



STRENGTH CHARACTERISTICS OF MICROBIAL INDUCED CALCITE PRECIPITATE/CEMENT STABILIZED LATERITE BLOCKS

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This paper assesses the strength characteristics of microbial induced calcite precipitate/cement stabilized laterite blocks. To achieve this, the compressive strength of unmodified lateritic soil blocks, *Bacillus coagulans* calcite precipitate modified lateritic soil blocks, cement modified lateritic soil blocks as well as the combined effects of the *Bacillus coagulans* calcite precipitate and 5% cement stabilized lateritic soil blocks were determined. *Bacillus coagulans* bacteria was used as the bio calcination agent and ordinary Portland cement as the stabilizer. The *B. coagulans* was mixed at various concentrations using the McFarland standard and cement was replaced at 5% to 20% replacement levels after which the crushing strengths were determined considering various curing ages. The compressive strength increased at the various curing ages ranging from 0.9 N/mm² to 2.0 N/mm² at 7 days, 1.3 N/mm² to 2.1 N/mm² at 14 days, 1.5 N/mm² to 2.15 N/mm² at 21 days and 1.65 N/mm² to 2.5 N/mm² at 28 days for all the stabilized blocks with varying concentrations of *B. coagulans* suspension. The compressive strength of the cement stabilized laterite blocks increased with an increase in percentage of cement replacement, and also with increasing *B. coagulans* suspension density for stabilized microbial induced calcite precipitate (MICP) laterite blocks. The 5% cement stabilized MICP laterite blocks performed better than cement stabilized laterite blocks with 20% cement replacement. The optimum concentration was achieved at *Bacillus coagulans* suspension of 2.4×10^9 cell/ml and 5% cement replacement at 28 days curing age with compressive strength value of 4.2 N/mm². Based on the study conducted, it is recommended that for production of laterite blocks, a quantity of 5% cement replacement for stabilization of laterite may be used in addition to *Bacillus coagulans* to produce stronger laterite blocks.

1.0 Introduction

There was a general survey by various African governments which found that slums and squatter settlements are steadily growing at alarming rates in cities of the African countries. In most cases, this growing phenomenon is an outcome of failed policies, poor governance, inappropriate planning regulations, unresponsive financial systems, strong pressure of rural-urban migration and lack of political will to reverse the situation amicably. The dominance of slums in urban areas adds to the toll on the people already burdened deeply by abject poverty and constrains the enormous potential for human development that urban life offers (Freire, 2006; Shome, 2023). Mud houses are found in large numbers around most of these slums in rural and urban parts of Nigeria and indeed all over Africa. They are the commonest dwelling places for low-income earners in the continent. Unfortunately, they are easily destroyed by the perennial floods that accompany the seasonal rains each year. The need to switch over from plain mud houses to houses built with stabilized lateritic soils becomes imperative as the Federal

Government of Nigeria recently announced a plan “to do away with mud houses in a not-too-distant future” (Ndubaba and Malgwi, 2016). It goes to show that research on better alternative materials that will meet the requirements of strength, economy and durability is important.

There have been many recent researches to look into the different ways in which Laterites can be stabilized to produce stronger, durable and more economical mud blocks. Most of such researches have looked into the use of cement as a stabilizer in laterite for blocks production (Dahiru *et al.*, 2016; Ndubaba and Malgwi, 2016; Chambua *et al.*, 2021; Tiboti *et al.*, 2021; Wahab *et al.*, 2021; and Ewa *et al.*, 2022) and most of these studies concluded that cement stabilized laterites produced a stronger and more durable blocks. However, the use of cement as the major stabilizer in lateritic soil for block productions also has some disadvantages in terms of cost, green house effects, etc. The emission of greenhouse gases (CO_2) is one of the major causes of global warming which also causes climate change. According to Suhendro (2014), 8 to 10 percent of the world’s total greenhouse gases emissions come from cement manufacturing. The introduction of supplementary cleaner cementitious material in stabilizing laterite for the production of blocks will go a long way into addressing this issue. One of such supplementary cementitious material is the microbially induced calcite precipitation (MICP).

