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

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ABSTRACT

This study investigates the strength and durability characteristics of molded laterite blocks stabilized with microbial-induced calcite precipitate (MICP) bacteria namely *Bacillus coagulans (B.coagulans*) and cement. The properties checked includes the water absorption and wet compressive strength of the laterite blocks tested at different curing ages of 7-, 14-, 21-, and 28 days by examining the impact of *B.coagulans* calcite precipitate, cement, and the combined effects of both on these properties. The *B.coagulans* bacteria having a 3g/l nutrient broth content served as the bio-calcination agent, while ordinary Portland cement acted as the stabilizer, 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 using the McFarland standards. From results obtained the water absorption properties shows improvement, decreasing from 32% for un-stabilized soil to optimal values of 15%, 9%, and 6% for MICP-stabilized, cement-stabilized, and MICP 5% cement-stabilized laterite blocks, respectively, at 28 days of curing. The wet compressive strength of un-stabilized soil ranges from 0.5 to 1.0 N/mm^2 for curing periods 7 to 28 days respectively which is lower than for the stabilized laterite blocks which were 1.99 N/mm^2 for 1.80E09 *cell/ml B.coagulans* suspension density and 3.7 N/mm^2 for 5% cement stabilized laterite blocks at 2.4E09 cell/ml *B. coagulans* suspension density after 28 days curing. Results obtained showed that the stabilized laterite blocks outperform the unstabilized blocks and therefore the cement-MICP combination used gave positive outcomes in stabilization of laterite blocks with a minimal percentage of 5% cement-stabilized MICP for sustainable building applications.

Keywords: *Bacillus coagulans*, Bio-calcination, Cement, Compressive strength, Laterite blocks

INTRODUCTION

The rapid growth of the world population has led to an unprecedented demand for housing, creating a pressing need for adequate shelter. Unfortunately, the global economic downturn has made it challenging for low- and middle-class individuals to attain homeownership, both in rural and urban areas. Consequently, there is an urgent requirement for research to assess the suitability, affordability, and sustainability of utilizing enhanced locally available materials, such as laterite soil, for civil infrastructure development.

Roads, buildings, and other man-made structures constitute significant consumers of the plentiful natural resources that could be used with ease and at a lower cost (Sitton *et.al*, 2018). The escalating demand for natural resources, surpassing the available supply in both developed and developing nations, underscores the necessity to explore more suitable and enhanced natural construction materials. As a response to the widespread failures of mud houses, particularly during the rainy season, one of the recommended solutions is the stabilization of lateritic soils used for constructing blocks. This approach aims to improve the durability and resilience of low-cost houses, addressing the challenges posed by the high demand for housing in the face of resource scarcity. The need to switch over from plain mud houses to houses built with Compressed Stabilized Lateritic Soils (CSLBs) becomes imperative as the Federal Government of Nigeria few years ago announced a plan "to do away with mud houses in a not-too-distant future" (Guardian Nigeria, 2016). Therefore, the investigation of superior alternative materials that fulfil the criteria of strength, cost-effectiveness, and durability is of paramount importance. Numerous recent studies have been conducted to explore various methods of stabilizing laterite, aiming to produce laterite blocks that are stronger, more durable, and economically viable. Most of such researches have looked into the use of cement as a stabilizer in laterite for blocks production (Chambua *et. al*, 2021; Tiboti *et. al*, 2021; Abdul Wahab *et. al*, 2021; Obianyo *et. al*, 2021; Fall *et. al*, 2021; Olopade *et.al*, 2022; Awolusi *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. Nevertheless, relying on cement as the primary stabilizer in lateritic soil for block production comes with its drawbacks, including cost implications and environmental concerns such as greenhouse gas emissions. According to (Suhendro, 2014), 8 to 10 percent of the world's total greenhouse gas emissions arise from cement manufacturing, contributing to global warming and climate change.

In the year 2019, the global buildings and construction sector claimed a substantial share of energy resources, amounting to 35% of the total global energy consumption. A noteworthy aspect of this environmental impact is that about 10% of these CO_2 emissions stemmed directly from the production processes involved in crafting building materials. These materials include fundamental components such as cement, steel, brick, and glass. Amidst these environmental apprehensions, the pursuit of sustainable alternatives gains paramount importance. One promising avenue is the utilization of microbially induced carbonate precipitation (MICP), which harnesses microbial metabolites to promote the precipitation of calcium carbonate (CaCO3) minerals , offers high process efficiency and versatility as well as low energy requirements and environmental impacts, and is widely regarded promising for engineering applications (Fu *et. al,* 2023).

