Durability Studies on Low-Strength Bacterial Concrete

B. S. Shashank and P. S. Nagaraja

1 Introduction

In the construction sector usually, contractor wants to achieve early concrete strength so that the job can be finished on time or before schedule [1, 2]. The use of high initial strength cement and low water/cement ratio addresses this requirement. But this process leads to a large degree of heat liberation, drying shrinkage, elasticity modulus and a lower creep. Concrete also displays greater cracking behavior with an upper quantity of concrete due to increased thermal shrinkage and drying shrinkage, but many of the time it is not possible to reduce these problems only with variation in ingredients of concrete and due to congestion in the work difficult to repair also, on this regard autogenous self-healing mechanism is required which will heal these cracks and increase the durability. One such mechanism is bio-mineralization [3–6].

2 Self-healing Material

Based on the $CaCO_3$ precipitation, calcifying bacteria are collected from various sources such as soil and water. Calcification of bacteria yields an enzyme termed urease that transforms the urea into ammonia and CO_2. Reactions are reported as follows [7, 8].

$$CO(NH_2)_2 \rightarrow CO_2 + NH_4$$

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The reaction between CO_2 acquired from urea with the $Ca(OH)_2$ of concrete is as follows

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O \uparrow$$

The precipitated calcium carbonate will deposit in the cracks and seal the opening which in turn reduces the permeability of the concrete.

2.1 Types of Bacteria

1. Bacillus subtilis
2. Bacillus sphaericus
3. Bacillus pasteurii

All of these bacterial species can precipitate calcium carbonate in different quantities and are best suited for the investigation and also nonpathogenic. Out of these three Bacillus pasteurii bacteria have got better calcium carbonate precipitation.

2.2 Objectives

An objective of the current investigation is to understand the durability performance of low-strength (M20) bacterial concrete.

3 Materials and Properties

3.1 Bacterial Source

Bacillus sphaericus bacteria was procured from (MTCC) Microbial Technology Institute and Bacillus, subtilis, and Bacillus pasteurii bacteria are isolated from soil and water source respectively and same has been shown Fig. 1.

Fig. 1 Bacterial inoculation

Table 1 Properties of cementitious material

S. No.	Tests of cement	Test results	References
01	Specific gravity of cement	3.05	IS 2720–Part III
02	Standard consistency (%)	32%	IS 4031–Part IV
03	Initial setting time of cement, min	90 min	IS 4031–Part V

4 Experimental Investigation

4.1 Cement

In the present study, the same brand OPC 43 grade cement is used. Different basic experimental investigations were performed to understand the property of cement, and their findings are enumerated in Table 1.

4.2 Aggregates

Coarse and fine aggregates were tested in the laboratory to confirm IS 383-1970 obtained from the nearest source; the baseline test results are shown in Table 2.

Table 2 Aggregate properties

S. No.	Test on aggregate	Results obtained for fine aggregate	Results obtained for coarse aggregate
01	Specific gravity	2.6	2.68
02	Water absorption, %	11	2
03	Fineness modulus, %	2.85	2.85

Table 3 Growth medium

Growth medium	Bacillus subtilis and Bacillus sphaericus and Bacillus pasteurii
Growth medium name	Nutrient agar Beef extract 1.0 g Yeast extract 2.0 g Peptone 5.0 g NaCl 5.0 g Agar 15.0 g Distilled water 1.0 L

4.3 Culturing of Bacteria

The evolution of a single colony of bacteria took place in the research laboratory, while the development of other bacteria in the medium was limited and various chemical formulations were prepared for the media [8, 9] as per Table 3.

4.4 Inoculation of Bacteria

Due to agar, the media became solid once the media had been shifted to Petri dish plates and tubes. Bacteria are inoculated with the aid of a needle, commonly known as nichrome, made of nickel and chromium. Figure 1 shows the growth of the presence and bacteria for Bacillus subtilis, Bacillus pasteurii and Bacillus sphaericus, respectively [9–12].

