EFFECTS OF CURING TIME AND COMPACTIVE EFFORT ON UNCONFINED COMPRESSIVE STRENGTH TEST OF MICROBIAL INDUCED CALCITE PRECIPITATE TREATED LATERITIC SOIL

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Abstract: Unconfined compressive strength (UCS) of soil is usually affected by curing time (in days) and compactive effort. In order to determine the effect of curing days and compactive effort on microbial induced calcite precipitate (MICP) treated lateritic soil, the UCS of *Bacillus pumilus* (*B. pumilus*) microbial induced calcite precipitate treated lateritic soil were carried out at different curing days and different compactive effort. Lateritic soil was treated with stepped densities of *Bacillus pumilus* suspensions densities of 0 /mL (for natural soil), $1.5x10^8$ /mL, $6.0x10^8$ /mL, $12x10^8$ /mL, $18x10^8$ /mL and 24 $x10^8$ /mL, respectively and compacted with three compaction energies namely; British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). The treated soil samples were cured for 7, 28 and 56 days. The result shows an increase in UCS value with increase in *B. pumilus* suspension density and also with increase in compactive energy. The UCS values obtained showed an increase with curing days from 7 to 28 days curing but beyond 28 days curing period UCS value obtained were constant which indicates that MICP process has sustainability strength values even after long time curing which is an indication of a very good construction material. The peak UCS values were obtained at 1.8×10^9 cells/mL of *B. pumilus* suspension density for all compactive effort considered.

Keywords: *Bacillus pumilus*, compactive effort, curing time, lateritic soil

Introduction

Relatively green and sustainable soil improvement technique in recent years has been introduced which is termed Microbially Induced Calcite Precipitation (MICP). It involved the utilization of biochemical process in soil to improve their engineering properties which are strength and impermeability (Achal *et al.*, 2011).

MICP find natural treatments for soil by the combine knowledge from the interdisciplinary researches at the confluence of microbiology, geochemistry, and geotechnical engineering (DeJong *et al.*, 2010). MICP occurs in nature and it is a biological process. It is achieved by introducing in large quantity, population of urease-producing micro-organisms together with cementation reagents into the soil matrix, whereby a cement compound (Calcite) is generated to improve engineering properties of soil. The major advantage of the MICP is its environmental friendly nature whereby the urease producing micro organisms will cause a very little or no impairment to the soil in question, human health, and environment. Although, the idea of the MICP soil improvement technique is relatively young evolving technology pertaining MICP have been reported by many researchers like Baveye *et al*. (1998); Castainer *et al.* (1999); Ehrlich, (1999); Mitchell and Santamarina; (2005); Lian *et al.*, (2006); Ivanov and Chu, (2008); DeJong *et al*., (2010); Okwadha and Li, (2010); Harkes *et al.*, (2010); Lu *et al.*, (2010); Hanifi *et al.,* (2015). Most researches on MICP focused on the use of sand and little documented literature exist on the use of MICP on lateritic soil as a construction material, hence this research seems to investigate the effect of MICP on unconfined compressive strength of lateritic soil and also determine the long time effect of the MICP process.

Laterites, which are formed in tropical and sub-tropical regions of hot and humid climatic condition with heavy rainfall, warm temperature and good drainage according to Townsend (1985), are very rich in iron and aluminium and occur mostly as the capping of the hill. They therefore find extensive use in numerous construction activities such as subgrade material for road construction and brick production material (Goswani and Mahanta, 2007). They have also been proposed by Anderson and Hee (2000) for use as liner in the construction of landfill because they have low hydraulic conductivity. Similarly, they are categorised as natural resources of importance in geo-environmental applications (Gabas *et al.,* 2007; Frempong and Yanful, 2008) because of their adequate chemical resistance and low desiccation induced shrinkage potential (Osinubi and Nwaiwu, 2008). Most tropical laterites predominantly composed of kaolinite, non swelling, non expanding 1:1 clay mineral which are engineering materials (Osinubi *et al.,* 2009); some often contain swelling 2:1 clay mineral sand therefore constitute problematic engineering structures.