In this innovative process, the metabolic activities of microorganisms trigger the precipitation of calcium carbonate minerals ($CaCO_3$) in the presence of urea and calcium ions. This phenomenon effectively binds soil particles together, offering a structurally sound alternative to conventional construction materials. By harnessing the inherent capabilities of microorganisms, MICP not only addresses environmental concerns but also aligns with principles of sustainability and nature-inspired design. Such advancements hold significant promise in reshaping the landscape of construction practices, steering them towards a more environmentally conscious and ecologically harmonious future. As society increasingly seeks to mitigate its carbon footprint and minimize environmental impact, embracing innovations like MICP could pave the way for a more sustainable built environment. The MICP which is an ecological soil enhancement method, can be carried out by the bacteria that mainly originated from the soil (Zhao *et. al*, 2014).

This practice leverages a biochemical process in the soil to enhance soil engineering properties. The use of this mechanism has also been found to be promising with positive results in different fields of civil engineering (Rowshanbakht *et. al,* 2016). The incorporation of additional cleaner cementitious materials for stabilizing laterite in block production represents a significant step in addressing environmental pollution concerns. Microbially induced calcite precipitation (MICP) stands out as one such supplementary cementitious material with the potential to contribute to environmentally friendly practices in construction.

A contemporary strategy for enhancing the Microbially Induced Calcite Precipitation (MICP) process focuses on isolating and characterizing ureolytic bacterial strains, notably *Bacillu*s *coagulans*, sourced from various natural habitats. These habitats encompass limestone caves, concrete specimens, indigenous soils, and activated sludge. Research indicates that certain bacteria derived from natural settings exhibit notable urease activity, offering promising applications in bio cementation (Montano Salazar *et. al*, 2018). Adobe has historically been the predominant building material in many countries, with a significant number of buildings, particularly in rural regions worldwide, being constructed from it. While traditional adobe buildings generally exhibit lower mechanical properties compared to those made from red clay bricks, certain adobe structures have withstood the test of time, enduring for millennia. This research delves into the longevity of these historical structures and investigates the presence of specific microorganisms as potential factors contributing to their durability. These microorganisms are then explored as suitable sources for screening in the context of enhancing the durability and longevity of adobe structures.

Recently, bacterially induced mineralization has emerged as a method to protect and reinforce deteriorating construction materials. In natural settings, structures are constructed and restored using locally available materials, often without significant energy consumption. This technology, referred to as Microbially Induced Calcium Carbonate Precipitation (MICCP), employs microbes to facilitate the deposition of calcium carbonate, also known as microbial concrete. This approach demonstrates effectiveness in tackling diverse durability issues encountered in construction materials. Leveraging the abundance of microorganisms in nature, there exists significant potential for the large-scale production of bacterial calcium carbonate crystals, calcite, or concrete. Unlike traditional cement, microorganisms have the capability to infiltrate and proliferate within soil or similar environments without causing disruption to the ground or surrounding areas. This innovative technology not only offers novelty but also aligns with environmentally friendly practices

MATERIALS AND METHODS

Materials

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

Laterite was collected from a borrow pit located at Shika, Giwa Local Government Area of Kaduna State (Latitude $11^0$18’0” N and $7^0$27’0” E) 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). The urease positive bacterial 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 p 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. The Cementation reagent used contains 3g of Nutrient broth, 20g of urea, 10g of NH_4C1, 2.12g of $NaHCO_3$ and 2.8g $CaC1_2$ per litre of distilled water in accordance with that described by (Stocks-Fischer *et. al,* 1999). The water used was potable obtained from Civil Engineering laboratory of Ahmadu Bello University, Zaria.

