Bacteria Based Healing of Cracks with The Use of Pseudomonas and Kocuria in Concrete

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Abstract

The present study aims to find the mechanical properties of bacterial concrete. Two types of bacterial species were used, i.e., Pseudomonas BG and Kocuria 2M7 for concrete. SEM was done to confirm that applied micro-organism can produce calcium carbonate in concrete for healing of cracks or not. Due to production of calcium carbonate crystals, it is necessary to check the strength properties of concrete. The compressive strength and split tensile strength were increased as we apply the micro-organism to the concrete. For the durability aspect, capillary water absorption (sorptivity) of concrete core specimen was measured with and without bacteria. The result of effect of two different strains that is pseudomonas BG and kocuria 2M7 were also compared to check which one is ideal for concrete.

Keywords: *Bacterial concrete, Pseudomonas, kocuria, Self-healing concrete, Cracks repairing.*

INTRODUCTION

Concrete is broadly used material in the world. More than ten billion tonnes of concrete are consumed annually. Based on global usage it is placed at second position after water. In Conventional concrete, a versatile material, is a mixture of cement, aggregate, sand, water, etc. Aggregate content has the direct effects on the quality of concrete itself. The aggregate component has extremely variable in terms of the shape and grading. Water and cement do not replace any specific characteristic except in the quantity in concrete. Due to high tensile stresses of structures, it leads to cracking in concrete [1]. Due to cracks occurs in concrete, it allows water to seep through concrete and results corrosion of steel reinforcement and decrease the lifespan of a structure [2]. Porous building material allows to enter some reactive and harmful chemicals and moisture and that will affect the material and reduce its life and strength [3].

There are numbers of man-made traditional repairs techniques have been developed. These repairs techniques mostly followed a procedure to monitoring, detection and repairing. When cracks are spotted in concrete, repairing agent is applied from the outside. This traditional repair technique is generally used when cracks are very large and reachable. However, this traditional repair technique is relatively high operational costs and it is difficult to repairs deep cracks and micro (small) cracks. These repair techniques need regular inspection and maintenance, particularly in underground structures and infrastructure and large-scale construction [4]. Tradition crack repair technique has so many disadvantages related to health hazard and environment. The use of concrete is widely increasing in the world. Therefore, environmentally friendly repair technique needs to be introduced [5-6]. In concrete matrix, some non-reacted cement particles may have self-healing capacity up to some limited extent. But this self-healing characteristic may not be satisfactory for concrete structures. Bacterially induced precipitation of calcium carbonate technique is based on the addition of bacteria that would make up a part of the concrete matrix without or insignificantly affecting its structural and mechanical characteristics [7].

In order to use bacteria in concrete structure, it needs to produce huge amount of calcium carbonate for crack repair [8]. Micro-organism is applied during the casting of concrete. Whenever cracks will occur, micro-organism will active in concrete matrix and produces calcium carbonates to seal cracks from inner side to outer side. This technique is very useful to repair deep-micro cracks and to restrain early-age cracks which generate large cracks. Compared with the healing agents like polymers and expanded additives, bacteria-based healing technique is more compatible with the concrete matrix. Micro-organism is more environmentally friendly in comparison with other healing agent. Under suitable conditions, most bacteria can produce calcium carbonate and repair cracks [9]. For production of $CaCO_3$ in concrete, some organic nutrients added which sometimes create negative effects in strength of a concrete. Concrete beyond 7 days of curing, there are pores in concrete matrix. These pores shrank to small size which is too small to survival of bacteria. The cell walls of bacteria are negatively charged under neutral environment or high alkaline pH which attracts the calcium ions and generate calcium carbonate crystals on the cell surface [10]. A lot of research work has been done on precipitation of calcite crystals on concrete matrix and its effect on strength in concrete [11].

