A study on strength and self-healing characteristics of Bacterial concrete

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ABSTRACT - - *Concrete plays a vital role as a construction material in the world. This project presents the results of an experimental investigation carried out to evaluate the influence of Bacillus Subtilis and Bacillus Licheniformis on the compressive strength, split tensile strength, flexural strength, water absorption and its self-healing properties. An attempt is made to heal these cracks by the addition of the bacteria in the concrete and also to increase of the strength of the concrete. Each bacteria of concentration* 10^5 *cells/ml are added. Tests were performed at the ages of 7, 14 and 28 days. The applicability of specifically calcite mineral precipitating bacteria to fill the cracks in concrete and the bacteria chosen must have the self-healing capacity and the bacteria used must be non-pathogenic and sustainable. It is found that the cracks in the concrete have been healed and the formation of calcite precipitation is observed using Scanning Electron Microscopy (SEM). Usage of bacteria like Bacillus Subtilis, Bacillus Licheniformis improves the strength and durability of concrete through self-healing effect.*

Keywords: *Bacillus Subtilis, Bacillus Licheniformis, SEM*

I. INTRODUCTION

Concrete is one of the construction materials that is weak in tension, has limited ductility, little resistance to cracking and sometimes causes deterioration. Due to microbial activities of the bacteria, Microbiologically Induced Calcite Precipitation (MICP), a highly impermeable calcite layer is formed which contributes to increase the performance and service-life of concrete structures. Calcium carbonate precipitation is a phenomenon, in which Bacillus Licheniformis and Bacillus Subtilis can produce calcite precipitates at its optimal growth temperature around 30° C and 25° C to 35° C respectively.For the present investigation, OPC 53 grade confirming to IS 12269:1987 and locally available sand was confirming to IS 383:1970 was used. Ordinary blue granite crushed stone aggregate confirming to IS383:1970 was used as a coarse aggregate in concrete. Water confirming to the requirements of IS 456:2000, is found to be suitable for making concrete. As per the past research by the Delft University, 5 ml of bacteria solution is adequate for per liter of water for their efficient growth.

A. AIM AND OBJECTIVE

The aim of the present study is to incorporate an autonomous self-healing mechanism in concrete based on the application of bio-mineralization ofbacteria and to recover the strength after the formation of cracks in concrete. This paper also aims to prevent further concrete deterioration, such as corrosion, using Bacillus Subtilis and Bacillus Licheniformis. The properties of self-healing capacity can also be determined using these bacteria along with the potential of microbial concrete in lengthening the service of the structure.

B. MATERIALSAND SPECIMEN DETAILS

Optimum size of the coarse aggregate in most situations about 20mm was adopted. In this present study, casting and curing of specimens were done with the portable water that is with the Bhavani water. The concrete used for making the samples have the Cement:Fine Aggregate:Coarse Aggregate in ratio of 1:1.569:2.57 with the water cement ratio of 0.45.The initial and final setting time of the cement used is 33 minutes and 583 minutes respectively.The cement has a soundness value of 7 mm. The cement of strength 54.2 MPa is used. The specific gravity of cement, fine aggregate and coarse aggregate are found to be 3.15, 2.63 and 2.76 respectively. The fineness modulus of fine aggregate and coarse aggregate used were 2.5 and 4.1 respectively. The water absorption percentage of fine aggregate and coarse aggregate were 0.61% and 0.66% respectively. The fine aggregate pertaining to Zone III is used. The pH value and chlorine content in water used is 6.8 and 210 mg/l. Generallycement and water obtains pH value up to 12 when mixing. Most organisms die in an environment with a pH value of 10 or above. Bacillus Subtilis and Bacillus Licheniformis can withstand only up to a pH value of 8 and around 9 to 10 respectively.The concrete with bacteria is mixed in the water which contains calcium chloride and urea of50 ml and 20 ml for per liter of water respectively.For split tensile strength test, flexural strength test and water absorption test 3 cylinders, 3 prisms and 3 cubes respectively are casted and tested at 7, 14 and 28 days. For compressive strength test 3 cubes and 3 cylinders are casted and tested at 7, 14 and 28 days. Six concrete cubes, after 28 of curing were casted for SEM Analysis, in which 3 cubes were for the analysis of material property and the other 3 for the analysis of self-healing property.