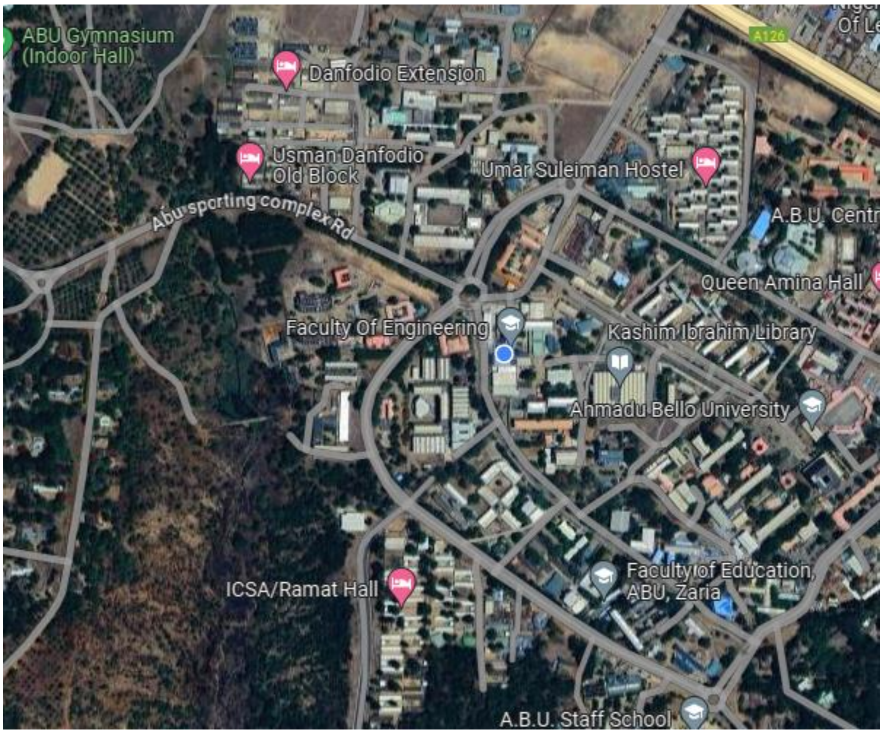

Plate 1: Map showing point of excavation of laterite sample

Methods

Mix Proportions for Cement, B. coagulans, cementitious reagent, laterite and water

Three different mix proportioning was used in this study. In the first mix, laterite was mixed with cement by replacement at 0%, 5%, 10%, 15% and 20% cement and mixed with water at optimum moisture content of the laterite as obtained during geotechnical investigation. 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.

Note

i. 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 using the McFarland standards.
ii. 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/m^3.

Table 1. Mix proportion for cement, *B. coagulans* and water in Laterite

Mix	Materials quantity (kg)				
	Laterite	Cement	*B. cogulans*	C.Reagent	Water
0% cement	5.03	0	0	0	0.57
5% cement	4.78	0.25	0	0	0.57
10% cement	4.53	0.50	0	0	0.57
15% cement	4.28	0.75	0	0	0.57
20% cement	4.02	1.00	0	0	0.57
0.00E+00	5.03	0	0	0	0
1.50E+08	5.03	0	0.13	0.39	0
6.00E+08	5.03	0	0.13	0.39	0
1.20E+09	5.03	0	0.13	0.39	0
1.80E+09	5.03	0	0.13	0.39	0
2.40E+09	5.03	0	0.13	0.393	0
0.00E+00	4.78	0.25	0.12	0.37	0
1.50E+08	4.78	0.25	0.12	0.37	0
6.00E+08	4.78	0.25	0.12	0.37	0
1.20E+09	4.78	0.25	0.12	0.37	0
1.80E+09	4.78	0.25	0.12	0.37	0
2.40E+09	4.78	0.25	0.12	0.37	0

Moulding of laterite blocks
The mix was compressed to fill the 230 x 110 x 100 mm moulds at the maximum dry density of the laterites to obtain solid blocks.

Wet compressive strength
The blocks, prepared according to the outlined procedure, underwent testing to determine their wet compressive strength and water absorption over various ageing periods, calculated from the preparation date in accordance with the procedure specified in IS: 3495 (Part 1)-1992. The wet compressive strength results represent the average of tests performed on five blocks for each ageing period. Prior to testing, the blocks were submerged in clean water for 48 hours. Following this immersion period, the blocks were taken out, their surfaces were dried by wiping, and then they were subjected to compressive strength testing using a Universal Testing Machine (UTM). The load was applied at a rate of 2 N/mm²/min. Plywood sheets, each 3 mm thick, were positioned on both faces of the blocks before applying the load.