The aim of this study is to determine the effects of curing time and compactive effort on unconfined compressive strength test of microbial induced calcite precipitate treated lateritic soil.

Materials and Methods

Soil

The lateritic soil sample used in this study was collected by the method of disturbed sampling (Osinubi *et al.,* 2017) from an erosion site in Abagana (Lat. 6.186549° and Long. 6.980070°), Njikoka Local Government Area of Anambra state, South East Nigeria. The soil samples were collected at a depth of 1.5 m below the natural earth surface to minimize organic matter.

Microorganisms

B. pumilus which was identified in the Micro Biology laboratory of Ahmadu Bello University using the Microgen ID was used in this study.The bacteria were cultured in liquid media consisting of 3 g Nutrient Broth, 330 mM of urea, 186.7 mM of NH_4Cl, 25.3 mM of $NaHCO_3$ per litre of glass distilled water, with a pH measured at 9.7. Liquid media were sterilized by autoclaving for 20 minutes at 121°C. The bacterial cell densities were determined using McFarland Turbidity scale using 0, 0.5, 2, 4, 6 and 8 being equivalent to $1.5x10^8$ cells/mL, $6.0x10^8$ cells/mL, $12x10^8$ cells/mL, $18x10^8$ cells/mL and 24 $x10^8$ cells/mL, respectively (McFarland, 1907). The growth phase of the inoculating culture was controlled. The *B. pumilus* suspensions were prepared in stepped suspension densities of 0 cells/ml (which is the control), 1.5×10^8 cells/mL, 6.0×10^8 cells/mL, 12.0×10^8

cells/mL, 18.0 x 10^8 cells/mL and 24.0 x 10^8 cells/mL, respectively for the MICP treatment and was used in treating each soil sample.

Cementation reagents

Cementation reagents served as the raw materials for calcite formation in the MICP process. The cementation reagents that were employed in this study comprised 333 mM of urea ($CO(NH_2)_2$) and 25.2 mM of calcium chloride ($CaCl_2$). The cementation reagents also contained 3 g nutrient broth, 186.7 mM ammonium chloride (NH_4Cl), and 25.3 mM of sodium bicarbonate ($NaHCO_3$) per litre of deionized water which is an alkaline culture medium (Stocks-Fischer *et al.*, 1999; Stoner *et al.*, 2005; DeJong *et al.*, 2006; Qabany *et al.*, 2011).

Compaction

Each soil sample was compacted in the compaction mould using British Standard Light or standard Proctor (SP), West African Standard (WAS) and British Standard heavy (BSH) compaction energies in accordance with BS 1377 (1990) to determine the compaction characteristics (optimum moisture content and maximum dry density) of the natural soil.Soil samples were passed through 4.76 mm sieve. Soil samples were mixed with *B. pumilus* suspension density of 0, 1.5 x 10^8, 6.0 x 10^8, 1.2 x 10^9, 1.8 x 10^9 and 2.4 x 10^9 cells/mL at 25% of the natural optimum moisture content (OMC) of all compactive effort used while the remaining 75% was for the cementation reagent. Soil samples were allowed to air dry on trays before tests were carried out on them. Tests to determine the moisture–density relationships were carried out in accordance with BS 1377 (1990) for the three energy considered.

MICP treatment

The soil sample that were mix with 25% *B. pumilus* suspension density and 75% cementation reagent were compacted at the three compactive effort. Then the cementitious reagents were introduced by gravity into the pores of the soil matrix until they were relatively saturated. Saturation was ascertained by the cementitious reagent dripping from the bottom of the compaction mould and the applied reagent on the surface of the sample does not permeate into the soil. A series of compacted soil samples were repeatedly treated (one each) with different bacterial suspension densities (control; 1.5 x 10^8 cells per mL; etc.) every 6 hours for two days and the cementitious reagent with alkaline culture medium was injected into the soil to initiate the MICP process. Upon completion of the treatment, the soil specimen was used for unconfined compressive strength test.

