Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Effect of Calcite Precipitation on Properties of Fresh and Hardened Laterized Concrete

A. M. Kabir*, A. Lawan, J. M. Kaura, I. Aliyu

Department of Civil Engineering, Ahmadu Bello University Zaria, Nigeria
*almuhkab@gmail.com

Research Article

Abstract

Reduction in strength and durability is the limitation for use on laterized concrete in various engineering applications. This research focuses on the effect of calcite precipitation on the strength and durability of laterized concrete. The laterized concrete sample was prepared by fine aggregate replacement with laterite at 0%, 10%, 20%, 30%, and 40% by weight of fine aggregate. A prescribed concrete mix proportion of 1:1.5:3 and a water-to-cement ratio of 0.5 was used to prepare the concrete. At each level of replacement, Sporosarcina Pasteurii bacteria at concentrations of 0, 1.5×10^8*,* 3.0×10^8*, and* 6.0×10^8 *cells/ml were incorporated in the laterized concrete. Fresh concrete samples were tested for slump, hardened concrete cubes were tested for Compressive Strength at 7, 14, 21 and 28 days of water curing and a durability test in form water absorption was performed after 28 days. The slump results showed that the workability of the concrete reduces as the laterite content increases due to more water absorption during mixing, however, the concentration of bacteria had no discernible impact on the slump value. The results of the compressive strength test showed that the compressive strength at all bacterial cell concentrations improves with curing age and declines with increasing laterite content. However, the strength of laterized concrete prepared at a 10% level of replacement is marginally similar to the control sample. All the bacterial concrete performed better than their corresponding non-bacterial concrete with* $1.5x10^8$ *cells/ml giving the optimum result. The water absorption of the samples was found to increase with an increase in laterite content and after the bacteria introduction, the concrete samples showed reduced water absorption when compared with the non-bacterial samples with* $1.5x10^8$ *cells/ml giving the optimum improvement. Calcite crystals and denser surfaces were found by scanning electron microscopy imaging in the bacterial concrete. The bacterial laterized concrete with laterite replacement not exceeding 20% produced concretes of compressive strengths greater than* $25N/mm^2$ *and is suitable for reinforced concrete works*

doi: 10.5455/nje.2023.30.03.03

Keywords

Laterized Concrete, Microbial Induced Calcite Precipitation, SporosarcinaPasteurii, Slump, Compressive Strength, Water Absorption, SEM.

Article History

Received: – September, 2023
Reviewed: – October, 2023
Accepted: – November, 2023
Published: –December, 2023

1. Introduction

The most commonly used material for construction is concrete, hence the need to develop a sustainable alternative for use by developing countries like Nigeria. The utilization of materials in abundance in place of conventional concrete materials would surely be more cost-effective in developing economies provided there is a database on the use of such materials in concrete (Tardy, 1997).

River sand has been used in Nigeria and most other nations for the production of concrete. The ceaseless quarrying of sand from rivers has led to environmental depletion and debasement of its reserve (Anya, 2015). Due to the damage sand mining causes to the environment, many sites have been closed which has led to scarcity of the product forcing it to be transported from relatively far-off locations at a significant expense. This has restricted the less privileged communities from owning individual personal houses. This problem could be avoided if an alternative like laterite could be used in place of the river sand, to produce concrete.

According to Olusola (2005), laterized concrete is described as concrete in which stable laterite fines completely or partially replace river sand, terracrete is a term used for whole replacement of the river sand with laterite. In 1995, Neville claimed in an earlier study that laterite could not produce concrete with strength greater than 10MPa. However, Osunade (2002) and Ata (2003) disproved Neville's assertion and reported that higher grades could be achieved with laterite. In a similar vein, a report by Udoeyo (2006) showed that squared concrete grade was achieved with a 40% sand replacement by laterite suggesting the potential for utilizing laterite as fine aggregate replacement in concrete.

Awoyera, Akinmusuru, and Ndambuki (2016) investigated the workability of laterized concrete; the findings revealed that river sand-based concrete was more workable than laterized. The concrete's laterite content should be kept to a maximum of 40% for optimal workability, compressive strength, and permeation resistance (Olufemi and Ayodeji, 2019).

