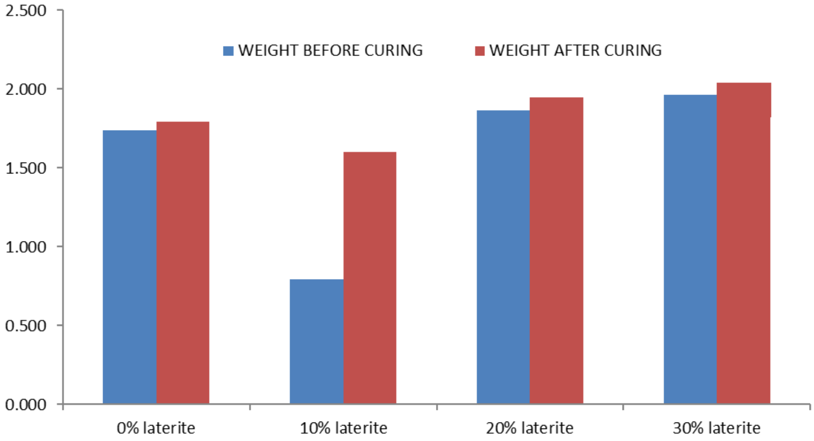

Figure 7: Absorption of Control before and after 14 days curing

Effect of Percentage Replacement on Compressive Strength

The results of the compressive strength characteristics of the masonry mortar produced bricks are shown Figure 8, 9 and 10 respectively, as there was a tremendous improvement in the strength characteristics observed after 3 days of curing period where the strength characteristics increased at 10% replacement. There is an observed decreased after the 10% replacement up to the 30% replacement levels. The increase in compressive strength values could be attributed to ion exchange at the surface of soil particles (Oriola, and Saminu 2012). Subsequently, the increase in cement content in the stabilized lateritic soil results in deposition of interlocking cement gel between the soil particles binding the soil particles together and creates high strength thus the increase in compressive strength with the increase in cement content (Oriola and Saminu 2012).

According to George, et al., (2019), the early improvement in compressive strength of the lateritic cement based bricks at 10% could be attributable to the adequate content of laterite which makes it possible for the cement to be compacted at high density, while the later decrease could be due to high number of fines associated with the laterite sample which makes it difficult for the mortar to be compacted so as to achieve improved compressive strength of the hardened cement-lateritic bricks. This finding is in agreement with works of Joshua, et al., (2014).

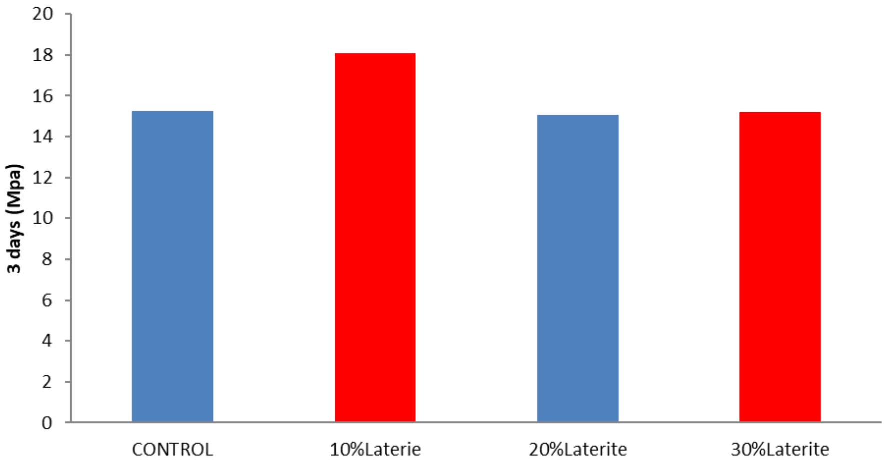

Figure 8: Compressive Strength of Masonry mortar against Percentages of Laterite at 3 Days curing

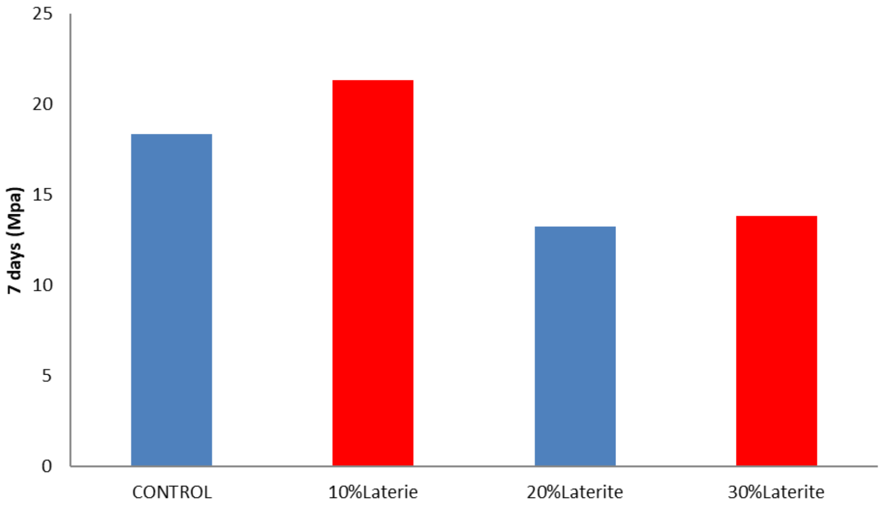

Figure 9: Compressive Strength of Masonry mortar against Percentages of Laterite at 7 Days curing

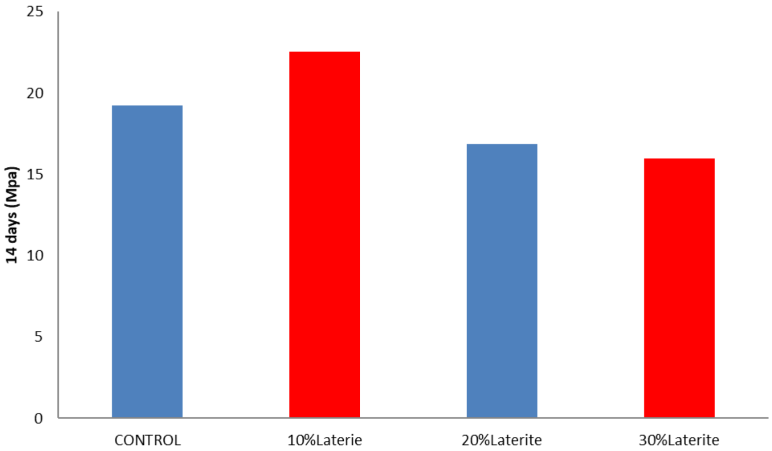

Figure 10: Compressive Strength of Masonry mortar against Percentages of Laterite at 14 Days curing.

Conclusion

It can be seen from the results of this analysis that the performance of masonry mortar can be enhanced considerably by incorporating laterite to replace cement in levels ranging 10 to 30%. Despite the low strength associated with the laterite-cement based brick produced at 10%, 20% and 30% respectively of cement replacement levels; the optimal replacement level of 10 % was achieved without compromising quality. In addition, there is also the added environmental advantage by utilizing laterite, a readily available raw material that is locally sourced, while a further study is recommended to encourages the use of sand and cement for stabilization of poor lateritic soils as the addition of cement and sand to laterite positively modifies the engineering properties (particularly the strength properties) of laterite making them satisfy the criterion for use as building construction material.

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