Index properties

The index properties of the soil were determined in accordance to specifications outlined in BS, 1377 (1990). Soil passing through British Standard No. 40 sieve (425 µm aperture) was used to determine Atterberg limits consisting of liquid limit, plastic limit, plasticity index and the linear shrinkage was also determined.. The various *B. pumilus* suspension density was mixed at 25% of the natural liquid limit value while the cementation reagent was mixed at 75% of the same natural liquid limit value. The treated soil specimens were then air-dried at the laboratory temperature of 23 ±2°C, before being used to carry out the test. The soil samples were treated in *B. pumilus* suspension densities of 0, 1.5 x 10^8, 6.0 x 10^8, 1.2 x 10^9, 1.8 x 10^9 and 2.4 x 10^9.

Specific gravity

Dried treated soil samples mixed for index properties were used for the test in accordance to specification outlined in BS 1377 (1990).

Unconfined compressive strength

3 kg of air-dried soil sample was mixed with optimum moisture content derived from dynamic compaction of the soil sample. The conventional BS compaction mould was used. The sample was placed and compacted in the mould in three (3) layers and twenty-seven (27) blows of 2.5 kg rammer were given to each layer. The sample was then removed from the mould with aid of hydraulic jack and three samples of 38 by 76 mm were cored out and wrapped in a polythene bag for a minimum of 48 hours to allow for complete saturation. It was then taken to unconfined compression test machine for the test, where axial stress was applied gradually until shear failure occurred. Failure is taken to have occurred when two or three subsequent readings are equal or reducing in descending order.

The experiment was carried out with the addition of *B. pumilus* suspension density (cells/mL) of 0, 1.5x10^8, 6.0x10^8, 12x10^8, 18x10^8 and 24x10^8, respectively, following the same procedure and was repeated for WAS and BSH compactive efforts. The samples where cured for 7 days, 28 days and 56 days then the unconfined compressive strength was computed using eq. (1):

$$UCS\ (\delta) = PCr\frac{(100 - \varepsilon\%)\ x\ 10^3}{100Ao} \qquad (1)$$

Where:

ε = Strain sustained sequent to failure = x/L_0
x = Strain dial reading in mm
L_0 = Initial length of tested sample (m)
A_0 = Initial cross sectional area of tested sample (m^2)
P = Load proven ring reading sequent to failure (kN)
Cr = Compressive stress factor
δ = Compressive stress at strain ε (kN/m^2)

Results and Discussion

Oxide composition of lateritic soil

The results of X-Ray Fluorescence (XRF) carried out in Nigeria Geological Survey Laboratory Kaduna, Kaduna State to determine the oxide composition of lateritic soil is shown in Table 1. The silica – sesquioxide ratio of 1.65, which is between 1.33 and 2.00 classifies the natural material as lateritic soil in accordance with the specifications given by Joachin and Kandiah (1941).

Table 1: Oxide composition of lateritic soil

Oxide	Concentration %
SiO_2	56.50
Al_2O_3	19.00
CaO	0.33
TiO_2	2.89
V_2O_5	0.06
Cr_2O_3	0.05
Fe_2O_3	15.41
MnO	0.06
CuO	0.06
ZrO_2	0.29
L.O.I	4.54

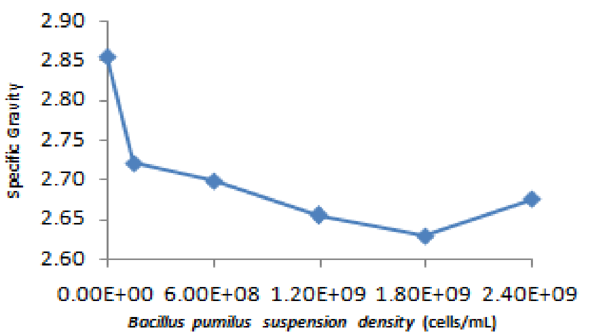

Fig. 1: Variation of the specific gravity of lateritic soil with *B. pumilus* suspension treatment

Specific gravity

The variation of specific gravity of lateritic soil with *B. pumilus* is shown in Fig. 1. Specific gravity value decreased from 2.86 for the natural lateritic soil to 2.63 at 1.8×10^9 cells/mL and thereafter increases to 2.68 at 2.4×10^9 cells/mL. The specific gravity of the soil generally decreased with increased *B. pumilus* suspension density.