4.5 Broth Preparation

Broth preparation required the same nutrients; however, due to the exclusion of agar broth will be in liquid form. Figures 2 and 3 show the broth before bacteria inoculation and the development of bacteria after bacteria inoculation correspondingly [13–17].

Fig. 2 Broth of bacterial species

Fig. 3 Prepared broth for concrete with bacteria

Table 4 Concrete mix design

Grade of concrete	Cement kg/m^3	Water liter/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3
M20	394	197	759	1037

4.6 Mix Design

Mix design was made using Indian standard codes the IS 456-2000 and IS 10262-2009, and these codes were used to assess the coarse aggregate, fine aggregate and cement ratios. The found quantities are shown in Table 4.

5 Results and Discussion

Evidence and analysis were presented on various investigations conducted on the specimen. Mainly here slump test, compressive strength, split tensile strength, flexural strength, modulus of elasticity, water absorption and acid attack test results are discussed.

5.1 Slump Test

Slump test was carried out on various M20 grade concretes. The mixes and values obtained are described below. From Table 5, it can be seen that there is no considerable

Table 5 Concrete slump

S. No.	Type of concrete	Slump (mm)
01	Conventional	101
02	Bacillus subtilis	95
03	Bacillus sphaericus	91
04	Bacillus pasteurii	95

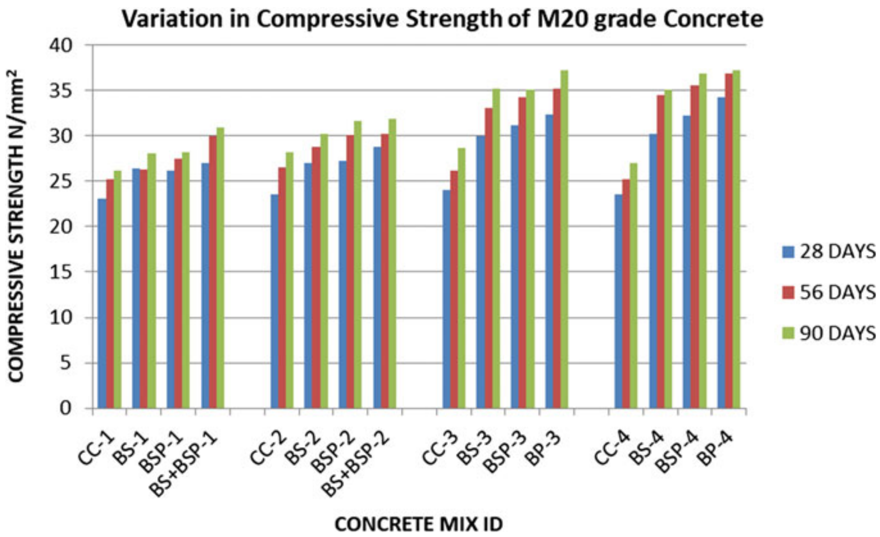

Fig. 4 Compressive strength variations

impact on the slump of concrete due to incorporation of bacteria. This is due to no effect of bacteria or cell concentration on concrete as the size of bacteria is very small and no calcium carbonate precipitation is started initially. Hence, bacteria do not affect the workability of concrete.

5.2 Compressive Strength Test

From Fig. 4, variation of compressive strength of concrete with different cell concentrations, 10^4 to 10^7 with 3 different bacteria for 28, 56 and 90 days, is shown and it can be observed that as the cell concentration increases the strength of the concrete also increases, especially 10^6 and 10^7 cell concentration; a maximum of 37% increase in the compressive strength was observed. This increase in strength is mainly due to the closing of micro-cracks due to microbiological calcite precipitation. Combination of two different bacteria also showed similar characteristics as single inoculation of bacteria.

