

Experimental Characterization of Bacterial Concrete Against Mechanical and Durability Performance

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Abstract—This study experimentally investigates the mechanical and durability performance of bacteria concrete in terms of density, compressive strength, split tensile strength, and water absorption capacity. The concrete specimens were produced with a ratio of 1:2:4, w/c ratio of 0.45, and having a bacteria dosage level ranging from 1 to 6% by weight of water. To investigate the usefulness of the bacteria dosage level, cubic and cylindrical specimens were cast and tested after 28 days of water curing in a Universal Testing Machine with a constant loading rate. The density of each specimen was also recorded soon after casting and after the curing period ended. Moreover, the water absorption test was similarly conducted on cube specimens at various time intervals to record the penetration depth. The test results of normal concrete (without bacteria) were compared with the ones of the specimens containing bacteria. The optimum level of bacteria was found to be 3.5%, which showed the highest values in terms of compressive strength, split tensile strength, and density. Bacteria tend to generate more crystalline materials inside the concrete mass due to reactions with the surrounding moisture which produces a compact surface, thus strength properties were improved and water penetration was blocked which suggests better durability of the concrete.

Keywords—bacteria; curing; compressive strength; tensile strength; density; water absorption

I. INTRODUCTION

Concrete is commonly used in almost every kind of construction, but, apart from its many advantages, it has some limitations. Due to its weak tensile ability, it is less resistant to early-age cracking and has low durability. Various researches have been conducted to control such kind of deficiencies in concrete and make it more sustainable [1-7]. The research in the field of solid innovation has shown extraordinary advancements in concrete with regard to the amount of time of

development, the quality of cement, the toughness of cement, and the mixture with natural materials such as fly debris, impact heater slag, silica smolder, metakaolin, etc. Microbial mineral precipitation has been proposed due to the metabolic reaction of microbes in concrete enhancing the general conduct of cement. Frequently bacterial reactions trigger an adjustment in the arrangement science that prompts over immersion and mineral precipitation [6], while the behavior of concrete produced from bacteria was enhanced because of inorganic sleet generated from metabolic activities of auspicious microbes in concrete. These kinds of reactions may occur on the inner or the outer side of the microbial cell or even some distance away within the concrete. Bacterial actions also merely cause a variation in solution chemistry that leads to over-saturation and precipitation of minerals. Bacterial concrete came into existence because of the use of bio mineralogy perceptions in concrete [8, 9].

Various studies have been conducted to investigate the performance of concrete with embodied bacteria. The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of calcium carbonate in a calcium-rich environment. Through this process, the bacterial cell is coated with a layer of calcium carbonate [10]. Microbial calcium carbonate precipitation in a cement mortar/concrete is a complex mechanism. Based on continuous research, several innovations have been made to improve the strength and durability performance of cement mortar/concrete [11]. The abundant significance of Microbially Induced Calcium Carbonate Precipitation (MICCP), also known as carbonatogenesis, has attracted attention from both basic and applied points of view in civil engineering [12]. The CaCO_3 precipitation is a function of ionic strength and pH in the medium. The increase of compressive strength of mortar is due

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to the complex interaction between the bacterium and cement matrix [13].

The present study includes the usage of bacteria and their effect on the early age mechanical behavior of concrete under different exposure conditions. The core purpose of the carried-out work was to correlate the physical properties of healed/unhealed to that of normal concrete. Compressive strength, tensile strength, density, and water absorption were tested during this study.

II. OBJECTIVES

The specific objective of the present study is to investigate the mechanical and durability performance of concrete by adding bacteria as partial water replacement. Various dosage levels varying from 0% to 6% were used and the performance was determined at 28 days of water curing.

III. MATERIALS AND METHODS

A. Materials

The materials which were used in this study are described below.

- Cement: Ordinary Portland Cement (OPC) of Type-I complying with the ASTM C150-05 (2005) and BS 12 (1991) was used. It was purchased from the local market of Nawabshah under the trade name 'Lucky Cement' manufactured by the Lucky Cement Industries.
- Fine aggregates: 4.75mm sieve was used to obtain fine aggregates from locally available sand. The sand was washed and dried up to SSD (Saturated Surface Dry) before mixing.
- Coarse aggregates of size 10-15 were used. The sieved aggregates were washed to separate any sticky material and were left to dry up to SSD.
- Water: Normally, drinking water is considered to be suitable for the manufacture of cement concrete/mortars/grouts, and it was also used in this study.