The results of the research conducted by Md.Shoaib et al. (2022) showed that the tensile and compressive strength of the laterized concrete also increased with the percentage of laterite. However, laterite soil can be utilized for a maximum of 22.5 % in concrete. Laterite could also be effectively utilized as a replacement of both fine and coarse aggregate in concrete as reported by Karthik and Acharya (2021). The findings of the study indicated that the compressive, split tensile, and flexural strength of laterized concrete reduces as the percentage of lateritic aggregate replacement increases, this signifies that as the percentage of lateritic aggregate replacement increases, the compressive, split tensile, and flexural strength of laterized concrete decreases. However, concrete with lateritic stone contents of 15% and lateritic soil contents of 15% performed similarly to the control indicating it can be used up to a maximum of 15% substitution. These researches do not consider the effect of calcite precipitates on the properties of the laterized concrete.

The most frequent mineral that bacteria deposit is calcium carbonate, which occurs as a result of a process known as microbial-induced calcite precipitation (MICP). Because MICP uses ureolytic bacteria, often known as microorganisms, the concrete is sometimes known as bacterial or microbial concrete. Calcite can be constantly precipitated by the bacteria in the concrete, according to Hamilton (2003).

Chunhua and Zhongao (2022) investigated the effectiveness of crack repair in concrete by analyzing microstructure, durability improvement in permeability, and chlorine resistance. The findings indicate permeability and chloride resistance had average improvement coefficients of 79.7% and 60.9%, respectively. According to a related study by Sikder and Saha (2019), when bacteria were used in the MICP process for cement treatment, concrete production or curing of mortar, compressive and split tensile strength increased, the porosity and hence water-absorption decreased, and the chloride permeability decreased, making concrete more durable. Thus, it can be said that bacterial concrete can be utilized in construction to improve durability, self-healing, and crack repair.

This study focuses on investigating the effects of calcite precipitation through MICP on the Slump, the compressive strength, and finally the water absorption of laterized concrete with calcite precipitate.

2. Materials and Methods

2.1 Materials

2.1.1 Laterite

Laterite was collected in Matari, Soba Local Government (Latitude 10°30’N and Longitude 7°50’E), they were well-graded and free from debris, tree roots and inorganic materials.

2.1.2 Cement

Portland Limestone Cement produced by Dangote with a strength class of 42.5R obtained from a dealer in Sabon Gari Market was used as a binder for this research.

2.1.3 Water

Tap water pumped from the Ahmadu Bello University (A.B.U) waterworks was used in preparing cement paste, concrete mixes and curing for the research.

2.1.4 Aggregate

Locally sourced river sand and crushed annular granite obtained from a local quarry within Zaria were used as fine and coarse aggregates for this research.

2.1.5 Bacteria and Nutrient Broth

Sporosarcina-Pasteurii was cultured following Microbiology Procedure/guidelines, (2010) in the Department of Microbiology, Ahmadu Bello University, Zaria.

2.1.6 Cementation Reagent

A solution consisting of 20g $CO(NH_2)_2$, 2.12g $NaHCO_3$, 10g NH_4Cl, 3g nutrient broth and 25g $CaCl_2.2H_2O$ per litre of water was used as cementation reagent for urea the hydrolysis (Stocks-Fischer et al., 1999)

2.2 Methods

2.2.1 Cement Tests

The consistency, initial and final setting time and soundness of the cement were carried out per BS EN 196-3: (2016). The consistency, setting times and soundness of the cement used are shown in Table 1. The values obtained satisfied the specification as recommended by the code for Portland limestone cement.

Table 1: Properties of the Portland limestone cement

Test	Value	Standard
Consistency (%)	29.67	$26 \leq$ consistency
Initial setting time (min)	164	≥ 45
Final setting time) (min)	197	≤ 600
Soundness (mm)	2.33	≤ 10

2.2.2 Soil Classification

The classification of the laterite was carried out according to BS 1377 (1990). The tests include: Natural moisture, particle size distribution and Atterberg limits. The Particle size distribution of the laterite is shown in Figure 1 and the properties of the laterite are shown in Table 2. The laterite was found to fall into class A-6 according to AASHTO.

