American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

The Effect of Curing Media on Compressive Strength of Microbial Laterite Concrete

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Abstract

Concrete is widely used in the construction of infrastructures and also, its compressive strength determines the function under the application of load. This research investigated the effect of curing media on compressive strength of microbial laterized concrete. 216 numbers of microbial laterized concrete cubes (150x150x150mm) batched by volume at 1:2:4 and water cement ratio of 0.5 were produced from Portland lime cement, aggregates (fine and coarse), laterite and bacteria (bacillus sp. Ct-5) water. Laterite was added at 0%, 15% and 30% respectively. They were then cured in four curing media; Distilled Water, Bacteria + Nutrient Broth Water, Bacteria Water, and Nutrient Broth Water for 28days. Compressive strength test was carried out at 7, 14, and 28 days respectively and some of the results were recorded as 17.38 kN/m^2, 22.00 kN/m^2, 22.24 kN/m^2 etc. The result shows that the compressive strength 22.24 kN/m^2 of concrete produced with zero percent laterite, mixed with bacillus sp. CT-5 water, and cured in nutrient broth + bacteria water was found to be most significant when compared with control and other media test results. It can be concluded that bacillus sp. Ct-5 can be easily cultured and safely used in improving the compressive strength of microbial laterized concrete.

Keywords: Concrete; Bacteria; Laterite; Nutrient Broth; Portland lime cement.

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1. Introduction

The strength of concrete is one of the most significant engineering properties of any structural materials [1,2]. There are numerous factors that influencing strength of concrete including curing [3], placing and setting with the goal that ideal properties of concrete may develop [4]. The requirement for satisfactory curing of concrete cannot be overemphasized. The degree of hydration is measured by the ambient temperature and the availability of moisture content in the mixture [5]. Curing affects the properties of concrete; adequate curing will help increase hardness, durability, strength, stability, and resistance to thawing. The strength of concrete increase at the beginning period because of higher temperature during placing and setting however obnoxiously influence the strength at later ages while they are ceaselessly immersed in water at 21^0c [6,7]. Laterite have been used in building for a long time back and till date a few proportions of the world population still lives in laterite structures [8]. The usage of these bounteously locally accessible materials to supplement the normal aggregate in the production of concrete have proved to be of monetary significance particularly in the developing countries given a reliable data based on concrete provided by these materials. In Nigeria, laterite soil has been the key material utilized for structures [8]. This material has additionally been utilized as fine and coarse aggregate of the world [9,10]. It has been observed that there is a general relationship between altitude and the chemical composition of lateritic soils. The table shows the chemical analysis of laterite soil.

Table 1: The Chemical Analysis of Lateritic Soil (Google, 2019)

CHEMICAL COMPOSITION	PERCENTAGE %
Silica	32.62
Aluminum	25.28
Iron	18.70
Lime	0.42
Phosphorus	0.07

Those soils in Table 1 are rich in silica, iron and aluminum but poor in potassium, lime and organic matter. Bacteria are microscope organisms, single-celled prokaryotic creature [11]. They come in different shapes and sizes. They are ubiquitous in every habitat on earth, growing in soil, acidic hot springs, radioactive waste, water and deep in the earth's crust, as well as in organic matter and the live bodies of plants and animals. They are usually classified on the basis of their shapes. Broadly, they can be divided in to: rod-shape bacteria (bacilli), sphere-shaped bacteria (cocci) and Spiral-shaped bacteria (spirilla) [12].

