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Effect of Bacterial Bio-Calcination on the Strength and Durability of Cement Mortar

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Abstract

This work investigated the effect of growth media on the strength development and microstructure of cement mortar. The bacterium called Bacillus Coagulans was incorporated at different cell concentrations of $1.5x10^8$, $6.0x10^8$ and $1.2x10^9$ suspension density with varying percentage replacement of Nutrient Broth Medium (NBM) at 30%, 40% and 50% and mixing water to the dry mix of cement and sand (fine aggregate). Mix ratio of 1:3 was used with water cement (w/c) ratio of 0.5. To establish the objective of gain in strength, mortar cubes were tested at 3, 7, 14 and 28 curing duration and the results compared with controlled cement mortar. Compressive strength obtained for control cement mortar was $24.08N/mm^2$ and optimal bio-cement mortar was $28.02N/mm^2$ at 28days curing age was achieved with the addition of $1.5x10^8$B. Coagulans suspension density with 50% NBM. The strength improvement is due to the growth of calcite crystals within the pores of the cement sand matrix as indicated from the microstructure obtained from Scanning Electron Microscopy (SEM) examination. It also indicates 3.46% improvement of water absorption at 28days for $1.5x10^8$ B. Coagulans suspension density with 50% NBM as against 5.98% water absorption at 28days curing age for control.

1. Introduction

Today, due to increase in population and urbanization, the need to provide safe and environmentally friendly structures have become a necessity. Concrete is widely used as construction material around the world because of its resistance, durability and low cost in comparison with other construction material [1, 2]. Cement is one of the most important components of the concrete, which provides properties of compaction. Modernization and industrialization have increased the demand for cement and the world attention has been focused on environmental preservation due to the alarming depletion of ozone layer as a result of pollution resulting from manufacturing processes. Cement production accounts for about 5-7% of global Carbon dioxide (CO_2) emission [3]. As demand for supplementary cementitious materials is increasing day by day, it is very important to find a suitable technology to ensure the improvement of properties of structures.

Bio-cement a recently discovered novel product of bio-mineralization based microbial induced calcite precipitation (MICP) process, is widely used to improve the durability of concrete [4]. To date, several studies have demonstrated the positive influence of microbial compounds on cement mortar and concrete properties. The MICP process is an effective and eco-friendly technology that can be applied to solve various environmental problems [5, 6, 7, 8, 9, 10, 11, 12]. MICP refers to the formation of calcium carbonate from a super saturated solution due to the presence of their microbial cells and biochemical activities [13]. Calcium carbonate is one of the most well know mineral that bacteria deposit by the phenomenon called bio-cementation or MICP. Such deposits have recently emerged as promising binders for protecting and consolidating various building materials [14]. It should be noted that bacteria have been in existence, however many of their biotechnological applications are not yet widespread [15]. Although most researchers are concerned in the calcite precipitation and the process is not yet clear and defined. The effect of multi-component growth media, containing germination and sporulation aids for the bacteria aerobic oxidation pathway, on the basic properties of fresh and hardened cement mortar instead of the potential self-healing efficiency in a structural service was investigated by [16] and also [17] altered the chemical dosage proportions of the nutrient growth medium to achieve early strength in concrete.

NUB enhance the germination of bacterial cells, sporulation of bacteria and precipitation of calcite within the pores of the cement-sand matrix, which typically consist of calcium, carbon and nitrogen sources. Thus, in this study, the microbially induced calcite precipitation process is utilized in cement mortar to improve its compressive strength.

2.0. Materials and Methods

2.1 Materials

2.1.1 Microorganism

In order to stimulate calcite mineralization, which is a by-product of microbial metabolic activity, a urease producing bacteria was used to induce the calcite precipitate. This MICP process is known as Urea Hydrolysis. The bacteria specie used for the study was *Bacillus Coagulans.* It is classified as ATCC 7050 in the American Type Culture Collection, endospore-forming (spore is formed within the cell) bacteria, it is a Gram-positive rod-shaped bacterium, grows optimally at 37°C and pH in the range 5.5 to 6.2. It is obtained from the Department of Microbiology laboratory Ahmadu Bello University, Zaria which was isolated from lateritic soil.