B. Size and Shape of Samples

Specimens of standard size, as specified for each parameter of the study were cast and tested. The standard size and shape for compressive strength tests were 100mm×100mm×100mm cubes and for tensile strength tests and density measurement, 100mm×200mm cylinders, were cast.

C. Casting and Curing

All the materials were weighed before mixing (by hand). Initially, sand and binder (OPC and Silica Fume-SF) were mixed thoroughly for 3-5min to ensure the uniform dispersion of SF in the mix. Then, water was added slowly into the mix and mixing continued for about 3min. Specific specimens of standard size were cast (Figure 1). After 24h, the specimens were demoulded and cured accordingly. For the testing, the specimens were taken out from the specific curing regime one day before testing and were cleaned properly with a dry cloth to remove foreign particles. The specimens were checked for any kind of deformation such as broken edges and cracks. The

tests were conducted in the Structure's Laboratory of the Civil Engineering Department, QUEST, Nawabshah. Only wet curing for 28 days was adopted for all the specimens. For this purpose, the specimens were kept in water immediately after their demoulding.

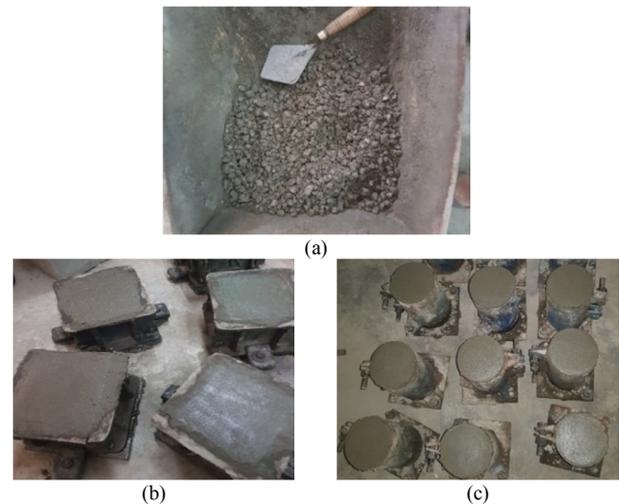


Fig. 1. Casting of concrete: (a) concrete mixing, (b) cubes for compressive strength tests, (c) cylinders for tensile strength and density tests.

D. Testing

1) Density Measurement

The density of all the cylindrical specimens was recorded after one day of casting and after the demoulding stage. The density was calculated by dividing the specimens' weight by their volume.

2) Compressive Strength Measurement

The compressive strength test is a key test for the mechanical/physical performance evaluation of concrete specimens. In this study, all the specimens with and without bacteria were tested for compressive strength, after 28 days of water curing, with a Universal Testing Machine (UTM) as shown in Figure 2 with a constant loading rate using (1), in which f_{cu} is the compressive strength, P is the maximum load taken by the specimen during testing and A is the area of the specimen.

$$f_{cu} = \frac{P}{A} \quad (1)$$



Fig. 2. A cubic specimen before and after compression testing.

3) Tensile Strength Measurement

Tensile strength test was conducted on the cylindrical specimens, as shown in Figure 3, with and without bacteria, with constant loading rate, after 28 days of water curing using (2):

$$f_t = \frac{2P}{\pi LD} \quad (2)$$



Fig. 3. A cylindrical specimen before and after tensile testing.

4) Water Absorption Measurement

The water absorption test is generally carried out to determine the degree of penetration of water inside the concrete cubes by measuring the weight of samples due to suction of water w.r.t the time duration only on the top surface of samples as presented in Figure 4. The smaller the amount of water that penetrates the concrete the better the results. This water penetration does not correspond with any reaction but just shows the water tightness of samples.



Fig. 4. Apparatus used for water penetration depth measurements.