II. EXPERIMENTS FOR STRENGTH, DURABILITY AND SELF-HEALING CAPACITY

A. EXPERIMENTS

1) Slump ConeTest

The slump mould of top diameter 100mm, bottom diameter 200mm and height 300mm is placed on a non-absorbent surface. Fill the concrete in the mould in three layers, in which each layer should be tamped 25 times uniformly. Remove the mould and measure the height.

2) SEM Analysis for Material Property

Concrete cubes of size 150mm x 150mm x 150mm is used to carry out the SEM Analysis at the end of 28 days of curing. Scanning Electron Microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. By scanning the sample and detecting the secondary electrons that hit the sample, an image displaying the topography of the surface is created. The material property is observed.

3)Compressive Strength Test

For each mix proportion three cubes(150x150x150 mm) and three cylinders(150 mm diameter and 300mm height) are tested at 7,14 and 28 days using Compressive Testing Machine of 2000 kN as per IS:516-1959. The reverse of needle indicates the total failure load of specimen. The dial gauge reading is noted at the instant of failure, which is the ultimate load of specimen.

4) Split Tensile Strength Test

Split tensile strength tests are carried out at 7,14 and 28 days for the cylindrical specimen of 150 mm diameter and 300 mm height, using compressive testing machine of 2000 kN as per IS:516-1959. The load is applied gradually till the specimens split and readings are noted.

5) Flexural Strength Test

The prism specimens of size 100 x 100 x 500 mm are used for the determination of the flexural strength.The specimen is then placed in the Universal Testing Machine and two point loads are applied at one third of the distance from each end (13.3 cm). The load is increased until the specimen fails and the load at failure is recorded and the flexural strength is determined.

6) Water Absorption Test

Concrete cubes of size 150mm x 150mm x 150mm were used to determine the water absorption at the end of 28 days. The test specimens were completely immersed in clean water at room temperature for 24 hours. After weighing, all cubes were dried in a ventilated oven at 100 to 1150°C for not less than 24 hours. The wet weight and dry weight are noted.

7) SEM Analysis for Self-healing Property

Concrete cubes of size 150mm x 150mm x 150mm is used to carry out the SEM Analysis. At the end of 28 days of curing, the crack is made on the cubes. Again it is allowed to cure for 28 days. Then the self-healing property is observed in the cubes after 14 days with the naked eyes.

B. *RESULTS AND DISCUSSION*

1) Slump Cone

The slump value of normal concrete is observed as 25 mm. The slump value of the concrete made with Bacillus Subtilis and Bacillus Licheniformis are found to be 15mm and 20mm respectively. Hence the bacterial concrete has good workability.

2) SEM Analysis for Material Property

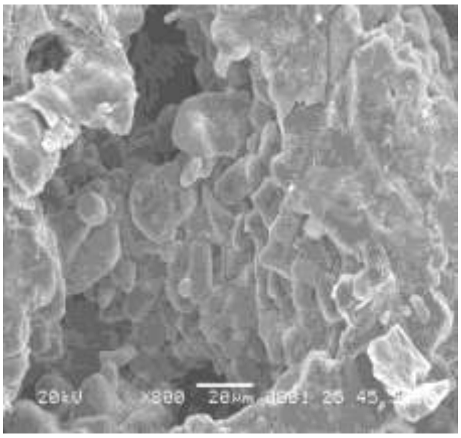

Fig.1 SEM image for normal concrete

The fig.1 shows the material property of the Normal Concrete. It is found to have more voids and they are not closely arranged.

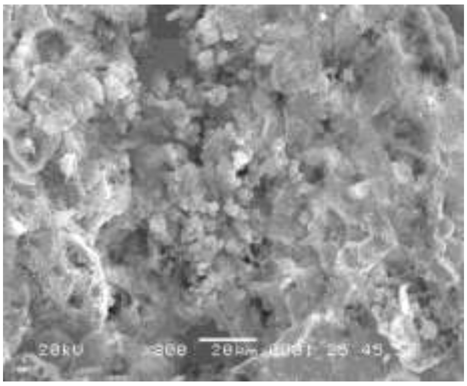

Fig. 2 SEM image for Bacillus Subtilis

The fig.2 shows the material property of the concrete cube made with Bacillus Subtilis. It is found to have lesser voids than the Normal Concrete Cube and they are comparatively closely packed.