This decrease may be caused by the calcites formed during the MICP process which caused the soil particles to be flocculated within the soil matrix and hence loosely parked particles. This result is similar to findings by Osinubi *et al.* (2017) and Osinubi *et al.* (2018).

Index properties

The index properties of the lateritic soil and treated lateritic soil are summarized in Table 2. The natural soil is reddish brown in colour and had 35.3% passing through BS sieve no. 200. It was classified as clayey sand (SC) under the USCS (ASTM, 1992) and A-4(0) under the AASHTO, system (AASHTO, 1986) with the dominant clay mineral being kaolinite.

Table 2: Index properties of the natural and treated lateritic soil

Property	***B. pumilus* (suspension density /mL)**					
	0	**1.5E8**	**6.0E8**	**12.0 E8**	**18.0E8**	**24.0E8**
Natural moisture content (%)	11.8					
Percentage Passing No. 200 Sieve (Wet Sieving)	35.3					
Liquid Limit (%)	36	35.4	35	34	35	35.5
Plastic Limit (%)	21.98	23.02	24.12	24.83	23.58	22.84
Plasticity Index (%)	14.02	12.38	10.88	9.17	11.42	12.66
Linear Shrinkage (%)	8.82	8.19	7.82	7.37	7.66	7.86
Specific Gravity	2.86	2.72	2.70	2.65	2.63	2.68
AASHTO classification	A – 4(0)	A – 4(0)	A – 4(0)	A – 4(0)	A – 4(0)	A-4(0)
USCS	SC	SC	SC	SC	SC	SC
Colour	Reddish brown					
Dominant Clay Mineral	Kaolinite					

Liquid limit

The effect of the *B. pumilus* treatment on the liquid limit of soil is shown in Figure 2. Liquid limit decreases from 36 to 34% at 1.2 x 10^9 cells/ml *B. pumilus* suspension density and thereafter increases to 35.5% at 2.4 x 10^9 cells/mL *B. pumilus* suspension density. This decrease may be as a result of the flocculation and agglomeration of the clay particles which occurred as a result of the production of calcites in the MICP process which in turn produced calcium ions which reacted with ions of lower valence in the clay structure. This result is contrary to reports by Osinubi *et al.* (2017) where it was reported that the liquid limit value rose with increase in *B. pumilus* treatment. However, similar studies (Portelinha *et al.*, 2012; Salahedim, 2013) which used cement to stabilize lateritic soil reported the effects of Ca^{2+} on the liquid limit of the clay soil, showed a decrease in the liquid limit value.

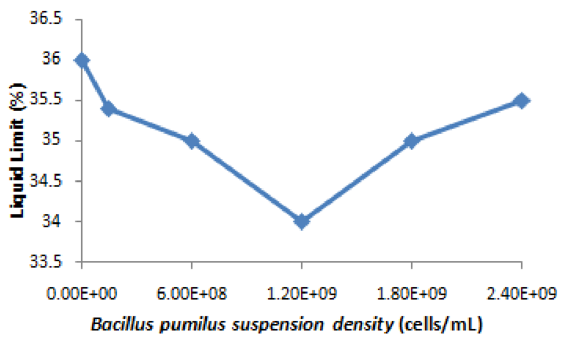

Fig. 2: Variation of the liquid limits of lateritic soil at various *B. pumilus* suspension density treatment

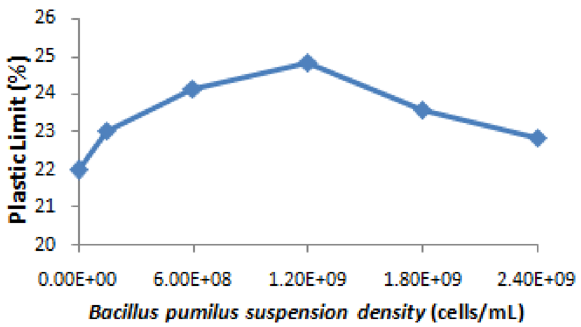

Fig. 3: Variation of the Plastic limits of lateritic soil at various *B. pumilus* suspension density treatment