The various bacteria used in the concrete are:

- Bacillus pasteurii
- Bacillus sphaeicus
- Bacillus subtilis
- Eschericha coli

The concept of bacteria concrete was first introduced by [13]. It is a novel technique adopted in remediating cracks and fissure in concrete by utilizing microbiological induced calcite $CaCO_3$ precipitation of bacteria. Under favorable conditions bacillus pasteruii, when used in concrete, can continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer [11]. In addition, it resists harmful agents like chlorides, sulphates, and carbon-dioxide in to the concrete thereby reducing the deleterious effects they cause [14]. This technique also improves the compressive strength of concrete and stiffness of cracked concrete specimens [12]. Microbiologically induced calcium carbonate precipitation (MICCP) is a process formed by bacteria cells comprises of series of complex biochemical reactions. As part of metabolism, some bacteria species produce urease, which catalysis urea to CO_2 and ammonia, resulting in an increase of Ph in the surrounding where ion Ca^{2+} and $CO^{2-}{}_3$ precipitate as $CaCO_3$. the biochemical reactions in the medium to precipitate $CaCO_3$ at the cell surface can be summarized as shown in Equations 1 to 3):

$$Ca^{2+} + \text{Cell} \longrightarrow \text{Cell} - Ca^{2+} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Cl^{-} + HCO_3^{-} + NH_3 \longrightarrow NH_4Cl + CO^{2-}{}_3 \ldots\ldots\ldots\ldots (2)$$

$$\text{Cell} - Ca^{2+} + CO^{2-}{}_3 \longrightarrow CaCO_3 \downarrow \quad \ldots\ldots\ldots\ldots (3)$$

Inspection of the impact of curing methods on mechanical properties of concrete with ordinary Portland concrete and silica fume cement was examined by Ibrahim and his colleagues [15]. Four diverse of curing methods including water-based, acrylic-based, bitumen-based and coal tar epoxy. Yash and his colleagues [16] investigated the impact of the curing methods on concrete samples made with four water-cement ratio proportions of 0.45, 0.5, 0.55, and 0.6. it was concluded that utilizing membrane curing process through chemical composition produced concrete properties that are 80% to 90% of samples cured utilizing ordinary water methods. The aim of this paper is to study the effect of bacteria cells and curing methods on the compressive strength and other durability properties of lateritic concrete.

2. Materials and Methods

The materials used for this research are Ordinary Portland Cement (OPC) fine aggregates, coarse aggregate and laterite which was in accordance with BS 882: 1992. The percentage of laterite replacement with sand was varied at 0%, 15 and 30%. The coarse aggregate size was 20 mm. The particle size distribution of river sand, laterite and coarse aggregates were determined. A laboratory cultured bacterium known as Bacillus sp. CT-5 was utilized to prepare the concrete cubes. The pure culture bacterium was isolated from the soil sample and was maintained constantly on nutrient agar slants. The culture was streaked on agar slants with an inoculating loop and the slants were incubated at 37^0c, after 2 to 3 days of growth, slant culture was preserved under refrigeration (4^0c) until further use. Contamination from other bacteria was checked periodically by streaking agar plates. Potable water suitable for domestic consumption was used for curing as well as other three curing media. Manual mixing was done and samples were cast in steel moulds. Cube sizes of 150 x150 x 150 mm were utilized for the examination of compressive strength as shown in Figures 1 to 3. All samples were cast in triplicate and were kept in the laboratory for 24 hours thereafter de-moulding of concrete cubes were done and transferred to appropriate curing media and testing was carried out at 7, 14 and 28 days. Table 2 and 3 shows the mix proportion for test specimen and control specimen.

Table 2: Mix proportion for (Test Specimen)

Test No	w/c Ratio	Sand %	Laterite %	Volume of water + bacterial (25ml)
1	0.63	0	100	26.87 kg
2	0.63	15	85	26.87 kg
3	0.63	30	70	26.87 kg

Table 3: Mix proportion for (Control Specimen)

Test No	w/c Ratio	Sand %	Laterite %	Volume of water
1	0.63	0	100	26.87 kg
2	0.63	15	85	26.87 kg
3	0.63	30	70	26.87 kg

Figure 1: Batching process of Aggregates .

Figure 2: Casting and Compaction of fresh concrete cubes.

Figure 3: Process of Crushing using Manual Crushing Machine.