Water absorption
Water absorption on CSEBs was carried out in accordance to IS: 3495 (Part 1)- 1992. The blocks were thoroughly dried in an oven kept at a temperature range of 105–115°C, and their mass was precisely recorded. Subsequently, the blocks were submerged in water for 24 hours. Following this immersion period, the blocks were reweighed to ascertain the increase in mass, allowing for the determination of water absorption.

RESULTS AND DISCUSSION
Effect of *B. Coagulans* on wet compressive strength
The 7-, 14-, 21- and 28- days mean wet compressive strength values of compressed laterite blocks stabilized with *B. coagulans* at 1.5 x 10^8/ml, 6.0 x 10^8/ml, 1.2 x 10^9/ml, 1.8 x 10^9/ml and 2.4 x 10^9/ml *Bacillus coagulans* suspension densities are shown in Figure 1.

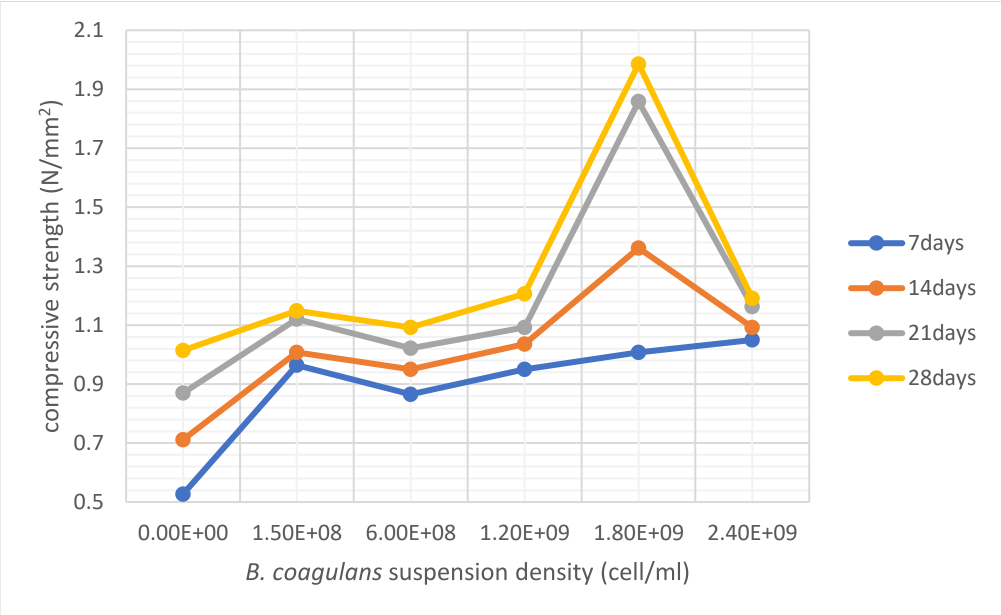

Figure 1: Variation of wet compressive strength with *B. coagulans*

Analyzing the trend in Figure 1, it is evident that the wet compressive strength exhibits an upward trajectory with an increase in the suspension density of *Bacillus coagulans*. For instance, the natural laterite blocks start at 0.5 N/mm^2 and show an increase to 1.99 N/mm^2 for laterite blocks induced with 1.8 x 10^9 cells/ml of *Bacillus coagulans* at 28 days of curing. Conversely, the wet compressive strength remains notably lower for unstabilized laterite, ranging from 0.5 N/mm^2 to 1.01 N/mm^2. This lower wet compressive strength suggests potential durability issues with blocks produced from natural laterite. However, the introduction of *Bacillus coagulans* results in an enhancement of wet compressive strength, reaching a peak value of 1.99 N/mm^2 at a suspension density of 1.8 x 109 cells/ml. The significant increase in strength compared to the control may be due to the calcite precipitate formed as *B. coagulans* produces the enzyme urease through its metabolic activity. This enzyme triggers the MICP biochemical reaction by hydrolyzing urea ($CO(NH_2)_2$). The resulting ammonium (NH_4^+) increases the pH, causing bicarbonate (HCO_3^-) to precipitate with calcium ions (Ca_2^+) from the supplied calcium chloride, thus forming calcium calcite. This is consistent with studies by Ramakrishnan *et. al.*, 2005 and Bang *et. al.*, 2010.