2.1.2 Nutrient Broth Growth Medium

The growth medium was prepared using a mixture of chemicals at varying proportions which is based on initial microbiological studies [18]. Chemical used include the following per liter of distilled water: 3g of nutrient broth (Bacto); 20g of urea; 10g of NH_4Cl and 2.12g (equivalent to 25.2mM) of $NaHCO_3$.

2.1.3 Cement and Sand

The cement used in this research work was 42.5N Portland Limestone Cement conforming to BS EN [19]. Locally available clean, well graded, natural river sand having fineness modulus of 2.76 and nominal maximum size of 5mm was used conforming to BS EN [20].

2.2 Method

2.2.1 Preparation of Microbial cement mortar

The mortar was prepared using cement sand ratio of 1:3 by weight. On 76mm cubic molds were prepared. Cement and sand were thoroughly mixed, adding along with grown culture at w/c ratio of 0.5 of different cells concentration of *B. Coagulans* corresponding to 1.5×10^8cells/ml, 6.0×10^8cells/ml and 1.2×10^9cells/ml, which the nutrient growth medium was also added at varying percentage (%) replacement of w/c ratio (30%, 40% & 50%). Cubes were cast and compacted using rammer. After demolding all specimens were cured until compressive strength at the intervals of 3, 7, 14 and 28 days. Control specimens were also prepared in similar way.

2.2.2. Compressive Strength

Compressive strength test was carried out on harden cement mortar and bio-cement mortar in accordance to BS EN [20]. The compressive strength test was conducted on cubes of 76mm×76mm×76mm mixed mortar using the compressive testing machine (Denison) at the concrete laboratory of A.B.U, Zaria. The failure load was observed and recorded and the compressive strength in N/mm^2 was calculated from Equation (1.0).

For mortar $$Rc = \frac{Fc}{76 \times 76} \quad (1.0)$$

Where, R_C is the compressive strength in newton per millimeters square, F_C is the maximum load at fracture, in newton and 76 x 76 is the area of the platens or auxiliary plates in square millimeters

2.2.3 Water Absorption

Water absorption test is carried out to determine the water absorption value of mortar, expressed in percentage. This property is particularly important in concrete used for water-retaining structure or watertight basement, as well as being critical for durability. This test was performed on 50mm x 50mm x 50mm cube specimens prepared in the laboratory. Water absorption measurements were done by weighing the saturated specimens (W_s) and dried specimens in oven at 110ºC for 24h (W_d) at curing times of 3, 7, 14 and 28 days.

The water absorption was calculated from Equation (2.0)

$$\text{Water absorption (\%)} = \left(\frac{W_s - W_d}{W_d}\right) \times 100 \quad (2.0)$$

2.2.4 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) has become an important tool for study of microstructures, hydration progress and structural morphology. This test was conducted to determine the microstructure of the sample and to examine it matrices. The mortar cubes considered for the test were control cement mortar cube for 28 days curing period and optimal bio-cement mortar cube for 28 days curing period. Which was conducted at the multipurpose laboratory of Umaru Musa Yar'adua University Katsina State using SEM with serial number MVE015707775 and model number 800-07334 (Phenom World made in the Netherlands).

3.0. Results and Discussion

3.1 Compressive Strength

The compressive strength results of the control cement mortar and the bio-cement mortar mixtures containing bacterial are shown in Fig. 1, 2 and 3. At 28 curing age, the compressive strength of the control cement mortar mixture was 24.08 N/mm^2, whereas that of the cement mortar mixtures for 1.5x10^{8}cells/ml are 24.53, 25.57 and 28.02 N/mm^2 respectively with varying proportioning of Nutrient Broth Medium (NBM) of 30% NBM, 40% NBM and 50% NBM. At 28 curing age, the compressive strength results of cement mortar mixtures of 30% NBM, 40% NBM and 50% NBM for 6.0x10^{8}cells/ml are 24.14, 24.18 and 25.33 N/mm^2 and that of 30% NBM, 40% NBM and 50% NBM for 1.2x10^{9}cells/ml are 24.21, 24.35 and 25.05 N/mm^2 respectively. The optimal compressive strength of 28.02N/mm^2 was obtained for 1.5x10^{8}cells/ml with 50% NBM.