Sieve analysis was carried out on all the aggregate used: 500g of the fine aggregate was weighed and oven dried. The sieves for the analysis were stacked in their order of increasing aperture size. The sample was transferred into the sieve stack on the topmost sieve and vibrated energetically for about 10 – 15 minutes. The sieves had been cautiously separated and the weight of soil retained on every sieve became weighed and recorded. Percentage retained and Percentage passing on each sieve had been determined using equations 4 and 5 respectively according to B.S 812 part 1 [17]

$$\% \text{ Retained} = \frac{\boldsymbol{Mass\ retained\ (g)}}{\boldsymbol{Total\ mass\ (g)}} \text{ x } 100 \qquad (4)$$

$$\% \text{ Passing} = 100 - \% \text{ Retained} \qquad (5)$$

ACV test was done with the aid of steel cylinder, plunger, base plate, tamping rod, weighing balance, IS sieves of sizes 12.5mm, 10mm and 2.36mm, compression testing machine, and dual gauge. The test was carried out in accordance with B.S 811 part 110 [17] using Equation 6

$$\text{ACV} = \frac{W_3}{W_2 - W_1} \times \mathbf{100}\% \qquad (6)$$

3. Results and Discussion

3.1. Aggregate Crushing Value

The ACV was obtained using this equation:

$$\text{ACV} = \text{B/Ax}100 \qquad (7)$$

Where: A is the mass of test sample before test

B is the mass of fraction passing the 2.36mm sieve

A = 1500g, B = 185.5g

Therefore, the ACV is 12.37%

The result of the aggregate crushing value for the coarse aggregate is 12.37% which is within the acceptable limit range of 30% prescribed by BS 882 [18]. These indicates that the aggregate is suitable for concrete production.

3.2. Sieve Analysis

From the results of the particle size distribution obtained with equation 9 for natural sand, laterite, and coarse aggregate as shown in Table 4-6, the particle size distribution of river sand is uniformly graded with a uniformity coefficient of 2.12, while laterite has a uniformity coefficient of 15.20 which is well graded. The particle size of coarse aggregate ranges from 9.5mm to 19mm with uniformity coefficient of 1.05. They all complied with the limit given by BS 882 [18]

Table 4: sieve analysis for river sand

Sieve Size (mm)	Weight Retained (g)	% Retained	% Passing
19	0	0	100
12.7	0	0	100
9.52	1.9	0.15	99.85
6.35	16.8	1.31	98.54
4.76	13.9	1.09	97.94
3.17	19.4	1.52	95.94
2.83	102.9	8.04	87.9
1.41	155.8	12.17	75.73
0.707	205.6	16.06	59.66
0.425	269.8	21.08	38.59
0.3	406.3	31.74	6.84
0.212	37.8	2.95	3.89
0.15	22.8	1.78	2.11
0.074	22.2	1.73	0.38
Pan	4.8	0.38	0

Total weight of river sand used = 1280g

$$uniformity\ coefficient = \frac{D_{60}}{D_{10}} \tag{9}$$

For sand, Cu= 0.7/0.33 = 2.12. thus, sand is uniformly graded soil according to ASTM D3282-09, [19]

Table 5: shows the sieve analysis for laterite

Sieve Size (mm)	Weight Retained (g)	% Retained	% Passing
19	0	0	100
12.7	32.6	4.43	95.57
9.52	33.5	4.55	91.02
4.76	232.6	31.59	59.43
2.83	208.6	28.33	31.09
1.41	37.3	5.07	26.03
0.707	32.6	4.43	21.6
0.425	34.6	4.7	16.9
0.3	64.6	8.77	8.12
0.15	30.2	4.1	4.02
0.074	27.4	3.72	0.3
Pan	2.2	0.3	0

Total weight of river sand used = 736.2g

From equation 9 $uniformity\ coefficient$ For laterite, Cu = 5.00/0.33 = 15.20. thus, laterite is well graded according to ASTM D3282-09 [19]

Table 6: shows the sieve analysis for coarse aggregate

sieve size (mm)	Weight Retained (g)	% retained	% passing
22.5	0	0	100
19	130	12.46	87.54
12.7	756.8	72.08	15.5
9.52	162.4	15.5	0