Plastic limit

The effect of the *B. pumilus* suspension density treatment on the plastic limit is shown in Fig. 3. Plastic Limit increase from 21.98 to 24.83 % at 1.2 x10^9 cells/mL *B. pumilus* suspension density treatment and thereafter decreases to a value of 22.84% at 2.4 x10^9 *B. pumilus* suspension density. This increase may not be unconnected with the flocculation and agglomeration of the clay particles which occurred as a result of the production of calcites in the MICP process. This result is similar to findings by Osinubi *et al.* (2017) and Osinubi *et al.* (2018) where it was reported that the plastic limit value rose with increase in *B. pumilus* suspension density treatment on lateritic soil.

Plasticity index

The effect of the *B. pumilus* cells/ml treatment on the plasticity index of lateritic soil is shown in Fig. 4. Plasticity index value of 14.02% was recorded for the natural soil which dropped to a value of 9.17% at 1.2 x 10^9 cells/mL *B. pumilus* suspension density and thereafter increases to a value of 12.66% at 2.4 x 10^9 cells/mL *B. pumilus* suspension density. This finding is also in agreement with Osinubi *et al.* (2017) and Osinubi *et al.* (2018) where it was reported that the plasticity index value decreased with increase in *B. pumilus* suspension density treatment on lateritic soil. This is also as a result of the Calcites that were formed through the MICP process.

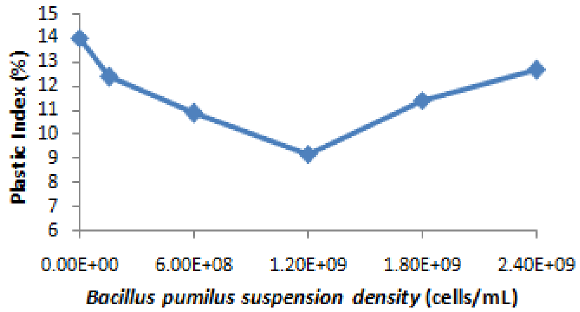

Fig. 4: Variation of the plasticity index of lateritic soil at various *B. pumilus* suspension density treatment

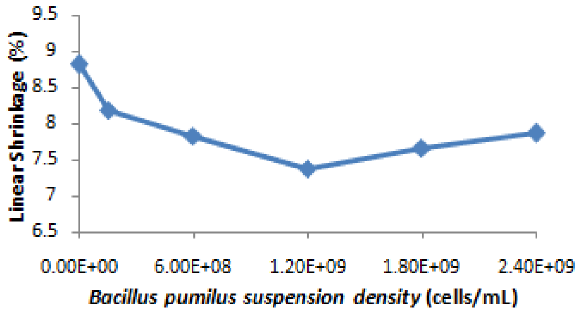

Fig. 5: Variation of the linear shrinkage of lateritic soil at various *B. pumilus* suspension density treatment

Linear shrinkage

The effect of the *B. pumilus* cells/ml treatment on the linear shrinkage of lateritic soil is shown in Fig. 5. The linear shrinkage decreased from 8.82% for the natural soil to 7.27% at 1.2 x10^9 cells/mL *B. Pumilus* suspension density and thereafter slightly increased to 7.86% at 2.4 x10^9 cells/ml *B. pumilus* suspension density. This finding is also in agreement with Osinubi *et al.* (2017) and Osinubi *et al.* (2018) where it was reported that the linear shrinkage value decreased with increase in *B. pumilus* suspension density treatment on lateritic soil. This is also as a result of the Calcites that were formed through the MICP process.

Generally, the properties of the lateritic soil were improved because of the calcite precipitate that was responsible for cementing and clogging the soil voids. These are similar to the findings reported by Miller and Azad (2002); Moses and Afolayan (2011), Amadi and Eberemu (2013); Salahudeen *et al.* (2014) who worked with other pozzolanic materials.