In this study, Compressive strength and split tensile strength of concrete were measured with and without bacteria. To check the durability behaviour of with and without bacteria in concrete, capillary water absorption (sorptivity) test was carried out [12]. To study the biological role of calcium carbonate precipitation in concrete matrix, scanning electron microscopy analysis was carried out.

MATERIALS AND METHODS

Concrete Sample

Ordinary Portland Cement was used for all concrete specimens.

Fig. 1: *Concrete Core Specimen.*

Moulds with the dimensions of 150 mm × 150 mm × 150 mm and cylinder with the dimension of 150 mm × 300 mm were used. All the moulds were placed at a normal room temperature for 24-hours. After de-moulding, the specimens were taken for the curing for 28 days. For curing, fresh portable water was used. Fine aggregate (4.75 mm to 150 micron) with the specific gravity of 2.7 and fineness modulus of 3.03 was used. Course Aggregates, conforming to IS: 383:1970 with the specific gravity of 2.59 and fineness modulus of 7.19 were used [13]. Concrete core specimens were prepared as shown in Fig. 1. to obtain capillary water absorption (sorptivity). The height and diameter of core were 30mm and 65mm, respectively.

Growth of Bacteria

Two micro-organism Pseudomonas BG and kocuria 2M7 were utilized. Micro-organism was directly applied to the concrete during casting. Pseudomonas BG and kocuria 2M7 can survive in concrete

environment and produces calcite crystal. Used bacteria in this research work are not harmful to human being. Applied micro-organism become active in presence of water and produces calcite crystals when cracks occur. Negatively charged bacterial cell wall draw cations from the atmosphere, including ca^{2+}, to add on their exterior cell. The ca^{2+} (-) irons then react with the co_3^{2-} (-) irons, leading to the generation of $caco_3$ at the cell surface (Eqs. (1) & (2)).

$$Ca^{2+} + \text{Cell} \longrightarrow \text{Cell} + Ca^{2+} \quad (1)$$

$$\text{Cell} + Ca^{2+} + CO_3^{2-} \longrightarrow \text{Cell} + CaCO_3 \quad (2)$$

Mix Proportion

Mix proportion was designed conforming to IS: 10262-2009. M25 grade of concrete was used [14]. Adopted water-cement ratio was 0.5 with 75 mm slump according to IS: 456 (2000) [15]. Mix proportion consist of 383.16 kg/m^3 of cement, 834.17 kg/m^3 of fine aggregate, 964.26 kg/m^3 of coarse aggregate, 182 liters per cubic meter of water, 9.57 liter per cubic meter of bacterial liquid.

TEST PROCEDURE

Compressive Strength Test

For determination of compressive strength, UTM was used according to guidelines of IS: 516-1959 [16]. The size of 150 mm × 150 mm × 150 mm cubes were prepared to determine the compressive strength of concrete specimen. After 7 & 28 days of the curing, compressive strength of specimen was measured, Average of three specimens was utilized. Gradual load is applied during the testing at the rate of 5.2 kN/second until the specimen fails. Measured load at the failure of specimen divided by the area of a specimen will give the compressive strength of the concrete.

Split Tensile Strength Test

For determination of split tensile strength, cylinders were used with 150 mm diameter and 300 mm of height. The procedure of split tensile strength test was done conforming to IS: 5816:1999 [17]. Split tensile strength was measured after 7 days and 28 days of water curing for cylindrical specimens. Average of three cylindrical concrete specimens was utilized. The load was increased continuously, at the nominal rate of 1.2 N/(mm^2/min) without shock. Split tensile strength was measured by following equation.

$$T = \frac{2P}{\pi L d} \quad (3)$$

where T = split tensile strength (kPa), P = applied load (kN), L = length of cylinder (m) and d = diameter of cylinder (m).

Scanning Electron Microscopy

After compressive test, some broken pieces of concrete specimen were separated for SEM. This study was done to check the movement of crystalline structures in concrete matrix. The subjected sample was dried before SEM study was done.