Total weight of river sand used = 1049.2g

From equation 9 $uniformity\ coefficient$ For coarse aggregate, Cu= 10.8/10.25 = 1.05. thus, granite is uniformly graded according to ASTM D3282-09 [19]

3.3. Compressive strength test

Figure 4 shows the summary of compressive strength test results at 7th, 14th, and 28th days (for test specimen, mixed with B.W). Figure 4a, compressive strength of concrete cured in Bacillus sp. CT-5 water (B.W), Figure 4b, cured in nutrient broth (N.B), Figure 4c, cured in water, and Figure 4d cured in nutrient broth (N.B) + Bacillus sp. CT-5 (B.W). Also, Figure 5 shows the summary of compressive strength test results at 7th, 14th, and 28th days (for control specimen mixed with water). Figure 5a, cured in Bacillus sp. CT-5 water (B.W), Figure 5b, was cured in nutrient broth (N.B), Figure 5c, cured in nutrient broth (N.B) and Bacillus sp. CT-5 (B.W), Figure 5d. 64-72 cured in water. In respect to these figures 4 and 5, it can be observed that the compressive strength of concrete cured in nutrient broth + micro-organism has greater compressive strength then followed by bacteria, nutrient broth and water with 0% laterite showed significant increase at 28th day in comparison with control. The improvement in compressive strength by bacillus CT-5 upon cell growth, precipitate $CaCO_3$ at the cell surface as well as within the concrete matrix. This provided a nucleation site which made it to become less porous and permeable. Once many of the pores in the matrix were plugged the flow of the nutrients and oxygen to the bacterial cells stopped, eventually the cells either died or turned into end spores and acted as an organic fiber, thereby increasing the compressive strength of the concrete [5].