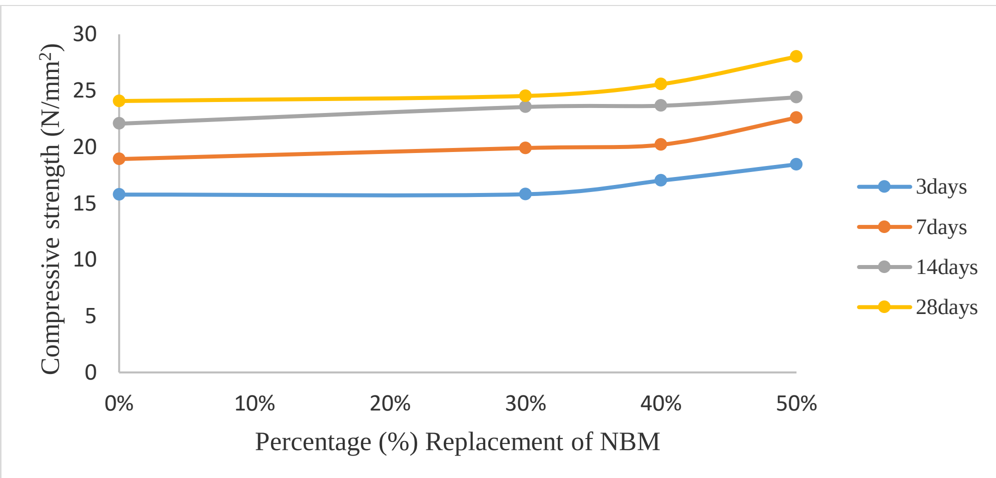

Fig. 1: Variation of Compressive Strength with NBM for 1.5x10^{8}cells/ml *B. Coagulans* Suspension density.

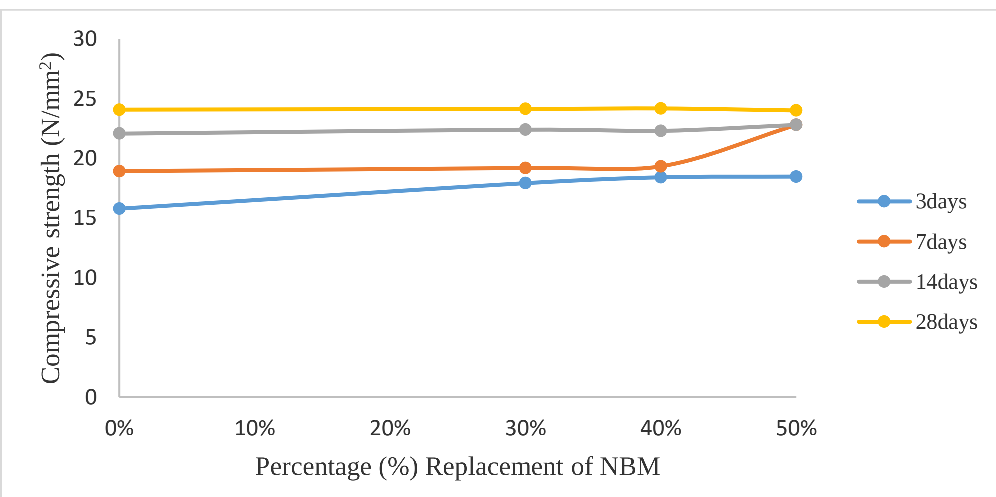

Fig. 2: Variation of Compressive Strength with NBM for 6.0x10^{8}cells/ml *B. Coagulans* Suspension density.