MICP has been identified to be environmentally sustainable and viable for increasing the strength properties of soils (Kim and Youn, 2016). Bacteria is a common microorganism found everywhere from soil, lakes, water dams etc. Siddique and Chahal (2011), states that there are approximately 40 million bacterial cells in 1g of soil and a million bacterial cells in a millimeter of fresh water. There are approximately five nonillions (5×10^{30}) of bacteria on earth. The bacteria species discovered by scientist from various places all around the world barely scratch the surface as there are constantly new discovery being made. In nature, some bacterial species have the tendency to deposit Calcium Carbonate (CaCO_3), a phenomenon called bio cementation. These depositions can prove to be a promising binder for the protection and consolidation of construction materials. Historical structures can be preserved by using the bacterial remediation technique (Ramachandran *et al.*, 2001). Application of bio cementation has been investigated by various researchers in order to increase the durability of cementitious materials and restoration of buildings (Iqbal *et al.*, 2021)

Bacterially induced mineralization has recently emerged as a method for protecting and consolidating decayed construction materials (Jroundi *et al.*, 2021). In nature, building and remediation of structures with local materials occurs without any requirement of extreme energy usage. The technology of using microbes for calcium carbonate deposition or microbial concrete, called as Microbial induced calcium carbonate precipitation (MICP) can be used for solving various durability issues of construction materials. Microorganisms are abundant in nature, which paves the way for massive production of bacterial calcium carbonate crystals/calcite/concrete. As the microorganisms can penetrate and reproduce themselves in soil or any such environments, there is no need to disturb the ground or environment unlike that of cement (Makul *et al.*, 2022). In view of this, this study investigated the compressive strength characteristic and effectiveness of using cement and Microbial Induced Calcite Precipitation (MICP) as stabilizers in laterite blocks.

2. Materials and Methods

2.1 Materials

The materials used for this study were; Laterite, Ordinary Portland cement (OPC) and Bacteria (*Bacillus coagulans*),

2.1.1 Laterite

The soil sample used in this research was collected from a borrow pit located at Shika, Giwa Local Government Area of Kaduna State (Latitude $11^{\circ}18'0''$ N and $7^{\circ}27'0''$ E) as shown in Figure 1 using method of disturbed sampling. The soil sample was taken at a depth of 0.7m after

removing the top soil. Part of the soil collected was wrapped in sealed polythene bag to avoid loss of moisture and transported in a sack to the soil laboratory for moisture content determination. The soil specimens were then air-dried before pulverizing to achieve particles passing sieve No.4 (4.76mm aperture).

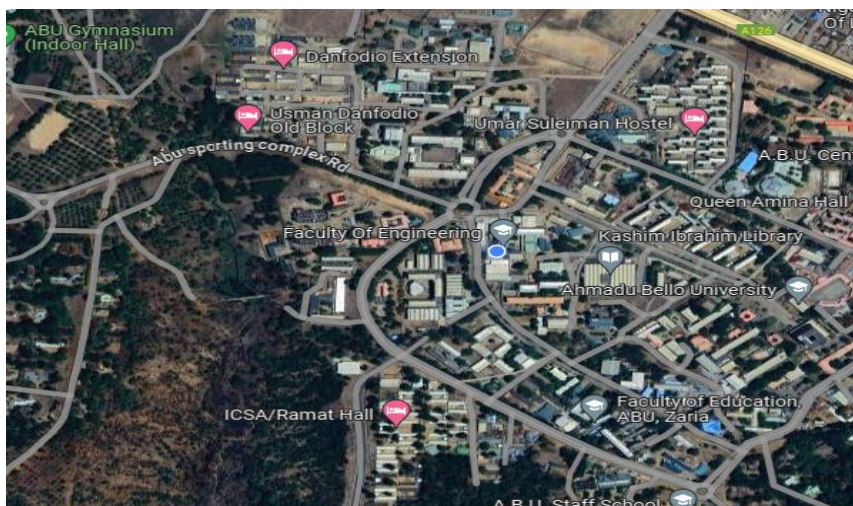


Figure 1: Map view of soil sampling point

2.1.2 Cement

Portland limestone cement (PLC) (Dangote Block Master, grade: 42.5R) was used for this research.