IV. RESULTS AND DISCUSSIONS

A. Density

Density is an important factor to be considered when regarding strength and permeability. Density increase due to the use of different bacteria dosage levels is depicted in Figure 5 and Table I based on the obtained test results. It should be noted that the density of concrete with the addition of bacteria rises up to the dosage of 3.5% of total water by weight. It may be noted that the concrete with 3.5% of bacteria dosage at w/c ratio of 0.45 exhibited a density high of 1783kg/m³ which is 5.1% higher than that of the concrete without bacteria. The density enhancement at that optimum dosage level of bacteria

is due to the fact that the concrete pores were filled by bacteria, thereby more compacted surfaces can be achieved.

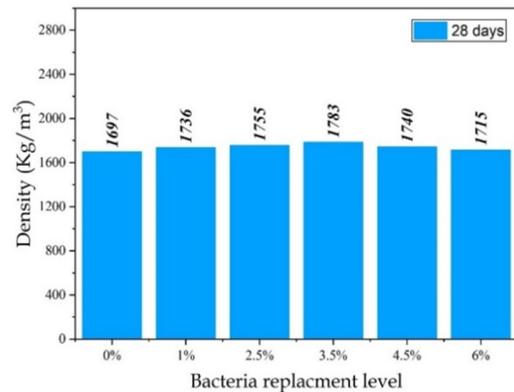


Fig. 5. Average density values vs. dosage level of bacteria after 28 days.

TABLE I. AVERAGE DENSITY OF CONCRETE WITH BACTERIA

Batch	Bacteria (%)	Average density (Kg/m ³)	Difference in values compared to B-1 (%ag)	
			Increase	Decrease
B-1	0	1697	....	....
B-2	1.0	1736	2.2	....
B-3	2.5	1755	3.4	....
B-4	3.5	1783	5.1	....
B-5	4.5	1740	2.5	....
B-6	6.0	1715	2.1	....

0.45w/c ratio

B. Compressive Strength

The results of the compressive strength tests of concrete with a 0.45w/c ratio are shown in Table II and Figure 6. It can be observed that the compressive strength of concrete with the addition of bacteria rises up to the dosage of 3.5% of total water by weight, in which it reaches its maximum value. It should be noted that the concrete with 3.5% of bacteria dosage exhibited compressive strength of 31.7MPa which is 25% higher than that of the concrete without bacteria.

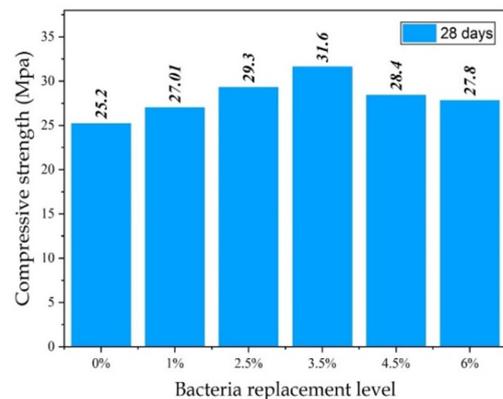


Fig. 6. Average compressive strength vs. bacteria dosage.

TABLE II. AVERAGE COMPRESSIVE STRENGTH OF CONCRETE WITH BACTERIA

Batch	Bacteria (%)	Average compressive strength (MPa)	Difference in values compared to B-1 (%ag)	
			Increase	Decrease
B-1	0	25.2	....	....
B-2	1.0	27.2	8	....
B-3	2.5	29.3	16	....
B-4	3.5	31.6	25	....
B-5	4.5	28.4	13	....
B-6	6.0	27.8	10	....

0.45w/c ratio

This increase is caused by the higher concentration level and increased calcite precipitation which generates more C-S-H gel, resulting in more strength at the same curing level. The addition of bacteria demands a lesser w/c ratio for the mixing and hydration process because the calcite precipitation is more responsible for higher compressive strength values, which has been observed and during this study.

C. Tensile Strength

The results of the split tensile strength tests are presented in Table III and Figure 7. We can see that at 28 days of curing, the optimum replacement percentage of water with bacteria is 3.5% with a value of split tensile strength of 2.4N/mm² (19% more than that of normal concrete). The maximum tensile strength is 13.1% of the respective compressive strength, while the minimum value obtained is 12.4%. The average value is 12.7%. Normally, the tensile strength of concrete lies between 5% and 15% of compressive strength. The same trend is observed during the current study.