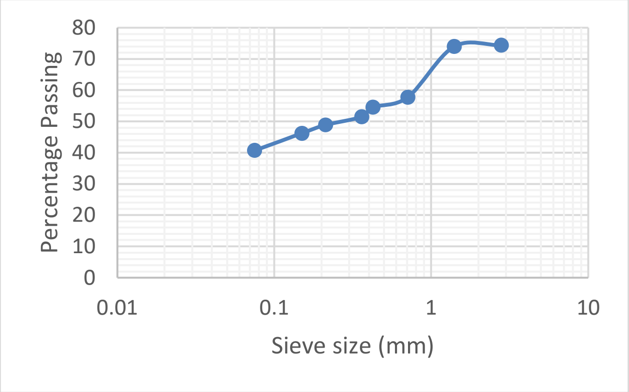

Figure 1: distribution of the particle sizes for laterite

Table 2: Properties of the laterite

Property	Quantity
Percentage passing sieve No. 200, %	74.3
Natural moisture content, %	5.35
Plastic limit, %	17.47
Liquid limit, %	32.81
AASHTO classification, %	A-6

2.2.3 Properties of Aggregates

2.2.3.1 Fine Aggregates

The specific gravity and finesse modulus of fine aggregates were carried out according to BS EN 1097-2: (2010) and the distribution of the particle sizes test for the fine aggregates was carried out following BS EN 933-1: (2012). Figure 2 shows the distributions of the particle sizes of the fine aggregates, the particles fall within the limits for zone II gradation and it is suitable for concrete works based on BS EN 1097-2: (2010). Figure 3 shows the coarse aggregate sizes distribution, it can be observed that the aggregate is well graded and within the limits specified for aggregates with nominal sizes of 5 to 20mm and is therefore suitable for concrete works following BS 882: (1992).

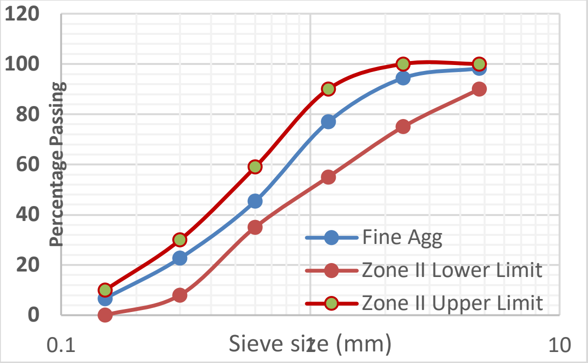

Figure 2: distribution of the particle sizes for fine aggregates

2.2.3.2 Coarse Aggregates

The impact and crushing value test of the aggregates were determined according to BS EN 1097-2: (2010) while distribution of the particle sizes test was done per BS EN 933-1: (2012).

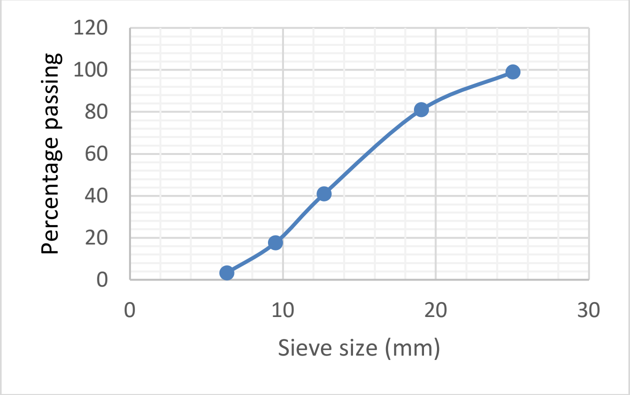

Figure 3: distribution of the particle sizes for coarse aggregates

Other Properties of aggregates such as Specific gravity, finess modulus, Aggregate Crushing Value and Aggregate Impact Value are shown in Table 3 and the aggregates used are within the specified limits.

Table 3: Properties of the aggregates

Property	Fine Aggregates	Coarse Aggregates
Specific gravity,	2.59	2.89
Finesse modulus	2.42	_
ACV	_	21.46
AIV	_	23.51

3.2.4 Sample preparation

The samples were prepared in accordance to BS EN12390-2: (2009). The batching was done by weight for a 1:1.5:3 concrete mix of and water-to-cement ratio of 0.5. Laterite replaced the river sand used as fine aggregates at replacement levels of 0 %, 10 %, 20 %, 30 % and 40 % for non-bacterial concrete (0 cell/ml) and bacterial concrete (1.5E8, 3.0E8 and 6.0E8 cells/ml).