Effect of cement on wet compressive strength The 7th, 14th, 21st and 28th days mean wet compressive strength values of compressed soil blocks stabilized with Portland cement at 5%, 10%, 15% and 20% replacement are shown in Fig. 2.

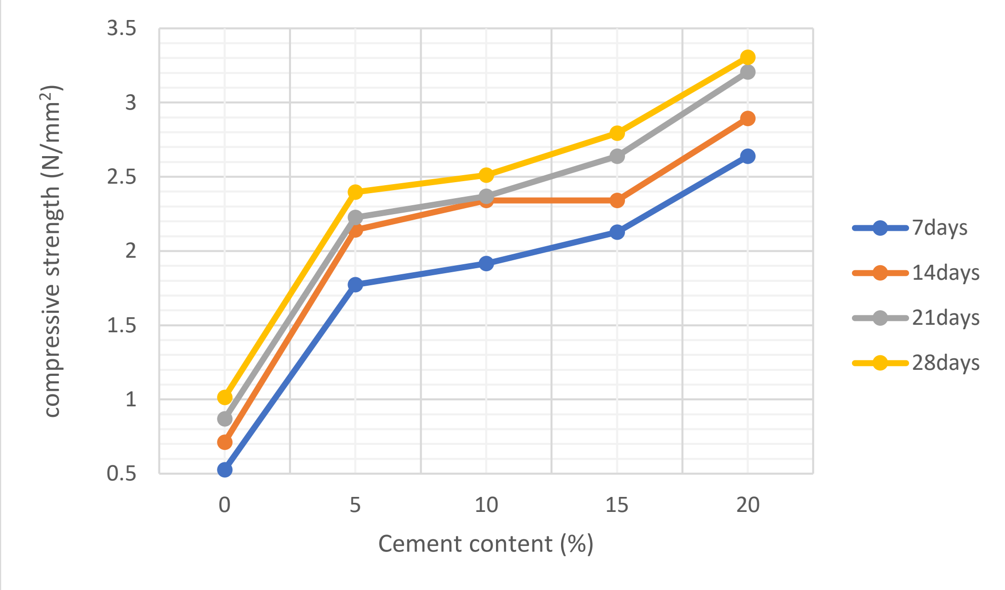

Figure 2: Variation of wet compressive strength with cement

From the trend in Figure 2, the wet compressive strength is seen to increase with curing age. Also, the wet compressive strength is seen to increase with increase in the cement replacement up to a peak compressive strength of 3.3 N/mm^2 from 0.5 N/mm^2 for the cement stabilized laterite blocks after 28 days curing. This value is greater than specified 2.5 N/mm^2 by the Nigerian industrial standards (SON, 2004) and 2.0 N/mm^2 in most literatures.

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

The 7-, 14-, 21- and 28 days mean compressive strength values of compressed soil blocks stabilized with *B. coagulans* at 1.5 x 10^8/ml, 6.0 x 10^8/ml, 1.2 x 10^9/ml, 1.8 x 10^9/ml and 2.4 x 10^9/ml *Bacillus coagulans* concentration and 5% cement are shown in Figure 3.