Compactions characteristics

Maximum dry density (MDD)

The variation of the MDD of MICP treated soil with *B. pumilus* suspension density for the three compactive efforts is shown in Figure 6. The MDD decreased with increasing *B. pumilus* suspension density for all compactive energies considered after an initial increase to 2 Mg/m^3 at 1.5 × 10^8 cells/ml of *B. pumilus* suspension density for BSL and increase to 2 Mg/m^3 and 2.05 Mg/m^{3}at 6.0 × 10^8 cells/mL of *B. pumilus* suspension density each for WAS and BSH respectively. The MDD decreased to 1.87 Mg/m^3, 1.86 Mg/m^3 and 1.98 Mg/m^3 for samples compacted at BSL, WAS and BSH respectively when treated with up to 2.4 × 10^9 cells/ml of *B. pumilus* suspension density. The reduction in MDD is probably due to the lower specific gravity values as the *B. pumilus* suspension density increased. Similar trend was also reported by Abo-El-Enein *et al*. (2012), Osinubi *et al.* (2017) and Osinubi *et al.* (2018).

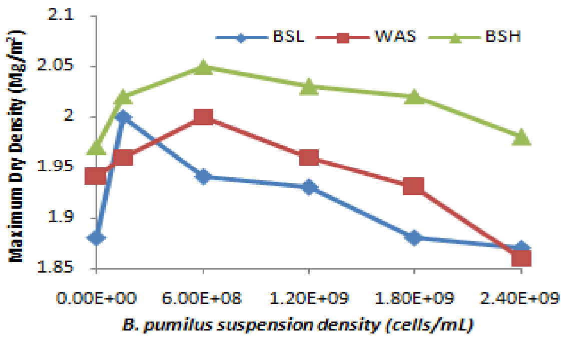

Fig. 6: variation of the MDD of the lateritic soil with *B. pumilus* suspension density treatment at different compactive effort

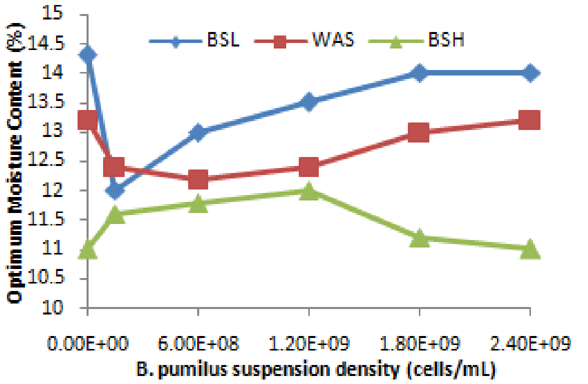

Fig. 7: Variation of the OMC of the lateritic soil with *B. pumilus* cells/ml suspension density treatment at different compactive effort

Optimum Moisture Content (OMC)

The variation of OMC with *B. pumilus* cells/ml at different compactive effort considered is shown in Fig. 7. The OMC increased to 14% and 13.2% at 2.4 × 10^9 cells/mL for both BSL and WAS compacted samples while the BSH compaction increases to 12% at 1.2 × 10^9 cells/mL and thereafter decreases. The OMC generally increased with increased *B. pumilus* suspension density treatment after an initial drop in the OMC value at 1.5 × 10^8 cells/ml for both BSL and BSH compaction. The increase in OMC recorded for all effort considered could be caused by the urease enzyme produced by *B. pumilus* that reacted with the cementation reagent to form larger surface areas that had greater affinity for water thereby leading to higher moisture content. This can also be attributed to the quantity of calcite that bridged the soil particles together by clogging of the pores spaces within the soil thereby allowing for more affinity of water hence absorption. Similar findings were reported by Abo-El-Enein *et al*., (2012), Osinubi *et al.*, (2017) and Osinubi *et al.*, (2018).

Unconfined compressive strength

7 Days curing period

The variation of unconfined compressive strength (UCS) with *B. pumilus* cells/ml at different compactive effort considered cured for 8 days is shown in Fig. 8.