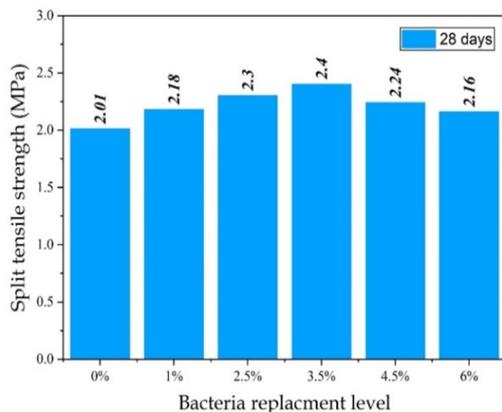


Fig. 7. Average split tensile strength vs. bacteria dosage.

TABLE III. AVERAGE SPLIT TENSILE STRENGTH

Batch	Bacteria (%)	Average tensile strength (MPa)	Difference in values compared to B-1 (%ag)	
			Increase	Decrease
B-1	0	2.01	....	....
B-2	1.0	2.18	8	....
B-3	2.5	2.3	14	....
B-4	3.5	2.4	19	....
B-5	4.5	2.24	11	....
B-6	6.0	2.16	7	....

D. Water Absorption

The water penetration depth results for different time durations for various specimens due to the use of different bacteria dosage levels are presented in Figure 8. Due to the use of bacteria, the penetration depth decreases as the dosage of bacteria increases and the same optimum level of bacteria dosage (3.5%) was found to be obtained in minimizing the water penetration in concrete cubes. The results showed that due to the better reaction of carbonates available in bacteria, a strong gel covering is produced on the concrete cubes, which prevents water from penetrating the pores of specimens. Thus, not only the durability is improved but also the water-resisting power of concrete cubes is enhanced by the strong gel formation.

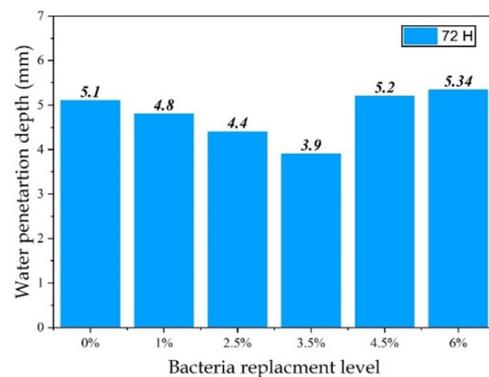


Fig. 8. Water absorption in terms of penetration depth vs time (72H).

E. Test Result Comparison

This study focuses on the use of bacteria in concrete to investigate its mechanical and durability performance, a combination that has not been widely researched. The present study depicted compressive strength 4% higher than that of [6, 14] at the same curing age and 6% higher than in [15] which used nanomaterials in order to investigate the difference of the molecular level of bacteria/nanomaterial on material's performance [16].

V. CONCLUSIONS

From the experimental results, it is concluded that bacteria can enhance the physical properties of cement concrete i.e. compressive strength, tensile strength, and density. The maximum compressive strength value of 31.6MPa was achieved at the optimum level of bacteria by weight of water (3.5%), which is 25% higher than the concrete without bacteria. This enhancement in strength is caused by the better calcite precipitation and generation of C-S-H gel inside the concrete mass. Maximum split tensile strength of 2.7MPa was achieved at the optimum level of bacteria, which is 19% higher than that of concrete without bacteria. Strength increase was achieved mainly due to the increased concentration of bacteria, which triggers the hydration process and improves strength, mainly tensile strength.

A maximum density value of 1783kg/m³ was achieved at the optimum level of bacteria (3.5%), which is 5% higher than

that of concrete without bacteria. This density enhancement at the optimum dosage level of bacteria is due to the filling by bacteria of the existent pores of concrete, thereby more compacted surface was achieved. Water penetration depth was also minimum (3.90mm) at the same optimum dosage level of bacteria.

From the above findings, it can be concluded that the optimum bacterial level according to the test results is 3.5%. This optimum level of bacteria dosage showed better performance by generating better C-S-H gel as well as sufficient calcite precipitation which not only enhanced strength but also helped in improving concrete durability.

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