2.2.5 Slump test

The slump test of the fresh concrete was carried out following BS EN 12350-2: (2009).

2.2.6 Compressive Strength Test

Three sets each of concrete cubes (100mm dimensions) were cast, the test was performed after 7, 14, 21 and 28 days curing period, the test was done following BS EN 12390-2: (2009). The compressive strength is expressed in equation (1)

$$f_{cu} = \frac{\text{failure load(N)}}{\text{cross sectional area}(\text{mm}^2)} \qquad (1)$$

2.2.7 Water absorption test

This was conducted per BS 1881-122 (2011). Three sets of concrete cubes were prepared and cured for 28 days. The samples were oven dried for 72 hours, then cooled for 24 hours. The water absorption of the concrete is expressed as in equation (2)

$$Absorption(\%) \; = \; \frac{W_S - W_D}{W_D} \; X \; 100\% \qquad (2)$$

Where: W_S = weight of submerged cube

W_D = weight of dry cube

2.2.8 Scanning Electron Microscopy (SEM)

SEM imaging was conducted to determine the microstructure of the sample and to examine its matrices by obtaining high-magnification images of the concrete fracture surfaces. This test was carried out in the Chemical Engineering Department of A.B.U Zaria.

3.0 Results And Discussion

3.1 Slump Test

Figure 4 illustrates the slump values against the percentage replacement of the laterized concrete and bacterial concentration. The slump value was found to decrease as the laterite content increases. This is because the laterite fines absorb more water than sand, hence, the amount of water present in the mix reduces with a corresponding decrease in slump value. This is similar to the findings of (Awoyera, Akinmusuru and Ndambuki, 2016). It can also be seen that the bacterial cell concentration does not show a remarkable effect on the workability of fresh concrete, this is because the maximum activity rate of *Sporosarcina Pasteurii* bacteria was attained at 16 hours after the concrete had been mixed and maintained till the nutrient media is consumed.

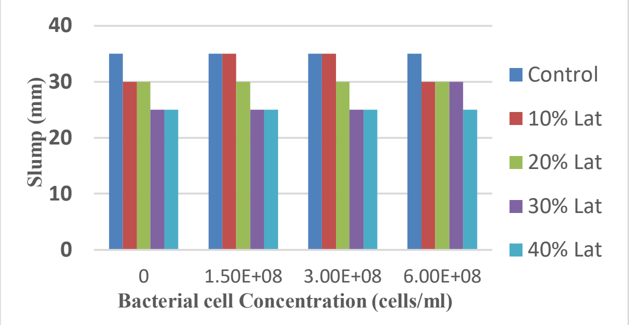

Figure 4: Slump result of the fresh concrete

3.2 Compressive strength of the laterized bacterial concrete

The variation of the samples compressive strength against bacterial cell concentration for the different laterite replacements at 7 days is shown in Figure 5. It was observed that for concrete samples without bacteria (0 cell concentration), the strength reduces as the percentage of laterite content increases, which is a result of laterite consisting of clay particles (quartz and granular aggregates of kaolinite) having weaker strength than the River-sand it substitutes in the mix. This is in line with the findings of (Udoeyo, 2006, Salau and Busari, 2015, and Karthik and Acharya, 2021). However, concretes produced with 10% laterite gave a result that is at par with the control, this could be because, at the 10% replacement, the laterite samples absorb the excess water, leaving just the required water necessary for adequate cement hydration, hence the reactive water-to-cement ratio reduction improves the strength. The trend of compressive strength against the concentration of bacteria shows a smooth increase up to 3.0E8 cell/ml beyond which a strength decrease was recorded. All the bacterial concretes performed better than their respective control samples.

The trend of the results at 14 days is quite similar to that of 7 days as shown in Figure 6, a compressive strength increase was noted with an increase in the curing, this is due to the formation of more calcium-silica-hydrates (hydration products), furthermore, the strength decreases with an increase in laterite replacement. All the bacterial concretes performed better than the non-bacterial concrete. 1.5E8 cells bacterial concentration gave the best result, slightly better than 3.0E8 cells.

At 21 days of curing, the pattern of variation of strength with the other variables is similar to that of 7 and 14 days, the bacterial concretes didn't show an accelerated increase over this period as can be seen in Figure 7, this could be as a result of retardation in the metabolic activities.