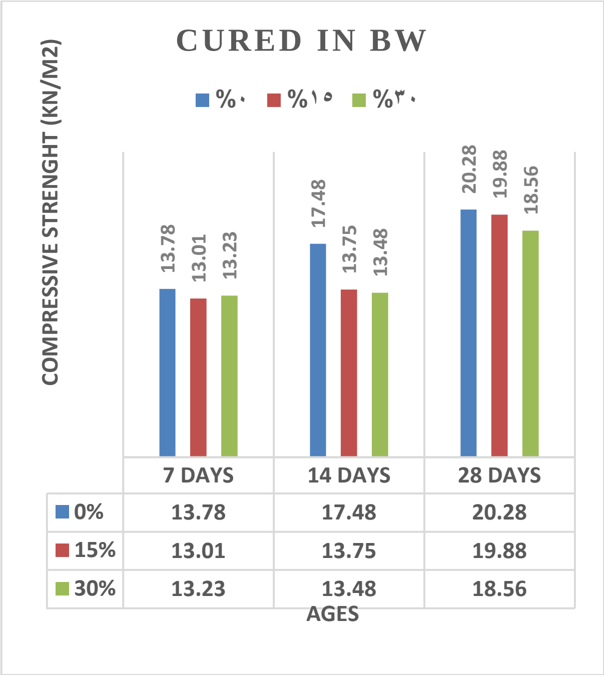

Figure 4a

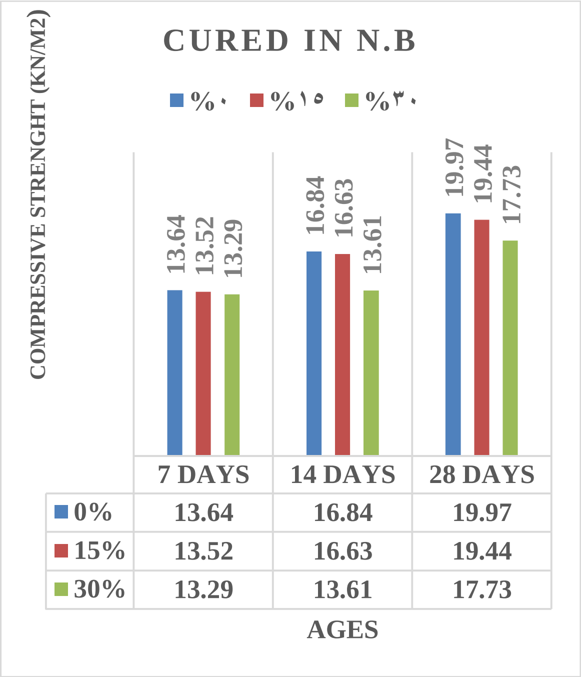

Figure 4b

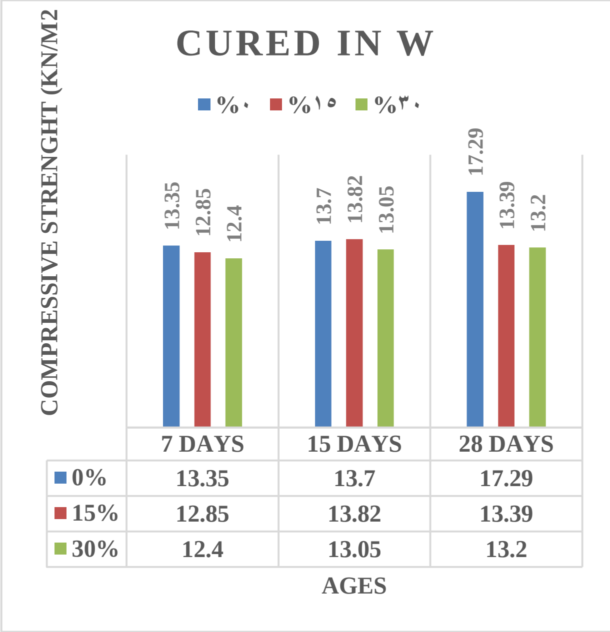

Figure 4c

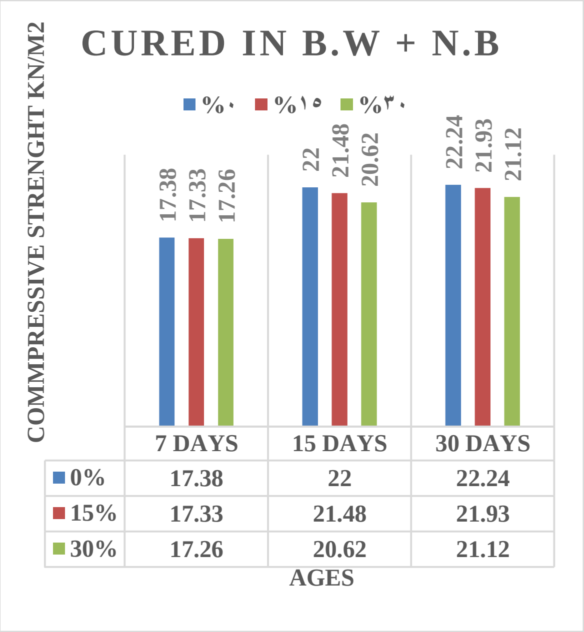

Figure 4d

Figure 4: The Graphs of Compressive Strength of Microbial Laterite Concrete for Test Specimen.