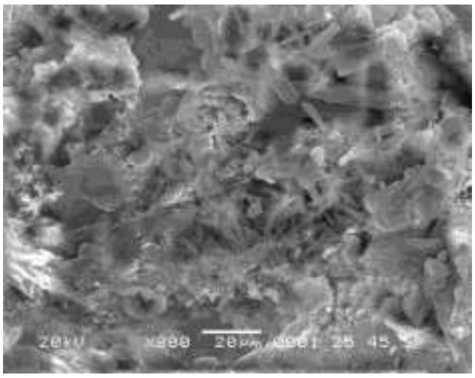

Fig. 3SEM image for Bacillus Licheniformis

The fig.3 shows the material property of the concrete cube made with Bacillus Licheniformis. It is found to have lesser voids than the Normal Concrete and Concrete made with Bacillus Subtilis. They are closely packed.

3) Compressive Strength Test

Using Cubes

Bacteria Used	Average Compressive Strength after 7 days (in MPa)	Average Compressive Strength after 14 days (in MPa)	Average Compressive Strength after 28 days (in MPa)
Normal Mix	16.25	23	25.5
Bacillus Subtilis	17.25	24.75	27
Bacillus Licheniformis	18	25	28.75

Table-1Compressive Strength Test results using cubes

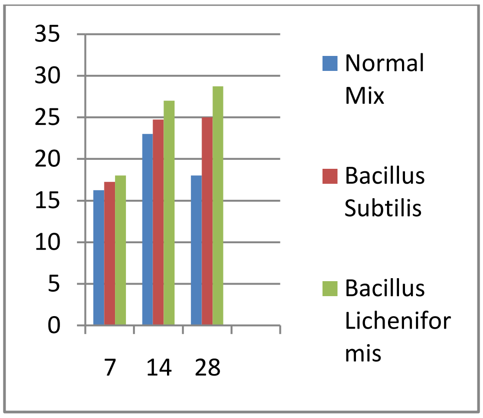

Fig. 4Compressive Strength Test results using cubes (x-axis and y-axis indicates curing period (in days) compressive strength(in MPa) respectively)

The table 1 and fig.4shows that the Compressive Strengthof Normal Concrete is lesser than the concrete made up of Bacillus Subtilis, which is lesser than that of the concrete made up of Bacillus Licheniformis in all the cubes (cured for 7, 14 and 28 days).

Using Cylinders

Bacteria Used	Average Compressive Strength after 7 days (in MPa)	Average Compressive Strength after 14 days (in MPa)	Average Compressive Strength after 28 days (in MPa)
Normal Mix	16	23	25
Bacillus Subtilis	17.25	25	26.5
Bacillus Licheniformis	18.5	24	28

Table-2Compressive Strength Test results using cylinders

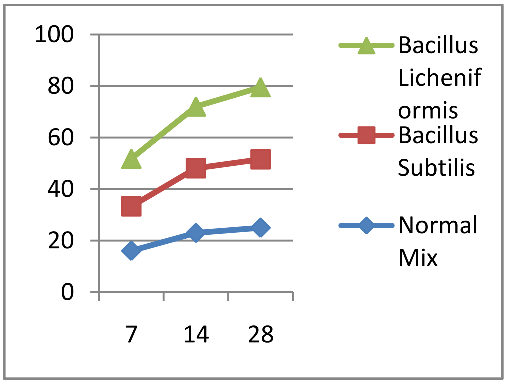

Fig. 5Compressive Strength Test results using cylinders (x-axis and y-axis indicates curing period(in days) compressive strength(in MPa) respectively)

The table 2 and fig.5 shows that the Compressive Strengthof the concrete made up of Bacillus Licheniformis is higher than the concrete made up of Bacillus Subtilis, which is higher than that of the Normal Concrete in all the cylinders (cured for 7, 14 and 28 days).