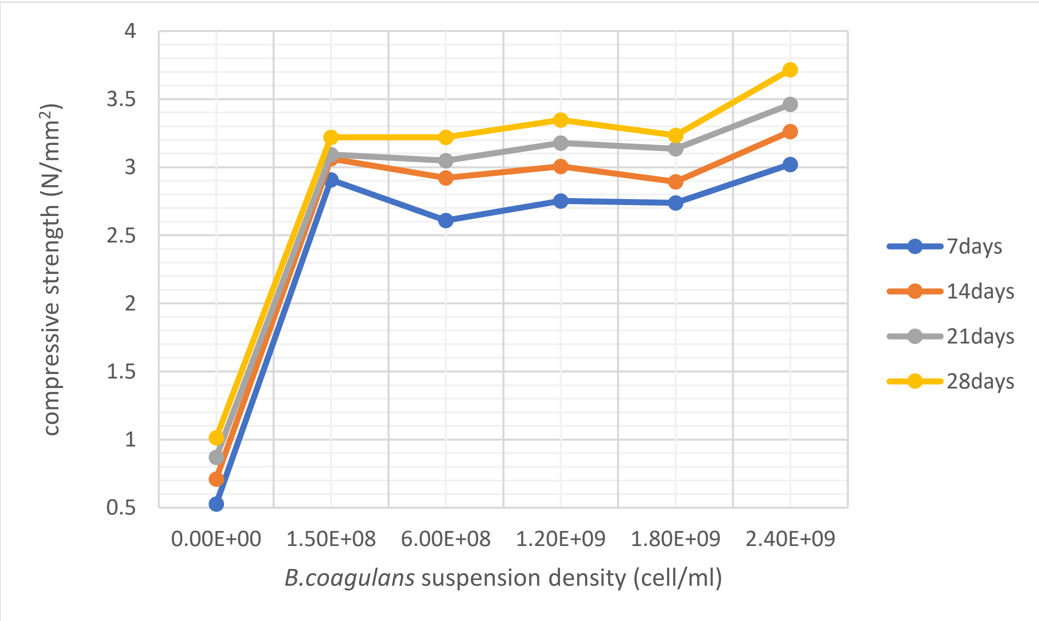

Figure 3: Variation of wet compressive strength with *B. coagulans* and 5% cement

From the trend in Figure 3, the wet compressive strength is seen to increase with curing age. Also, the compressive strength of the blocks is seen to increase from 0.5 N/mm^2 for the un-stabilized soil blocks to a peak wet compressive value of 3.7 N/mm^2 for 5% cement stabilized laterite blocks at 2.4 x 10^9 cell/ml *B. coagulans* suspension density after 28 days curing. This value is higher than the wet compressive strength of blocks stabilized using only 20% cement (i.e. without MICP).

Effect of *B. Coagulans* on water absorption

The 7th, 14th, 21st and 28th day's water absorption values of compressed soil blocks stabilized with *B. c*oagulans at 1.5 x 10^8/ml, 6.0 x 10^8/ml, 1.2 x 10^9/ml, and 1.8 x 10^9/ml and 2.4 x 10^9/ml *Bacillus coagulans* concentration are shown in Figure 4.