2.1.3 The Microorganisms

The urease (Ure) positive bacteria used in this research was *Bacillus coagulans*. American Type Culture Collection (ATCC) classified the microorganism as ATCC 8038 (ATCC, 2013). It is a rod-shaped gram positive incubated in a water bath shaker (Lab-line, Model 3540) operated at 200 rpm. Cell concentrations were determined by viable cell counting on Tris±YE plates.

2.1.4 Cementation Reagent

The Cementation reagent (C. Reagent) used contains 3g of Nutrient broth, 20g of urea, 10g of NH_4Cl , 2.12g of NaHCO_3 and 2.8g CaCl_2 per liter of distilled water in accordance with that described by Stocks-Fischer (Stocks-Fischer et al., 1999).

2.1.5 Water

Potable water supplied by Ahmadu Bello University, Zaria water works and obtained from the taps in the Civil Engineering laboratory of Ahmadu Bello University, Zaria was used for the experiments.

2.2 Methods

There are many methods to reduce a soil's susceptibility to weakening by water. These fall in to the following broad categories:

- i) Protecting the wall from exposure to water,
- ii) Reducing the permeability of the wall by increasing the soil density,
- iii) Making the soil water-repellant by the addition of a water proofing agent and
- iv) Providing a secondary cementitious- type strength mechanism which is largely unaffected by water.

2.2.1 Mix Proportions for Cement, *B. coagulans*, C. reagent, laterite and water

Three different mix proportions were used in this study. In the first mix, laterite was mixed with cement at 0%, 5%, 10%, 15% and 20% replacement and water at optimum moisture content of the laterite. In the second mix proportion, laterite was also mixed with *B. coagulans*

and cementitious reagent (25% *B. coagulans* and 75% cementitious reagent) at optimum moisture content with *B. coagulans* and cementitious reagent replacing water in the mix. In the third mix proportion, laterite was first mixed at 5% cement content and then with *B. coagulans* and cementitious reagent (25% *B. coagulans* and 75% cementitious reagent) at optimum moisture content with *B. coagulans* replacing water in the mix. It is shown in Table 1.

1. The *B. coagulans* concentrations were varied at 0, 1.5E+08, 6.0E+08, 1.2E+09, 1.8E+09 and 2.4E+09 cell/ml suspension densities.
2. The Optimum moisture content of the soil obtained during the British standard light compaction was 10.4% at a maximum dry density of 1.99Mg/m³.

Figure 2 presents the pictorial view of the mixing process of the stabilizers with the lateritic soil.

Table 1: Mix proportion for cement, *B. coagulans*, C. reagent and water in laterite

First mix (Laterite, cement and water)					
Mix	Materials quantity (kg)				
	Laterite	Cement	<i>B. coagulans</i>	C. Reagent	Water
0% cement	5.0300	0	0	0	0.57
5% cement	4.7785	0.2515	0	0	0.57
10% cement	4.5270	0.5030	0	0	0.57
15% cement	4.2755	0.7545	0	0	0.57
20% cement	4.0240	1.0060	0	0	0.57
Second mix (Laterite, <i>Bacillus coagulans</i> and cementitious reagent)					
	Laterite	Cement	<i>B.coagulans</i>	C. Reagent	Water
0.00E+00	5.0300	0	0	0	0
1.50E+08	5.0300	0	0.131	0.393	0
6.00E+08	5.0300	0	0.131	0.393	0
1.20E+09	5.0300	0	0.131	0.393	0
1.80E+09	5.0300	0	0.131	0.393	0
2.40E+09	5.0300	0	0.131	0.393	0
Third mix (Laterite, <i>Bacillus coagulans</i> , cementitious reagent and 5% cement)					
	Laterite	Cement	<i>B. coagulans</i>	C. Reagent	Water
0.00E+00	4.7785	0.2515	0.124	0.373	0
1.50E+08	4.7785	0.2515	0.124	0.373	0
6.00E+08	4.7785	0.2515	0.124	0.373	0
1.20E+09	4.7785	0.2515	0.124	0.373	0
1.80E+09	4.7785	0.2515	0.124	0.373	0
2.40E+09	4.7785	0.2515	0.124	0.373	0



Figure 2: Practical aspect of the mixing process

2.2.2 Moulding of laterite blocks

After mixing, the blend was compressed to fill the 230 × 110 × 100 mm moulds at the maximum dry density of the laterites to obtain solid blocks as presented in Figure 3.