4) Split Tensile Strength Test

Bacteria Used	Average Split Tensile Strength after 7 days (in MPa)	Average Split Tensile Strength after 14 days (in MPa)	Average Split Tensile Strength after 28 days (in MPa)
Normal Mix	2.4	2.82	3.15
Bacillus Subtilis	2.55	3	3.36
Bacillus Licheniformis	2.62	3.15	3.45

Table-3 Split Tensile Strength Test Results

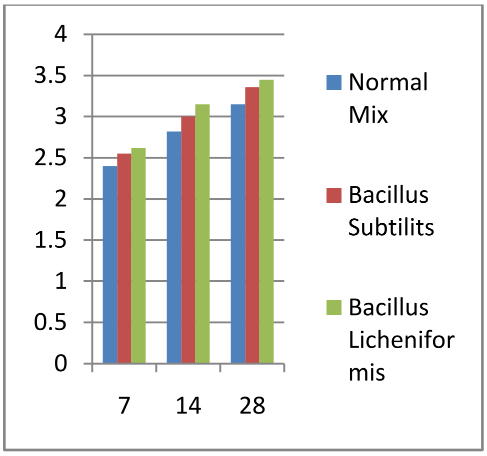

Fig. 6Split Tensile Strength Test results (x-axis and y-axis indicates curing period (in days) Split tensile strength (in MPa) respectively)

The table 3 and fig.6 shows that the Split Tensile Strength of the concrete made up of Bacillus Licheniformis is higher than the concrete made up of Bacillus Subtilis, which is higher than that of the Normal Concrete in all cylinders (cured for 7, 14 and 28 days) .

5) Flexural Strength Test

The table 4 and fig.7 shows that the Flexural Strength of the Normal Concrete is lesser than the concrete made up of Bacillus Subtilis, which is lesser than that of the concrete made up of Bacillus Licheniformis in all the prisms (cured for 7, 14 and 28 days).

Bacteria Used	Average Flexural Strength after 7 days (in MPa)	Average Flexural Strength after 14 days (in MPa)	Average Flexural Strength after 28 days (in MPa)
Normal Mix	3.8	4.27	4.71
Bacillus Subtilis	3.94	4.35	4.82
Bacillus Licheniformis	4	4.44	4.95

Table-4Flexural Strength Test results

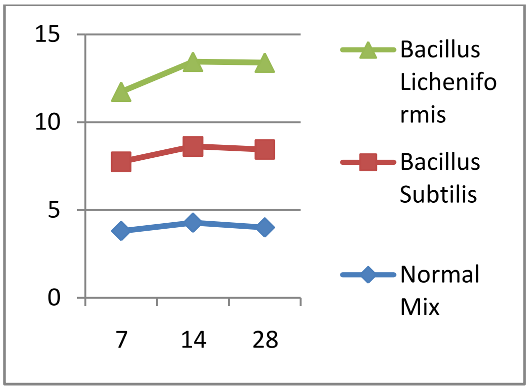

Fig. 7Flexural Strength Test results (x-axis and y-axis indicates curing period (in days) flexural strength (in MPa) respectively)

6) Water Absorption Test

Bacteria Used	Average Water Absorption after 28 days (in %)
Normal Mix	4.9
Bacillus Subtilis	2.6
Bacillus Licheniformis	2.35

Table-5Water Absorption Test results

The table 5 and fig.8 shows that the water absorption of the Normal Concrete is higher than the concrete made up of Bacillus Subtilis, which is higher than that of the concrete made up of Bacillus Licheniformis in all the prisms (cured for 28 days).