Sorptivity

Sorptivity test was done to check capillary water absorption of control and bacterial concrete core specimen. Concrete core sample with Diameter of 65 mm and height of 30 mm was used as shown in fig. 1. 28 days cured concrete core were used for Sorptivity test. Before Sorptivity test was carried out, Concrete core specimens were kept in hot air oven at 105 °C for 24 hours then cross- sectional area and weight of concrete core was measured. Tray containing water up to 2 mm depth was held level to ground. After that Specimen were placed inside the tray. After 5, 10, 30, 60, 120 min of time interval, specimen was removed from the tray and weighed. During the Sorptivity test, Water level was kept to 2 mm by adding the additional water into the tray [12]. Sorptivity coefficient was measured by the following equation.

$$i = s \times \sqrt{t} \quad (4)$$

where i = cumulative number of absorbed water per unit cross-sectional area (g/mm^2), s = coefficient of sorptivity (g/mm^2/mm$^{1/2}$) and t = measured time (min.).

RESULTS AND DISCUSSIONS

Strength Assessment

The average result of Compressive strength and split tensile strength after the 7 & 28 days of water curing with and without bacteria were measured and compared. From the Figs. 2 & 3, it is clear that the compressive strength and the split tensile strength of bacterial concrete specimen are higher than control concrete specimen. Percentage increase in compressive strength of kocuria 2M7 and pseudomonas BG is 16.7 % and 20.53 %, respectively, after 28 days of curing.

Kannan et al. [2], used micro-organism namely Bacillus pasteurii, they have found that percentage increased in compressive strength of bacterial concrete was 29.97 % after 28 days of water curing.

Percentage increased in split tensile strength of cylindrical specimen for kocuria 2M7 and pseudomonas BG was 21.36 % and 22.6 %, respectively, after 28 days of curing.

Meera and subha [1], found that addition of Bacillus Subtilis Jc3 on concrete can increase the split tensile strength of concrete up to 63.46 %.

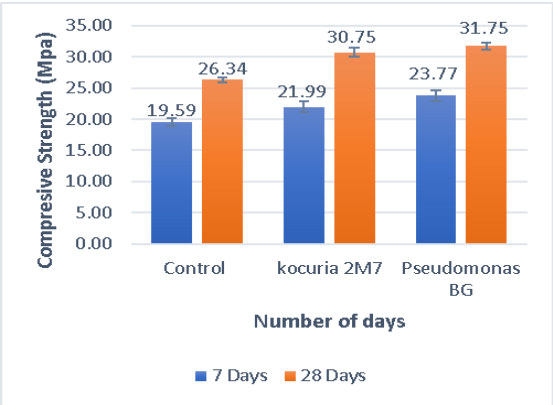


Fig. 2: *Compressive strength of control and bacterial concrete at the age of 7 days and 28 days.*

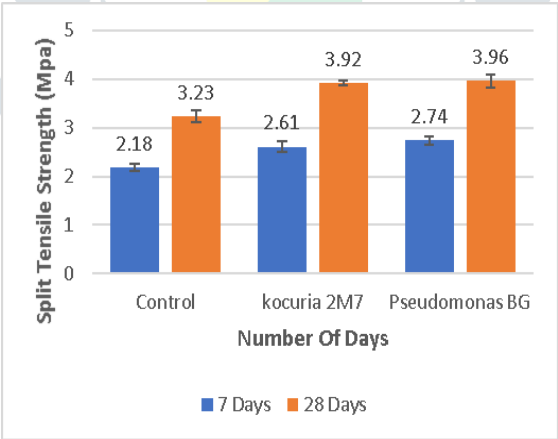


Fig. 3: *Split tensile strength of control and bacterial concrete at the age of 7 days and 28 days.*

Scanning Electron Microscopy

Figs. 4-6, show the results of SEM analysis. It is clear that bacterial concrete is grows $CaCO_3$ micro-nanowires as control concrete cannot produce such micro-nanowires.