5.3 Split Tensile Strength

Figure 5 shows variation of splitting tensile strength with different cell concentrations 10^4 to 10^7 with 3 different bacteria for 28 days. It can be understood from the figure that there is an increase in the splitting tensile strength of concrete with a maximum

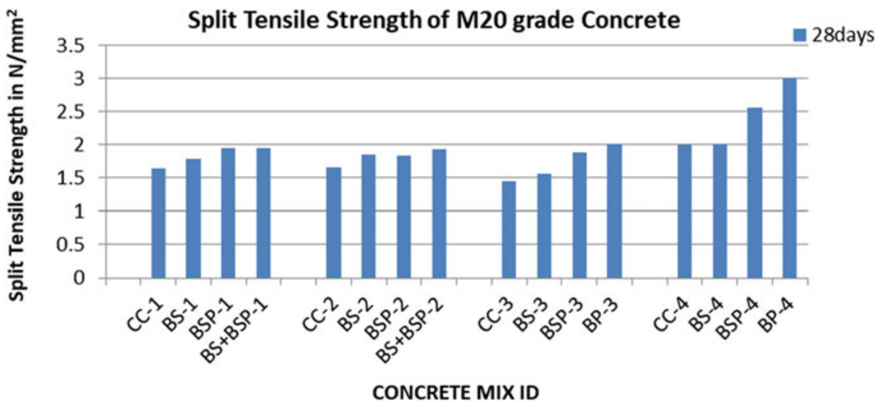

Fig. 5 Split tensile strength variation

of 51% for 10^6 cell concentration. This is also due to the addition of bacteria and calcite precipitation which sealed the micro-cracks and decreased the week one in the concrete.

5.4 *Flexural Strength*

From Fig. 6, variation of flexural strength of concrete with different cell concentrations, 10^4 to 10^7 with 3 different bacteria for 28 days, can be seen. And here also as cell concentration increased, the strength of the concrete also got increased. But for 10^4 and 10^5, a slight increase was observed compared to 10^6 and 10^7 where a maximum of 36% increase was observed.