Figure 3: Pictorial presentation of the laterite block moulding work

2.2.3 Compressive Strength of the lateritic moulded solid blocks

The compressive strength test on the molded blocks was conducted according to BS EN 12390-3, (2002). Solid blocks were molded and three samples for each mix was tested for an average for each curing regime (7 days, 14 days, 21 days and 28 days) using the Avery-Denison Universal Testing Machine.

3. Results and Discussion

3.1 Effect of *B. Coagulans* on compressive strength

The 7th, 14th, 21st and 28th days curing mean compressive strength values of compressed laterite blocks stabilized with *B. coagulans* at 1.5×10^8 /ml, 6.0×10^8 /ml, 1.2×10^9 /ml, 1.8×10^9 /ml and 2.4×10^9 /ml *Bacillus coagulans* concentration are presented in Figure 4.

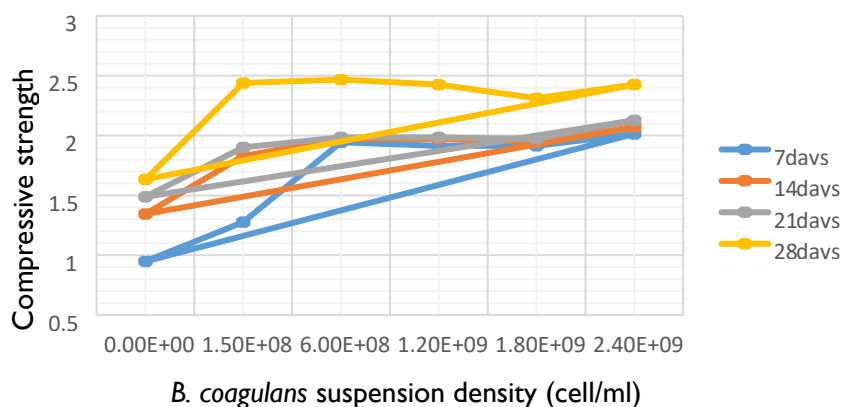


Figure 4: Variation of compressive strength with *B. coagulans*

From the trend in Figure 4, the compressive strength is seen to increase with increase in suspension density of *Bacillus coagulans* (i.e. from 0.9 N/mm² for the natural Laterite blocks to 2.0 N/mm² for 2.4×10^9 cell/ml *Bacillus coagulans* induced laterite blocks after 28 days curing), the compressive strength is also seen to be lower after 7, 14 and 21 days and increase sporadically at 28 days curing. This poor initial compressive strength could be due to the fact that the time was too short to allow for reaction to take place in the laterite.

3.2 Effect of cement on compressive strength

The 7th, 14th, 21st and 28th curing days mean compressive strength values of compressed soil blocks stabilized with Portland cement at 5%, 10%, 15% and 20% replacement are shown in Figure 5.