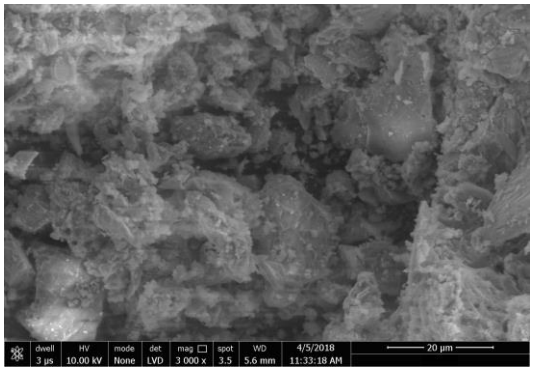
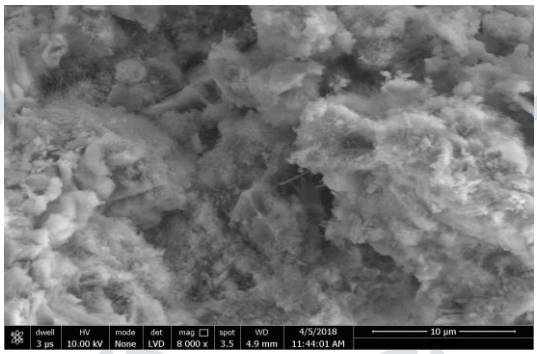
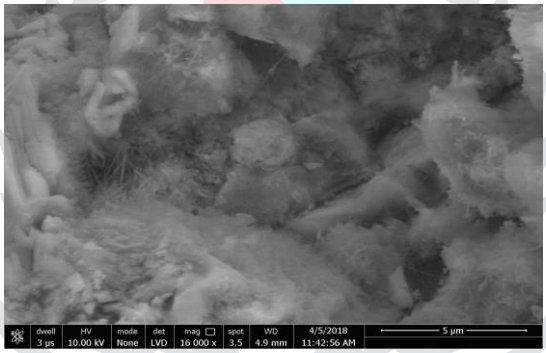


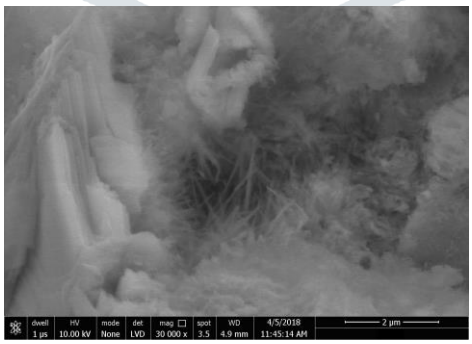
Fig. 4: *Control specimen.*



(A) Precipitation of calcite with kocuria 2M7, 8000x



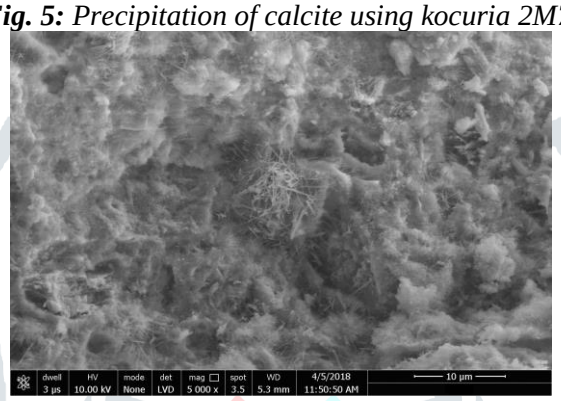
(B) Precipitation of calcite with kocuria 2M7, 16000x



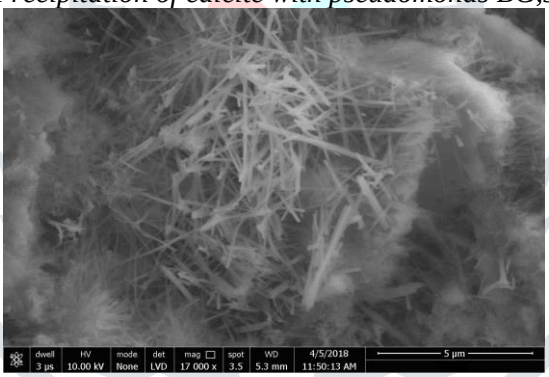
(C) Precipitation of calcite with kocuria 2M7, 30,000x