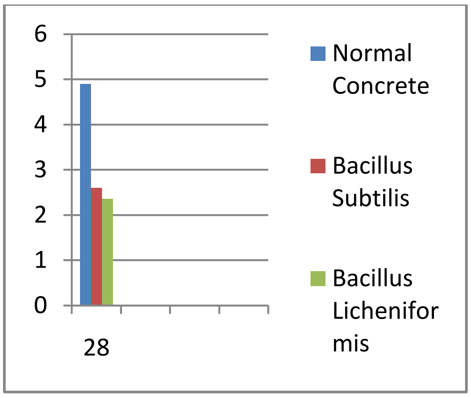

Fig. 8Water Absorption Test results(x-axis and y-axis indicates curing period(in days) water absorption (in %) respectively)

7) SEM Analysis of Self-healing Property

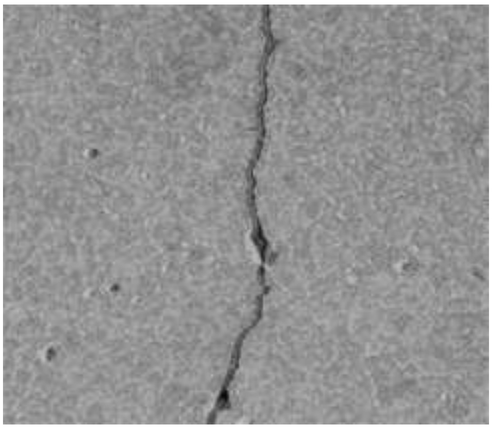

Fig. 9Crack in Normal Concrete after 28 days of Curing

The fig.9 shows the crack made in the Normal Concrete Cube (cured for 28 days)

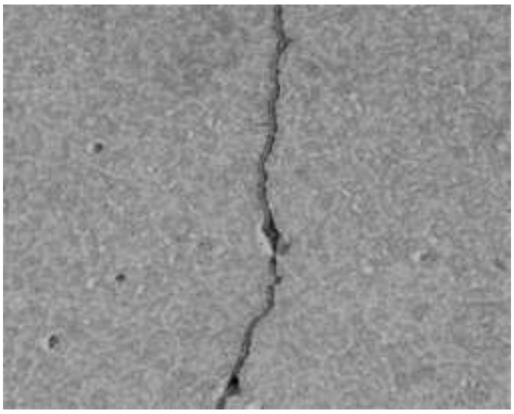

Fig. 10Crack in Normal Concrete after allowing for Self-healing

The fig.10 shows the crack on the Normal Concrete Cube after allowed for Self-healing (for 14 days) and it is found to remain same.

Fig. 11Crack in Bacillus Subtilis Sample after 28 days of Curing

The fig.11 shows the crack made in the Concrete Cube made up of Bacillus Subtilis (cured for 28 days)

Fig. 12Crack in Bacillus Subtilis sample after allowing for Self-healing

The fig.12 shows the crack on the Concrete Cube made up of Bacillus Subtilis after allowed for Self-healing (for 14 days) and it is found that the thickness of the crack decreases.

Fig. 13Crack in Bacillus Licheniformis Sample after 28 days of Curing

The fig.13 shows the crack made in the Concrete Cube made up of Bacillus Licheniformis (cured for 28 days)

Fig. 14Crack in Bacillus Licheniformis sample after allowing for Self-healing

The fig.14 shows the crack on the Concrete Cube made up of Bacillus Licheniformis after allowed for Self-healing (for 14 days) and it is found that the thickness of the crack decreases.

III. CONCLUSION

The bacterial concrete has good workability. Bacillus Subtilis and Bacillus Licheniformis can be produced in the lab and they are non-pathogenic and cost effective. The compressive strength of concrete cubes using Bacillus Subtilis and Bacillus Licheniformis has been increased upto 8% and 15% respectively. The compressive strength of Bacillus Licheniformis is 46.66% of Bacillus Subtilis. The split tensile strength of concrete cubes using Bacillus Subtilis and Bacillus Licheniformis has been increased upto 6.66% and 12.69% respectively. The split tensile strength of Bacillus Licheniformis is 47.52% of Bacillus Subtilis. The flexural strength of concrete cubes using Bacillus Subtilis and Bacillus Licheniformis has been increased upto 6.87% and 9.25% respectively. The flexural strength of Bacillus Licheniformis is 25.73% of Bacillus Subtilis. The water absorption value of concrete using Bacillus Subtilis and Bacillus Licheniformis has been decreased upto 46.93% and 52.04% respectively. The water absorption of Bacillus Licheniformis is 9.82% of Bacillus Subtilis. From the above it can be concluded that Bacillus Subtilis and Bacillus Licheniformis can be easily cultured and safely used in improving the strength characteristics of concrete.

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