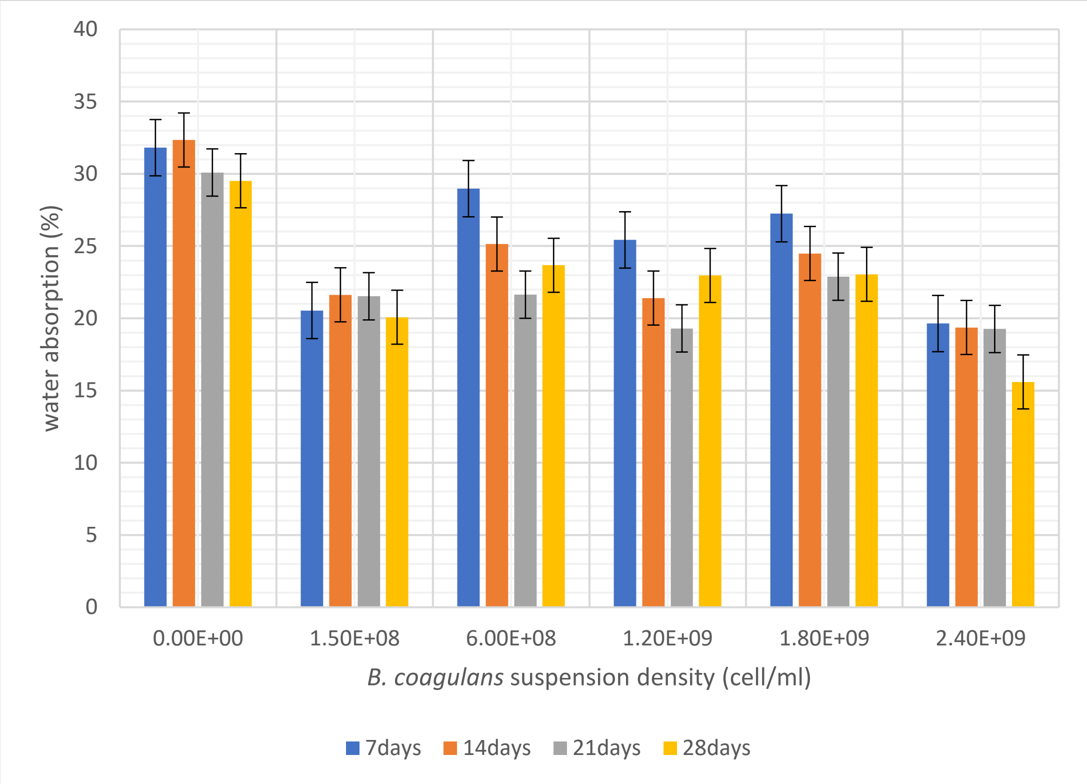

Figure 4: Variation of water absorption with *B. coagulans*

From the inclination in Figure 4, water absorption is seen to decrease with the introduction of *Bacillus coagulans* and curing age. The water absorption property of the block improved from 32% for the natural laterite blocks after 7days curing to 16% at 2.4 x 10^9 cell/ml *Bacillus coagulans* suspension density after curing for 28 days. However, despite the improvements recorded with the addition of *Bacillus coagulans*, the water absorption still does not meet the requirements of at most 12% specified by the Nigerian industrial standard (SON, 2004).

Effect of cement on water absorption

The 7-, 14-, 21- and 28 days water absorption values of compressed soil blocks stabilized with Portland cement at 5%, 10%, 15% and 20% replacement are shown in Figure 5.

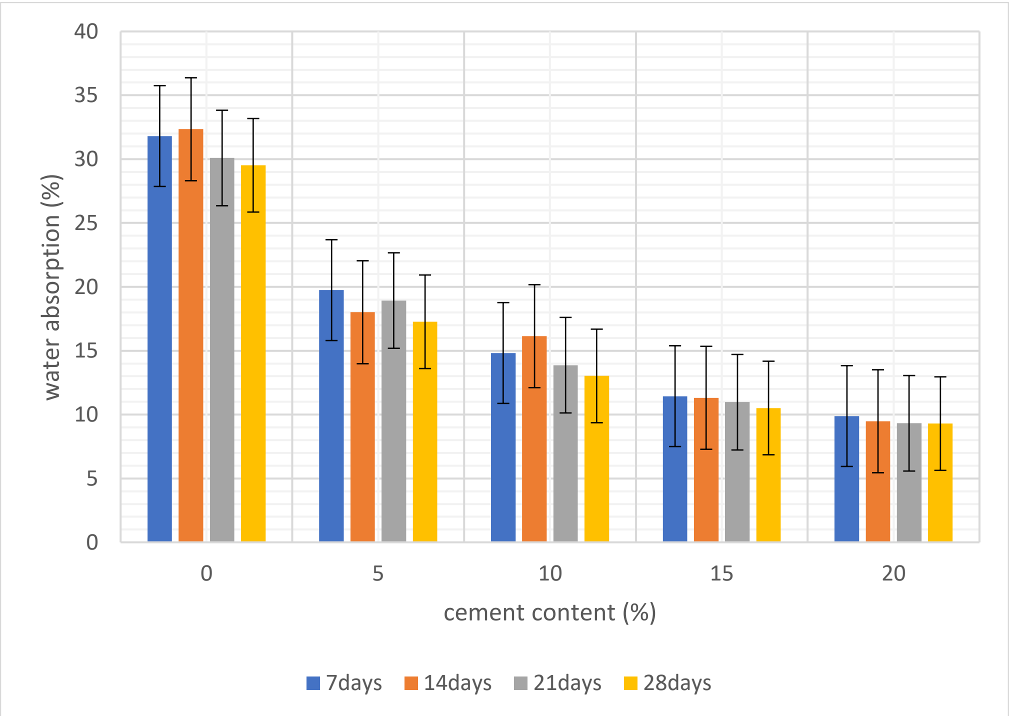

Figure 5: Variation of water absorption with cement

From the trend in Figure 5, the water absorption is seen to decrease with curing age. Also, the water absorption properties of the cement stabilized block are seen to improve with increase in the percentage of cement. The water absorption deceased from 32% for the un-stabilized soil blocks to 9% at 20% cement content and 28 days curing. This value is consistent with the 12% water absorption requirement for blocks as specified by the Nigerian industrial standard (SON, 2004).