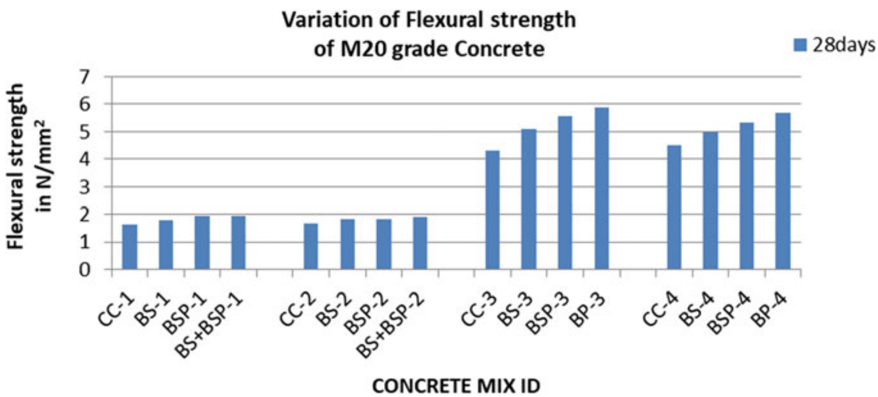

Fig. 6 Flexural strength variation

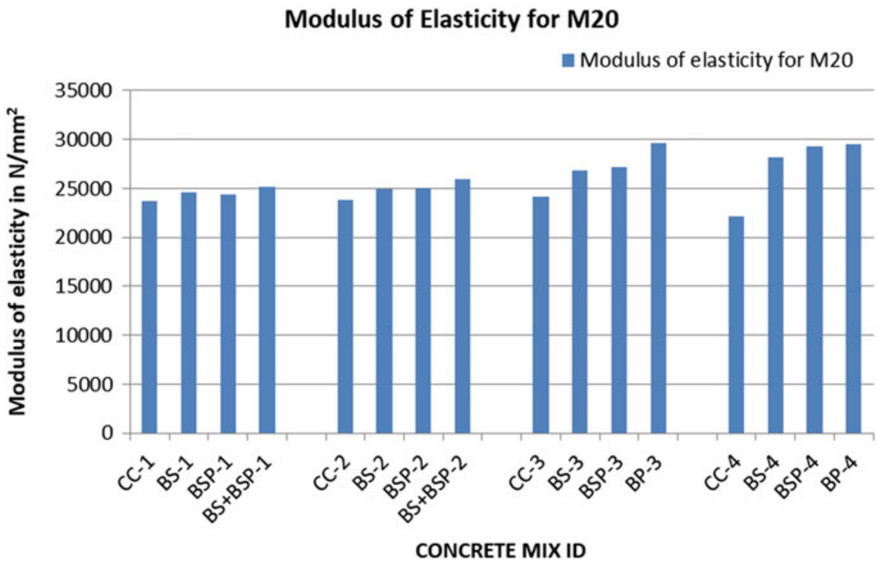

Fig. 7 Modulus of elasticity variations

5.5 *Modulus of Elasticity*

From Fig. 7, variation of modulus of elasticity of concrete with different cell concentrations, 10^4 to 10^7 with 3 different bacteria for 28 days, can be seen. And it was observed from the figure that for 10^6 and 10^7 bacterial cell concentration modulus of elasticity was more. A maximum of 34% increase was observed with Bacillus sphaericus bacteria for 10^7 cell concentration.

5.6 *Water Absorption Test*

Water absorption test was conducted on concrete to understand the permeability characteristics. For testing BS 1881: Part 122 (1983), guidelines are followed and the test results are presented in the graph.

In Fig. 8, water absorption of M20 grade concrete for different cell concentrations with different bacteria is shown. It can be seen that as cell concentration increases permeability decreases which were mainly due to deposition of calcium carbonate precipitation from bacteria in micropores. Also, a maximum of 64% reduction in water absorption was observed in Bacillus pasteurii for 10^7 bacterial cell concentrations.

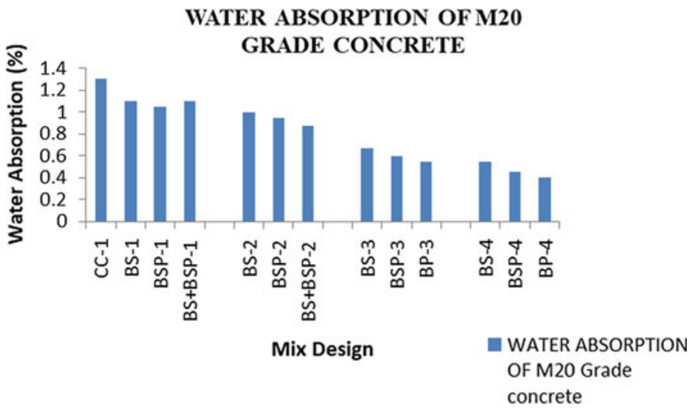

Fig. 8 Water absorption in percentage

5.7 Acid Attack Test

The resistance of concrete cube specimens to acids was found out by conducting an acid attack tests suggested by Murthi and Sivakumar (2008) [18, 19]. The samples were cured in water for 28 days after which they were immersed in 3% H_2SO_4 and 3% HCl solutions in plastic tubs. After 2 and 4 weeks, the cubes are weighed and compared with initial weight. The results of the experiments are shown in Fig. 8.