(D) *Precipitation of calcite with kocuria 2M7 with dimensions*

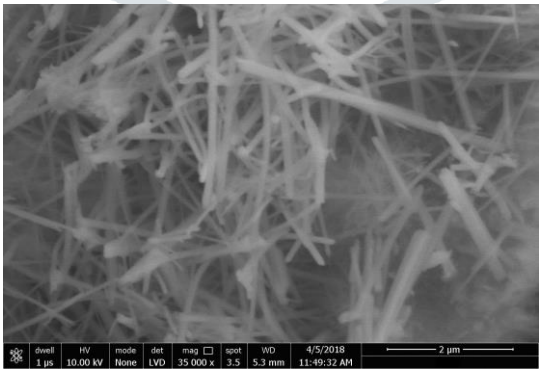
Fig. 5: *Precipitation of calcite using kocuria 2M7.*



(A) *Precipitation of calcite with pseudomonas BG,5000x*



(A) *Precipitation of calcite with pseudomonas BG, 17,000x*



(B) *Precipitation of calcite with pseudomonas BG, 35,000x*

Fig. 6: *Precipitation of calcite with pseudomonas BG.*

Sorptivity

Apparently, all specimens show an increase in water absorption at measured time intervals. It is found that control specimen shows highest amount of water absorption and bacterial concrete reduces water absorption per unit area. Pseudomonas BG reduces significant amount of water absorption as compare to kocuria 2M7 and control specimen. The graph of absorbed water per cross-sectional area of specimen (i) versus square root of time √t (Fig. 7.) was plotted, best strength line generated by regression analysis, after that gradient of best fit line calculated to determine sorptivity coefficient (S). Sorptivity coefficient (S) tabulated in Table 1.

***Table 1**: Sorptivity Coefficient*

Batch	Sorptivity Coefficients (10^{-4} $g/mm^2/min^{1/2}$)
Control	0.10
Pseudomonas BG	0.20
Kocuria 2M7	0.23

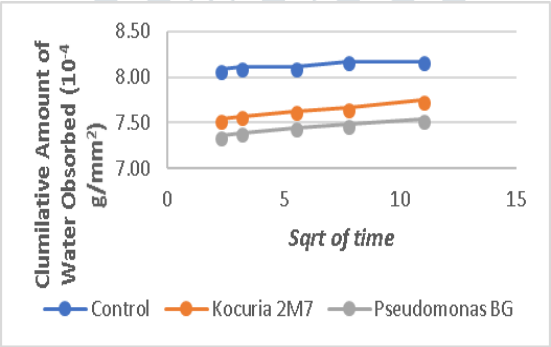


***Fig. 7:** Surface water absorption results.*

CONCLUSIONS

The experimental study shows that the addition of bacteria pseudomonas BG and kocuria 2M7 can improve the properties of concrete.

- These bacterial species can produce calcites crystal to heal the deep-micro cracks. By this technique self-healing of concrete is possible.
- SEM analysis confirms that used bacterial species able to produce $caco_3$ micro-nanowires in concrete matrix. These single crystalline $CaCO_3$ micro-nanowires increase durability and strength of concrete.
- The compressive and split tensile strength can improve while mixing these bacteria to the concrete mix. Pseudomonas BG shows good compressive and split tensile strength as compared to kocuria 2M7 and control concrete specimen.
- Bacterial concrete absorbs low water as compared to control concrete.

From this experimental study, it can be said that both bacteria could be useful for making a strong and durable structures. Pseudomonas BG is more efficient in concrete as compare to kocuria 2M7.

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