Figure 8 presents the result of the strength after curing for 28 days, it can also be seen that for all the samples, similar to earlier curing ages, the compressive strength reduces with an increase in the laterite replacement percentage. There is a noticeable increase in compressive strength for the bacterial concrete as compared to the non-bacterial concrete. There is a sharp increase between the control and 1.5E8 cells/ml beyond which a gradual decrease is observed. All bacterial concretes performed better than their corresponding non-bacterial concrete at the same laterite content.

Generally, the enhancement in compressive strength by the bacteria could be due to $CaCO_3$ deposit on the surfaces of the cells of the microorganism and within the pores of the concrete, which fills the pores within the concrete and produce a more dense and stronger concrete. This is in line with various works in the literature (Navneet et al., 2012, Dhami et al., 2013 and Andalib et al., 2016)

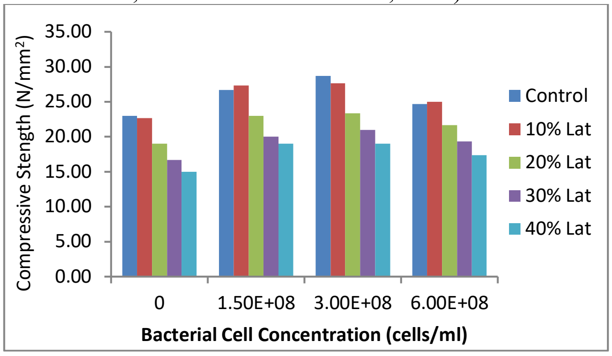

Figure 5: Compressive strength against Bacterial Cell Concentration at 7 days

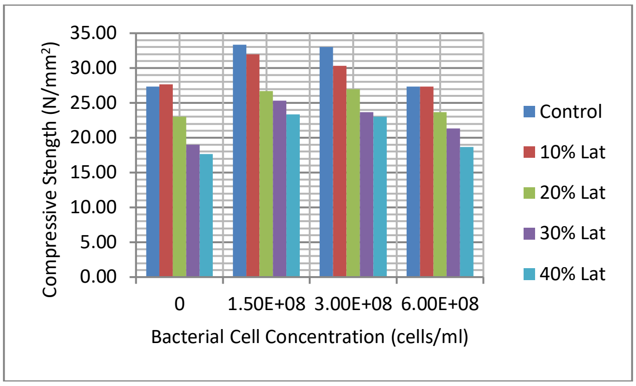

Figure 6: Compressive strength against Bacterial Cell Concentration at 14 days

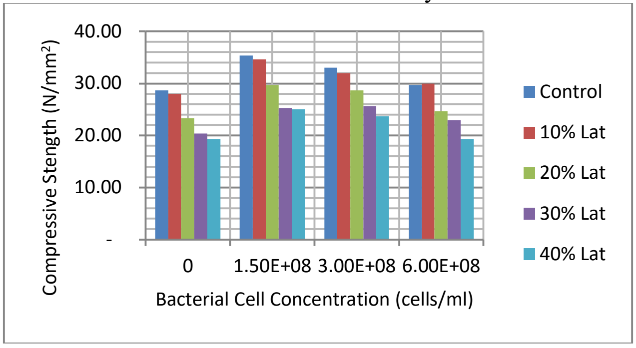

Figure 7: Compressive strength against Bacterial Cell Concentration at 21 days

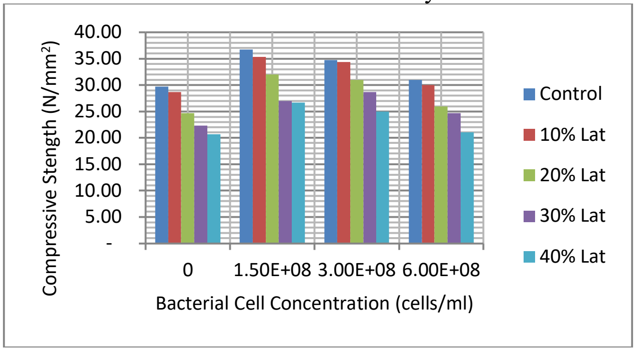

Figure 8: Compressive strength against Bacterial Cell Concentration at 28 days

3.3 Water Absorption Test

Figure 9 presents how the water absorption varies for the various percentages of laterite against the bacterial cell concentration. It can be illustrated that the water absorption for all the bacterial cell concentrations increases with an increase in percentage laterite proportion. This could be a result of the porosity created due to the presence of laterite and the tendency of laterite fines to absorb more water when compared with the river sand it ousted in the concrete mix (Ephraim and Adoga, 2016). However, the incorporation of bacteria significantly improves the durability through a reduction in water absorption with 1.5E8 cells providing the optimum improvement. The improvement by the presence of bacterial cells could be due to $CaCO_3$ precipitation by the *Sprosacina pasteriu* which helps in filling the voids in the concrete thereby making it less permeable (Abo-el-enein et al., 2013).