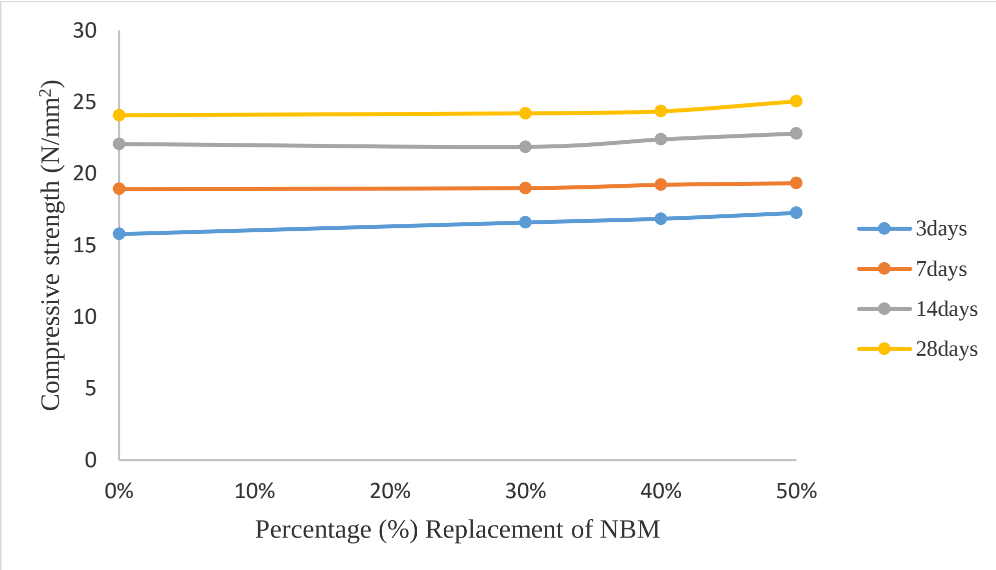

Fig. 3: Variation of Compressive Strength with NBM for 1.2x10^{9}cells/ml *B. Coagulans* Suspension density

From the result shown in Fig. 1, 2 & 3 above, the compressive strength increases as curing age progresses, this is as a result of the specimens mixed with bacterial cells and might be attributed to the behavior of microbial cells within the cement mortar matrix and also the strength increases with percentage increment of NBM. This study is in agreement with the result reported [11, 16]. As genre *Bacillus*, such as *Sporosarcina pasteurii*, *B. Subtilis and B. Cereus* has been most commonly used in research studies because of their ability to precipitate calcium carbonate in calcite form which makes them suitable to use for strength improvement in cement mortar and concrete [5, 21, 22].

3.2 Water Absorption

The results shown in Fig. 4, 5 and 6 illustrates that the water absorption of cement mortar with or without bacterial cells decreases with time of curing up to 28 days, this is due to the continuous hydration and accumulation of hydrated products which fill the open pores of the specimens. Also, the water absorption values of cement mortar specimens mixed with bacterial cells at 1.5x10^{8}cells/ml, 6.0x10^{8}cells/ml and 1.2x10^{9}cells/ml are lower than those of control specimens. This is attributed to that bacterial biomass and microbial calcite precipitation within the pores and on the surface of cement mortar and also percentage replacement of the NBM with curing days had effect on the water absorption, compared to the control at either age. However, the improvement is attributed to the nitrogen and carbon source in the growth medium which permit the germination of bacterial spores, growth of bacterial cells, precipitation of calcite and sporulation of bacteria as seen in similar study [16].

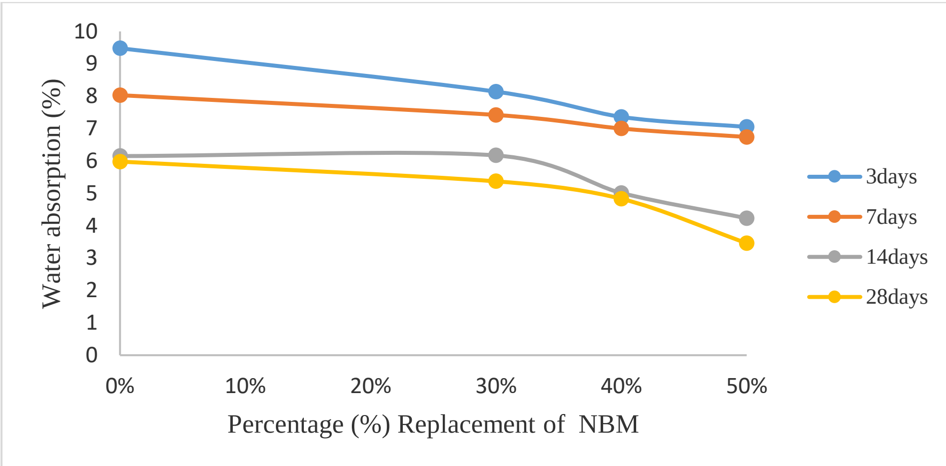

Fig. 4: Variation of Water absorption with NBM for 1.5x10^8cells/ml *B. Coagulans* Suspension density