Effect of 5% cement with various *B. coagulans* suspension densities on water absorption

The 7-, 14-, 21- and 28 days water absorption values of compressed soil blocks stabilized with *B. coagulans* at 1.5 x 10^8/ml, 6.0 x 10^8/ml, 1.2 x 10^9/ml, 1.8 x 10^9/ml and 2.4 x 10^9/ml *Bacillus coagulans* concentration and 5% cement are shown in Figure 6.

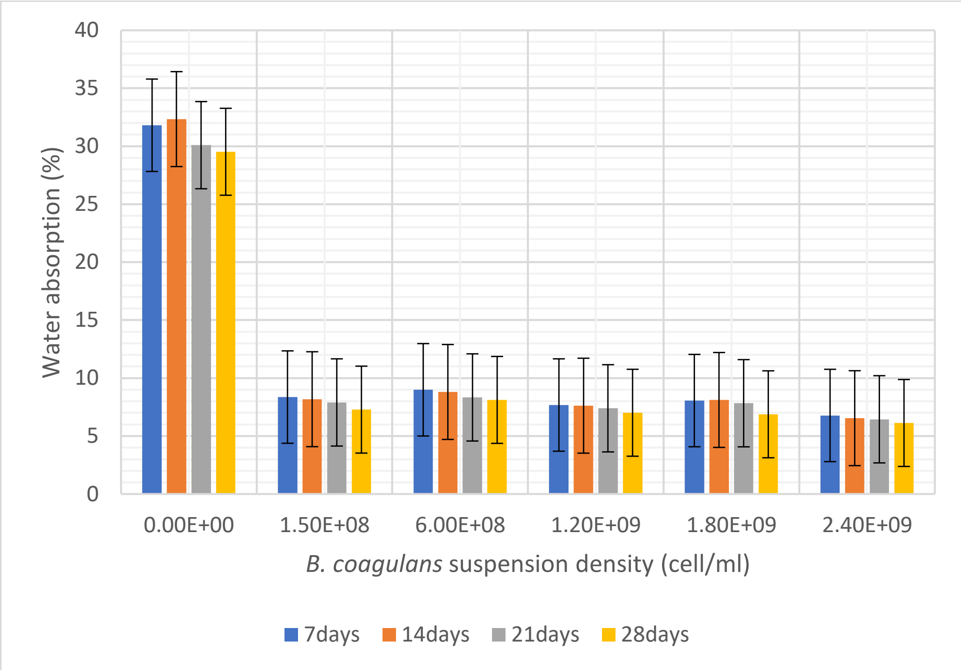

Figure 6: Variation of water absorption with *B. coagulans* and 5% cement

From the trend in Figure 6., the water absorption is seen to reduce with curing age for the MICP 5% CSLBs from 32% for the un-stabilized blocks to 6% for 5% cement stabilized laterite blocks at 2.4 x 10^9 cell/ml *B. coagulans* suspension density after 21- and 28-days curing. This value is in line with the Nigerian industrial standard (SON, 2004) requirement for water absorption of sandcrete blocks.

CONCLUSIONS

Based on the results presented, the following conclusions were drawn;

i. The wet compressive strength of laterite blocks stabilized with cement and *B.coagulans* suspension density individually improved more than the un-stabilized laterite blocks.
ii. Likewise, the wet compressive strength increased with increasing *B. coagulans* suspension density for the 5% cement stabilized MICP laterite blocks, with peak wet compressive strength at optimum content of 2.40E+09 cell/ml of *B.coagulans*.
iii. The water absorption of stabilized laterite blocks also increased with the treatment of laterite blocks with cement and *B.coagulan* suspension density individually.
iv. There was an improvement in the water absorption properties from 32 % for the un-stabilized laterite soil to an optimum water absorption value of 15%, 9% and 6% for MICP stabilized, cement stabilized and MICP/5% cement stabilized blocks respectively at 28 days curing.
v. Hence, the findings of this study confirm the potential of using lateritic soil stabilized with a minimal percentage of 5% cement-stabilized MICP for sustainable building applications

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