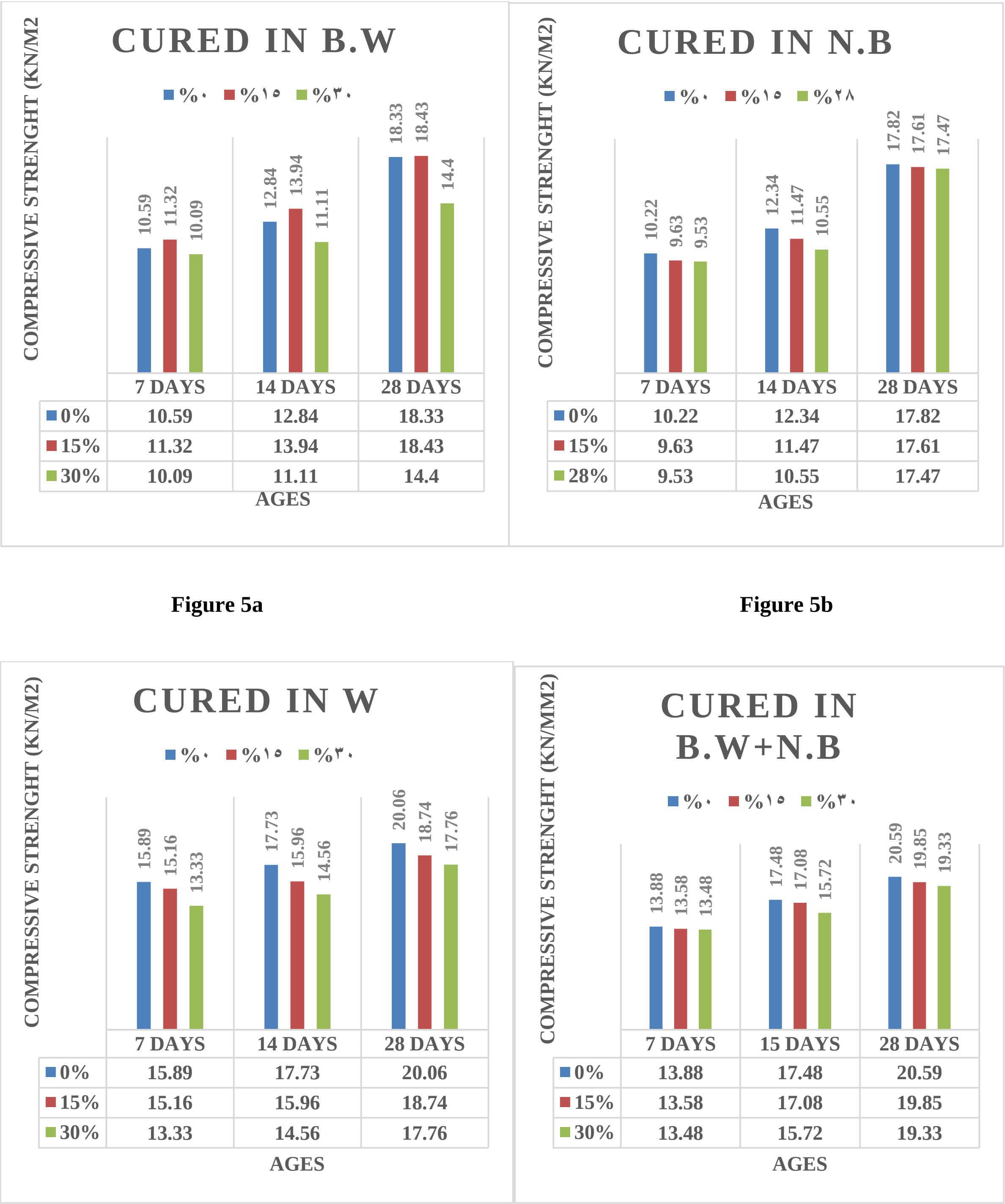

Figure 5a

Figure 5b

Figure 5c

Figure 5d

Figure 5: The Graphs of Compressive Strength of Microbial Laterite Concrete for Control Specimen.

4. Conclusions

- Based on the experimental investigations, the compressive strength of the concrete cured in nutrient broth+ bacillus sp. CT-5 medium was found to be higher when compared to control and other media for test specimen. This implies that bacillus sp. CT-5 can be safely used in improving the compressive strength of laterized concrete.

- Presence of laterite in concrete reduces the compressive strength of such concrete.

5. Recommendation

- The use of bacillus bacteria is recommended for curing of concrete. However, it is necessary to understand the long-term structural properties of microbial laterized concrete. Furthermore, research should be done on structural properties such as flexural strength, tensile strength of microbial laterised concrete, in order to fully understand its performance.

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