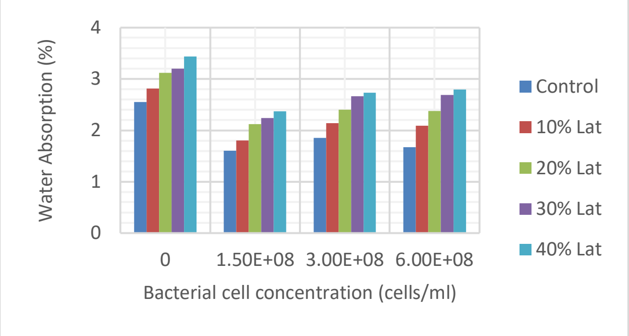

Figure 9: Water Absorption Result for the concrete.

3.4 Scan Electron Microscopy (SEM)

The micrographs for the non-bacterial laterized and bacterial laterized concrete are shown in Plate I and II respectively. It is observed that the non-bacterial laterized concrete has a relatively smooth surface. This could be attributed to laterite fines present in the concrete. The bacterial laterized concrete shows a denser surface. Closer observation shows evidence of Calcite crystals within the grains (Plate II) which are responsible for strength improvement formed during the MICP process by the bacteria. The micro-cracks are a result of the matrix fracture during the compressive strength test on the sample.

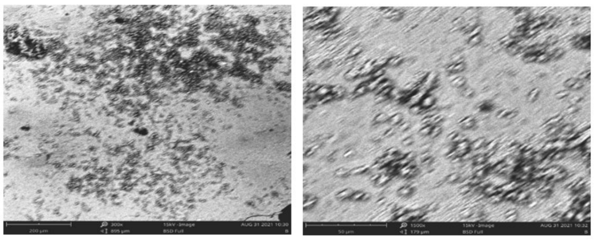

Plate I: SEM result of non-bacterial laterized concrete

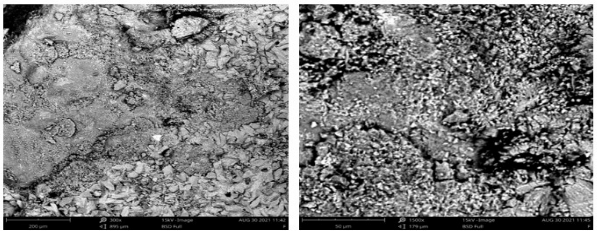

Plate II: SEM result of bacterial laterized concrete

4.0 Conclusion

Theconclusions drawn from the results obtained and the analysis presented are:

i. The workability of the fresh concrete reduces with the incorporation of laterite into the mix. However, bacterial cell concentration does not have much consequential effect on the fresh bacterial concrete workability.

ii. The compressive strength of laterized concrete reduces with an increase in percentage laterite replacement and the incorporation of the bacteria improves the compressive strength of laterizedconcrete with 1.5E8 cells/ml giving the best concrete compressive strength and thus the optimum concentration.

iii. The concrete ability to absorb more water (water-absorption) increases with addition of laterite, in other words, the addition of laterite reduces the durability of the concrete. However, the incorporation of bacteria reduces the absorption capacity of the laterized concrete at all levels of laterite content with 1.5E8 cells/ml giving the optimum result.

iv. The micrographs from SEM results indicate the presence of calcite in the bacterial concrete and an improved surface structure than the non-bacterial concrete

References

Abo-El-Enein, S. A., Ali, A. H., Talkhan, F. N. and Abdel-Gawwad, H. A. (2012). Utilization of microbial-induced calcite precipitation for sand consolidation and mortar crack remediation. *Housing and Building National Research Center*, *8*, 185–192.