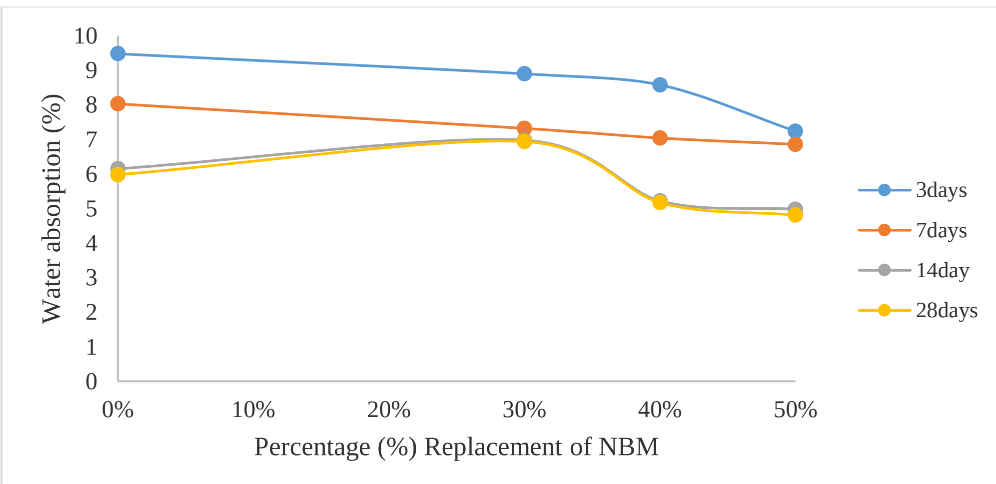

Fig. 5: Variation of Water absorption with NBM for 6.0x10^8cells/ml *B. Coagulans* Suspension density.

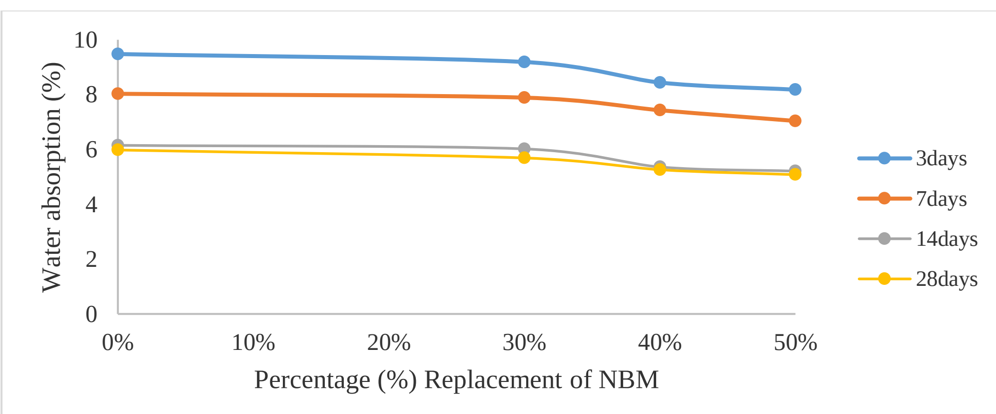

Fig. 6: Variation of Water absorption with NBM for 1.2x10^9cells/ml *B. Coagulans* Suspension density.

3.3 Scanning Electronic Microscopy (SEM)

To determine whether the increase in compressive strength of the specimens prepared with bacteria could be attributed to the microbial calcite precipitation, the mortar samples were taken off and examined under SEM. Plate 1 is a scanning electron micrograph of the matrix of bacteria-free cement mortar while Plate 2 shows micrographs of the specimen prepared with *Bacillus Coagulans*. The sample showed calcite crystals grown all over and precipitated.