In Fig. 9, resistances to the acid attack of M20 grade concrete for different cell concentrations with different bacteria for 2 and 4 weeks are shown. Calcium carbonate deposition at micro-cracks and decrease in permeability of concrete resistance to acid attack increased greatly for 2 weeks to 4 weeks. And here also cell

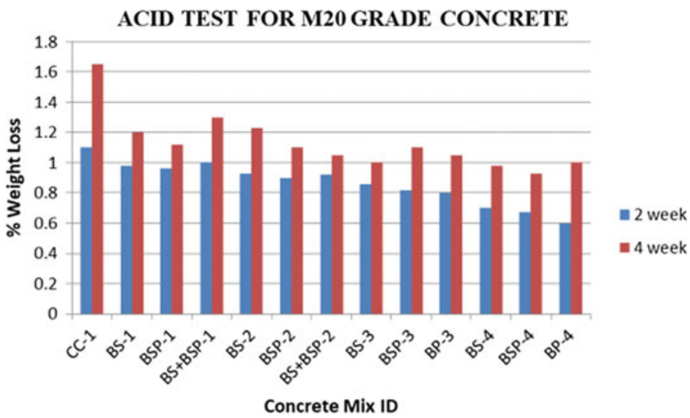

Fig. 9 Resistance to acid attack

concentration played a very important role, and for 10^7 cell concentrations resistance was shown up to 45% to acid attack compared to normal concrete for 2 weeks.

5.8 SEM AND XRD analysis

SEM and XRD images of the calcium carbonate deposition in concrete are shown in Figs. 10, 11, 12, 13 and 14; also, it clearly shows that as the cell concentration increases the calcium carbonate count also increases compared to controlled concrete and 10^6 and 10^7 bacterial cell concentration displayed a higher range of calcium carbonate which will validate the decrease of permeability and increase in the mechanical properties of bacterial concrete.