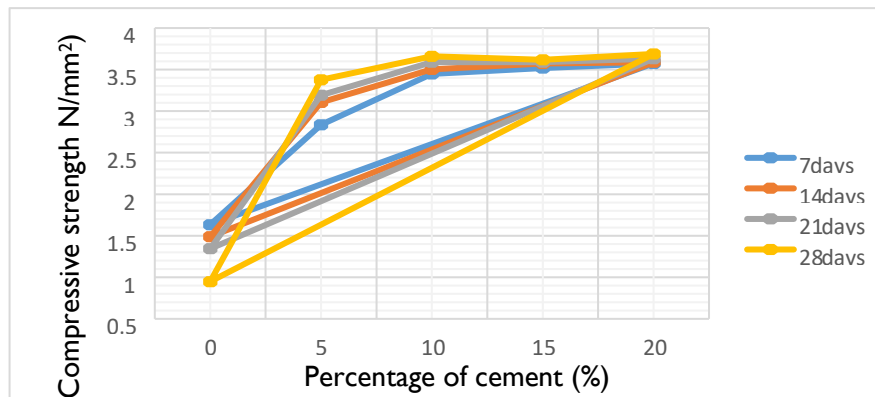


Figure 5: Variation of compressive strength with cement

From the trend in Figure 5, the compressive strength is seen to increase with curing age. Also, the compressive strength is seen to increase with increase in the cement replacement up to a peak compressive strength of 3.7 N/mm² from 0.9 N/mm² for the unstabilized laterite blocks after 28 days curing. This value is greater than the 2.0 N/mm² reported by Gonzalez-Lopez et al., 2017 and Taallah and Guettala, 2016.

3.3 Effect of 5% cement with various *B. coagulans* concentrations on the compressive strength of laterite blocks

The 7th, 14th, 21st and 28th curing days mean compressive strength values of compressed soil blocks stabilized with *B. coagulans* at 1.5×10^8 /ml, 6.0×10^8 /ml, 1.2×10^9 /ml, 1.8×10^9 /ml and 2.4×10^9 /ml *Bacillus coagulans* concentration and 5% cement are shown in Figure 6.

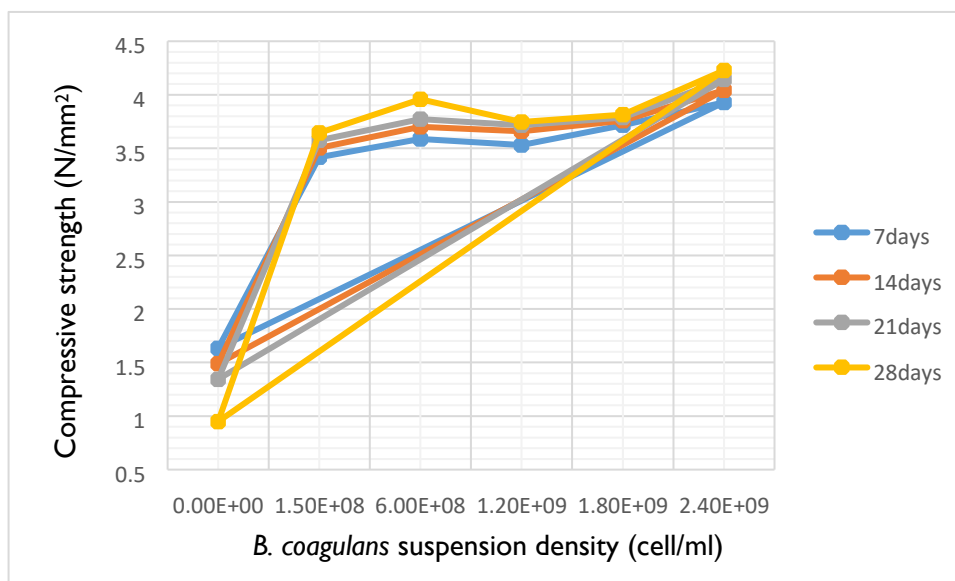


Figure 6: Variation of compressive strength with *B. coagulans* and 5% cement

From the trend in Figure 6, the compressive strength is seen to increase with curing age. Also, the compressive strength of the blocks is seen to increase from 0.9 N/mm² for the unstabilized

soil blocks to a peak compressive value of 4.2 N/mm² for 5% cement stabilized laterite blocks at 2.4 x 10⁹ cell/ml *B. coagulans* suspension density after 28 days curing.

4. Conclusion

Based on the results presented, the following can be concluded;

- i. The compressive strength increased with curing age for all the stabilized blocks with an average 28th day compressive strength of greater than 2.5 N/mm².
- ii. The compressive strength of the cement stabilized laterite blocks increased with increase in cement replacement.
- iii. The compressive strength increased with increasing *B. coagulans* suspension density for stabilized MICP laterite blocks.
- iv. 5% cement stabilized MICP laterite blocks performed better than cement stabilized laterite blocks at 20% cement replacement.
- iv. The optimum concentration of *Bacillus Coagulans* suspension of 2.4 x 10⁹ cell/ml and 5% cement at 28 days curing age, the compressive strength value of 4.2 N/mm² was achieved.

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