Andalib, R., Majid, M. Z. and Abd Hussin. (2016). The optimum concentration of Bacillus megaterium for strengthening structural concrete. *Constr. Build. Mater*, *118*, 180–193.

Anya, U. C. (2015). Models for predicting the structural characteristics of sand-quarry dust block. *PhD thesis,* University of Nigeria, Nsukka.

Ata, O. (2003). The effects of applied stress on the modulus of elasticity and deformability of terracrete. *Unpublished MSc Thesis*, Obafemi Awolowo University, Ile-Ife.

Awoyera, P. O., Akinmusuru, J. O. and Ndambuki, J. M. (2016). Green concrete production with ceramic wastes and laterite. *Constr. Build. Mater*, *117*, 29–36.

British Standards Institution, Method of test for soils for civil engineering purposes. Classification tests. BS 1377-2:1990

British Standards Institution, Methods of testing cement. Determination of setting times and soundness, BS EN196-3:2016

British Standards Institution, Test for geometrical properties of aggregates. Determination of particle size distribution. Sieving method, BS EN 933-1:2012

British Standards Institution, Test for mechanical and physical properties of aggregates. Method for the determination of resistance to fragmentation. BSEN1097-2:2010

British Standards Institution, Testing fresh concrete. Slump-test BS EN 12350-2:2009 80

British Standards Institution, Testing fresh concrete. Slump-test BS EN 12350-2:2009 80

British Standards Institution, Testing hardened concrete. Making and curing specimens for strength tests. BS EN12390-2:2009

British Standards Institution, Testing hardened concrete. Water Absorption. BS 1881-122:1991

Chunhua, L. U. and Zhongao, L. I. (2022). Durability assessment of repairing vertical cracks in concrete using microbially induced calcium carbonate precipitation technique. *7th International Conference on the Durability of Concrete Structures*, *1691*, 1

Dhami, N. K., Reddy, M. S. and Mukherjee, A. (2013). Biomineralization of calcium carbonates and their engineered applications. *Frontiers in Microbiology*, *4*(314), 1–13.

Hamilton, W. A. (2003). Microbially influenced corrosion as a model system for the study of metal microbe interactions: a unifying electron transfer hypothesis. *Biofoulin*, *19*, 65–76.

Karthik, R. and Acharya, G. (2021). Lateritic Aggregate as Partial Replacement for Aggregate in Concrete-An Experimental Investigation. *International Research Journal of Modernization in Engineering Technology and Science*, *3*(08), 496–504.

Md.Shoaib, H. S., Hemanth, K. R., Pradeep, S. N. and Tejas, H. T. (2022). An Experimental investigation on Mechanical & Physical properties of Concrete by the partial replacement of fine aggregate with Laterite Soil. *IJRTI*, *7*(6), 303–310.

Microbiology Procedure/Guidlines, (2010). College of physicians and Surgeons of Saskatchwan*Laboratory Quality Assurance Program*.

Navneet, C., Rafat, S., and Anita, R. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. *Construction and Building Materials*, *28*(1), 351–356.

Olufemi, S. and Ayodeji, O. (2019). Workability, compressive strength and initial surface absorption of laterized concrete. *Journal of Material Ad Egieerig Structures*, *6*, 455–463.

Olusola, K. O. (2005). Factors affecting compressive strength and elastic properties of laterized concrete. *PhD Thesis*, Obafemi Awolowo University, Ile-Ife, Nigeria.

Osunade, J. A. (2002). Effect of replacement of lateritic soils with granite fines on the compressive and tensile strength of laterized concrete. *Building and Environment*, *37*(6), 491–496.

Salau, M. A. and Busari, A. O. (2015). Effect of Different Coarse Aggregate Sizes on the Strength Characteristics of Laterized Concrete. *Materials Science and Engineering*, *96*(1).

Sikder, A. and Saha, P. (2019). Effect of Bacteria on Performance of Concrete / Mortar: A Review. *International Journal of Recent Technology and Engineering (IJRTE)*, (6), 12–17

Tardy, Y. (1997). Petrology of Laterites and Tropical Soils. Balkema, Rotterdam. p.408

Udoeyo, F. F. (2006). Strength performance of laterized concrete. *Construction and Building Materials*, *20*, 1057–1062.