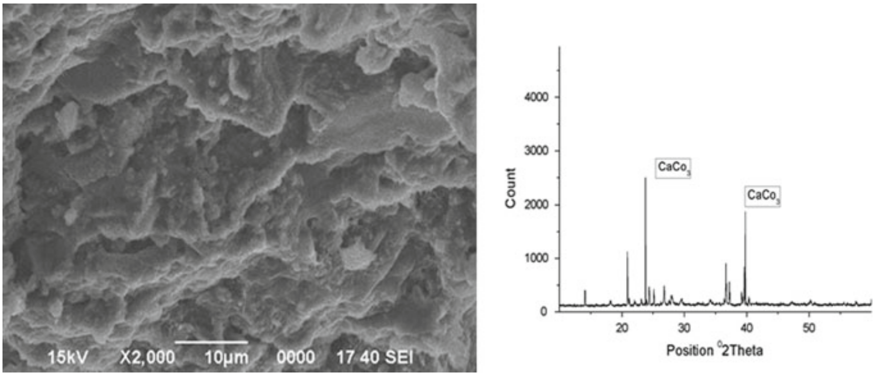

Fig. 10 SEM and XRD images of controlled concrete

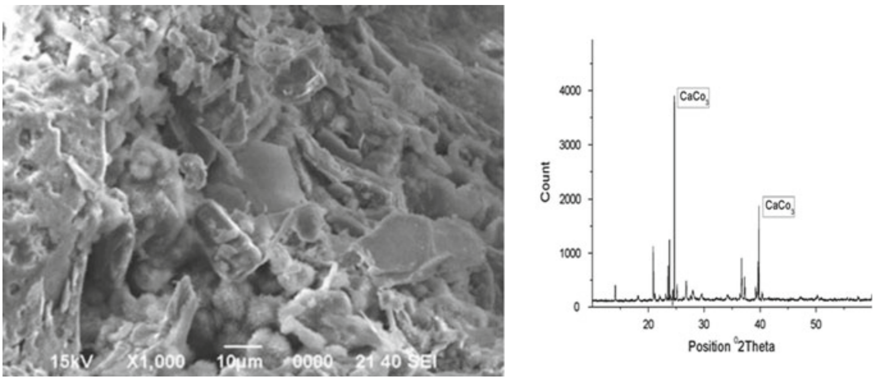

Fig. 11 SEM and XRD images of 10^4 cell concentration of Bacillus pasteurii

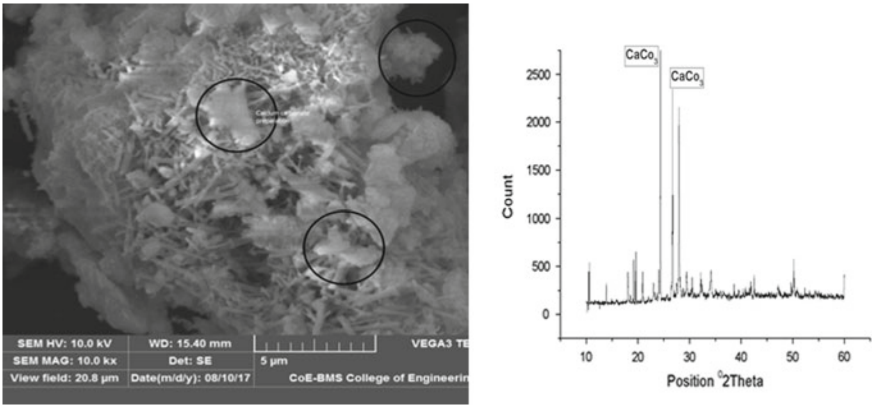

Fig. 12 SEM and XRD images of 10^5 cell concentration of Bacillus pasteurii

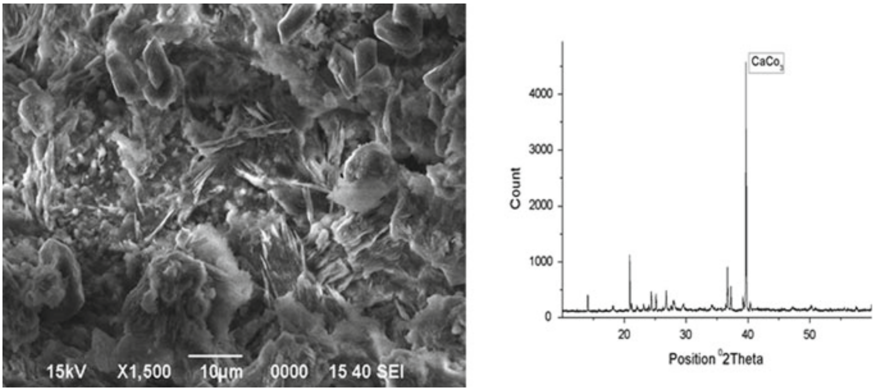

Fig. 13 SEM and XRD images of 10^6 cell concentration of Bacillus pasteurii

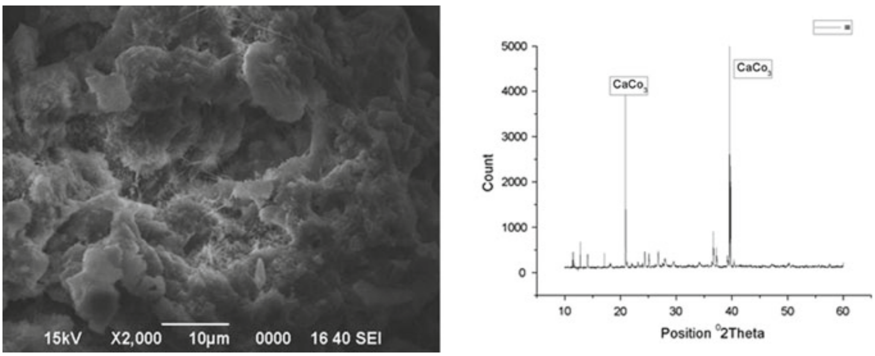

Fig. 14 SEM and XRD images of 10^7 cell concentration of Bacillus pasteurii

5.9 Discussions

In the present scenario of change with respect to advancement in construction sector, bacterial concrete is very much essential also by seeing its mechanical and durability performance, especially increase in compressive strength and decrease in permeability which leads to decrease in corrosion and increase of durability of structure which is required for the present that too without human interventions for any repair.

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