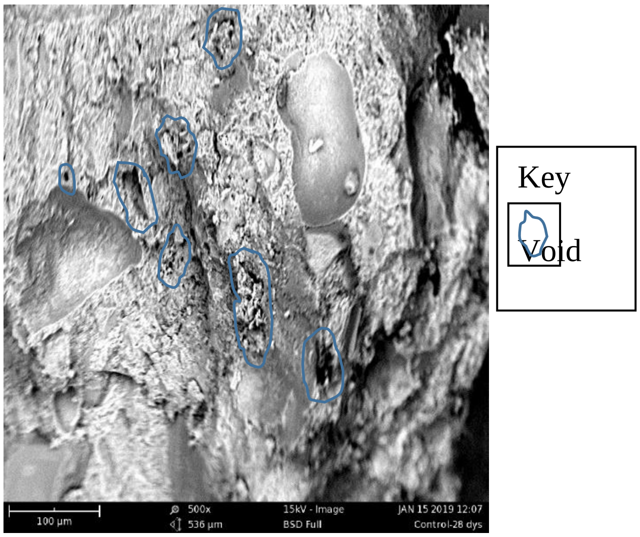

Plate 1: Cement Mortar at 28 days (Control)

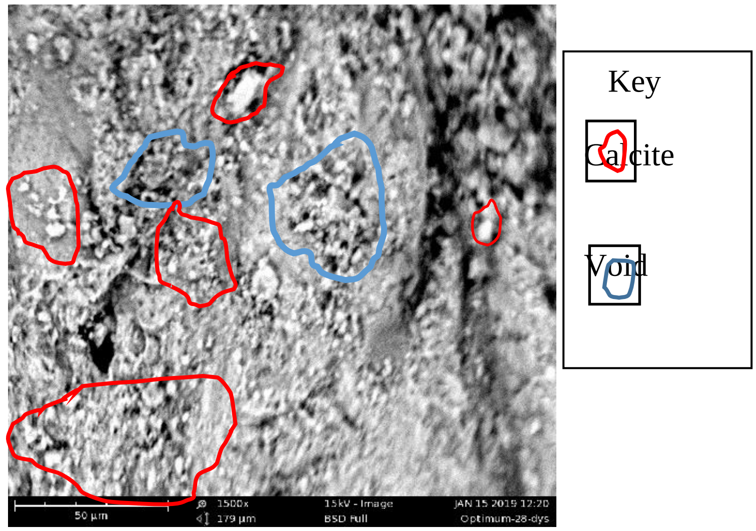

Plate 2: Optimal Bio-Cement mortar

4.0. Conclusion

Based on the result of the study, it is concluded that the compressive strength of the bacteria modified cement mortar were improved due to the deposition of the calcite by the bacterial activity. The compressive strength increases with concentration of bacterial cells while a decrease in strength improvement was observed when cement mortar mixed with 6.0×10^8cells/ml and 1.2×10^9cells/ml. The addition of bacterial cells with increment of the Nutrient Broth growth Media (NBM) to the cement mortar improves the compressive strength of the mortar with respect to control. Therefore, the optimum bacterial cells concentration which leads to the highest improvement in cement mortar gives higher compressive strength of 28.02N/mm^2 at 28days is 1.5×10^8cells/ml with 50% growth media. The compressive strength of the bacteria modified cement mortar were improved due to the deposition of the calcite within the pores of the cement-sand matrix as indicated from the microstructure obtained from scanning electron microscopy (SEM) examination. Based on the result of the study, it is concluded that the water absorption of the bacteria modified cement mortar were improved due to the deposition of the calcite by the bacterial activity. The water absorption decreases with concentration of bacterial cells while an increase in water absorption improvement was observed when cement mortar mixed with 6.0×10^8cells/ml and 1.2×10^9cells/ml. The addition of bacterial cells with increment of the Nutrient Broth growth Media (NBM) to the cement mortar improves the water absorption of the mortar with respect to control. Therefore, the optimum bacterial cells concentration which leads to the highest improvement in cement mortar gives lower water absorption of 3.46% at 28days is $1.5x10^8$cells/ml with 50% growth media.

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