The general trend of the UCS shows a general increase with increase in *B. pumilus* suspension density treatment for all compactive effort considered and it also shows that UCS value increases with increase in compactive effort with BSH compactive effort producing highest UCS for all treatment considered. The result indicates that higher UCS value obtained is a function of compactive effort and also the calcites precipitations that were formed through the MICP process. The UCS value of the natural soil cured for 7 days increases from a value of 678.45 to 917.76 kN/m^2 at 1.8 × 10^9

cells/mL of *B. pumilus* suspension density for BSL compactive effort, 719.57 to 1089.47 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for WAS compactive effort and from 963.70 to 1336.34 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for BSH compactive effort. At all compactive effort there was a drop in strength beyond 1.8 × 10^9 cells/mL of *B. pumilus* suspension density. This result is in consistent with the reports by Osinubi *et al.* (2017); Osinubi *et al.* (2019) and Osinubi *et al.* (2020).

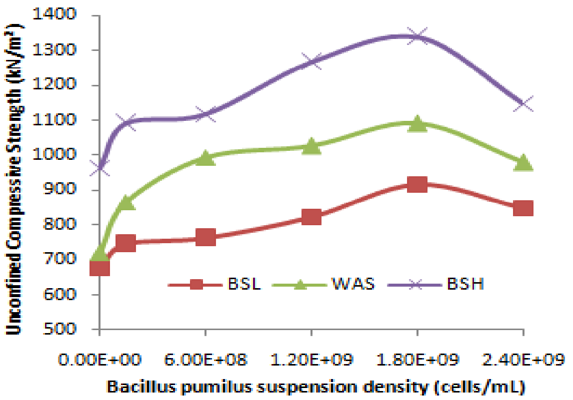

Fig. 8: Variation of unconfined compressive strength of the lateritic soil with *B. pumilus* cells/ml suspension density treatment at 7 days curing for different compactive effort

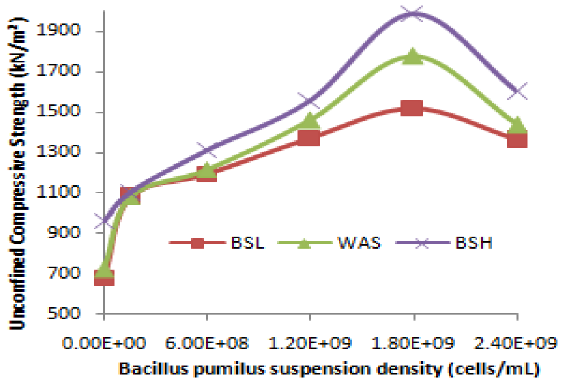

Fig. 9: variation of unconfined compressive strength of the lateritic soil with *B. pumilus* cells/ml suspension density treatment at 28 days curing for different compactive effort

28 Days curing period

The variation of unconfined compressive strength (UCS) with *B. pumilus* cells/ml at different compactive effort considered cured for 28 days is shown in Fig. 9. The general trend of the UCS cured for 28 days also shows a general increase with increase in *B. pumilus* suspension density treatment for all compactive effort considered to a peak value at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density.

The UCS values obtained also shows an increase with increase in compactive effort with BSH compactive effort producing highest UCS for all treatment considered. The result indicates that higher UCS value obtained is a function of compactive effort and also the calcites precipitations that were formed through the MICP process. The enzyme urease triggered the MICP biochemical reaction by hydrolyzing urea and the ammonium (NH_4^+) produced, increased the pH and caused the bicarbonate ions (HCO_3^-) to precipitate with calcium ion (Ca^{2+}) from the calcium chloride supplied to form calcium calcite ($CaCO_3$).

The calcite generated was responsible for binding soil particles and clogging the pores in the soil specimens. Bio-cementation is achieved when the calcite crystals precipitate on the surface or form bridges between the existing soil grains. These calcite crystals formed are responsible for the bond between the soil particles and forbid movement of its grains, and therefore improves the strength and stiffness properties of the soil (Harkes *et al.*, 2010; Mujah *et al.*, 2017; Osinubi *et al.*, 2019). The UCS value of the natural soil cured for 28 days increases from a value of 678.45 to 1519.15 kN/m^2 at 1.8 × 10^9 cells/ml of *B. pumilus* suspension density for BSL compactive effort, 719.57 to 1775.32 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for WAS compactive effort and from 963.70 to 1989.45 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for BSH compactive effort. At all compactive effort there was a drop in strength beyond 1.8 × 10^9 cells/mL of *B. pumilus* suspension density. This result is in consistent with the reports by Osinubi *et al.* (2017); Osinubi *et al.* (2019) and Osinubi *et al.* (2020).

56 Days curing period

The variation of unconfined compressive strength (UCS) with *B. pumilus* cells/ml at different compactive effort considered cured for 56 days is shown in Fig. 10. The general trend of the UCS cured for 56 are similar to those at 28 days curing but same UCS values are obtained as those cured for 28 days.

This indicates that beyond 28 days curing no more gain strength but there is no reduction in the strength value. This shows that MICP process has sustainability strength values even after long time curing which is an indication of a very good construction material.

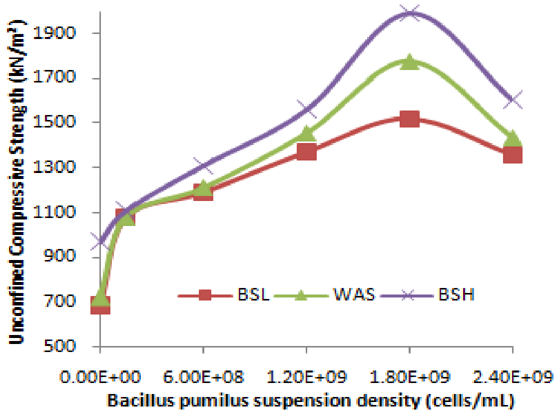

Fig. 10: Variation of unconfined compressive strength of the lateritic soil with *B. pumilus* cells/ml suspension density treatment at 56 days curing for different compactive effort

The UCS value of the natural soil cured for 56 days increases from a value of 678.45 to 1519.15 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for BSL compactive effort, 719.57 to 1775.32 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for WAS compactive effort and from 963.70 kN/m^2 to 1989.45 kN/m^2 at 1.8 × 10^9 cells/mL of *B. pumilus* suspension density for BSH compactive effort. At all compactive effort there was a drop in strength beyond 1.8 × 10^9 cells/mL of *B. pumilus* suspension density. This result is in consistent with the reports by Osinubi *et al.*, (2017); Osinubi *et al.*, (2019) and Osinubi *et al.*, (2020).

Conclusion
Based on the results of the study todetermine the effects of curing time and compactive effort on unconfined compressive strength test of microbial induced calcite precipitate treated lateritic soil, it can be concluded that:

1. The liquid limit, plasticity index and linear shrinkage decreases with increase in *B. pumilus* suspension density to a minimum value of 34 %, 9.17 % and 7.27 % respectively at 1.2 x10^9 cells/mL *B. pumilus* suspension density. The plastic limit on the other hand increases with increase in *B. pumilus* suspension density to a maximum value of 24.83 at 1.2 x x10^9cells/mL *B. pumilus* suspension density.
2. The compaction characteristic shows that the maximum dry density decreases with increase in *B. pumilus* suspension density after an initial increase but higher MDD were recorded at BSH compaction energy. The optimum moisture content (OMC) on the other hand increases with increase in *B. pumilus* suspension density after an initial decrease except the sample compacted with BSH that reduces after 1.2×10^9 cells/mL *B. pumilus* suspension density. BSL compaction gave a higher OMC while BSH compaction gave a lower OMC values.
3. The UCS test result shows an increase with increase in *B. pumilus* suspension density and also with increase in compactive energy.
4. The UCS values obtained shows an increase with curing days i.e. value increase between 7 days curing and 28 days curing but beyond 28 days curing period UCS value obtained were constant.
5. The UCS result also shows that long time curing (beyond 28 days) do not increase the UCS value and the value do not decreases either which indicates that MICP process has sustainability strength values even after long time curing which is an indication of a very good construction material.
6. The peak UCS values were obtained at 1.8×10^9 cells/ml of *B. pumilus* suspension density for all compactive effort considered and all curing days considered.

Conflict of Interest
Authors have declared that there is no conflict of interest reported in this work.

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