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Bio Concrete-A Self-Healing of Cracked Concrete by Bacterial Approach

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***Abstract* – Carbonate producing bacteria have attracted lots of interest as promising natural, environmental friendly novel technique to the improvement of concrete characteristics. Considerable research has been conducted on utilizing microbial induced carbonate precipitation to mitigate several concrete problems such as crack repair, reduction and modification of porosity and permeability. Furthermore, bacterial carbonate precipitation has shown positive influence on compressive strength improvement of concrete. In general, cracks in the concrete structures are early signs of distress which have to be diagnosed properly otherwise the repair of same crack takes place again and again causing loss of time and money. This led to the evolution of self healing concrete. Self Healing Concrete is a term that is used for cement-based materials that repair themselves after the material or structure gets damaged due to some sort of deterioration mechanism. The vast literature review indicated that self healing mechanism can be achieved in various ways, by using certain polymers or by the use of certain species of bacteria. Self healing concrete prepared by using bacteria is called Bio-concrete. There are three approaches for bio-concrete, namely, autogenous, vascular, and capsule-based self-healing. Based on these factors, the present study attempted to interpret the efficiency of Bacillus subtilis as a self healing agent and to study the change in the properties of concrete due to the addition of this species. In the view of this, the primary objectives of this study were to analyze the healing capacity of Bacillus subtilis and the effect of its addition on the compressive strength of concrete. Basic tests such as sieve analysis, determination of specific gravity, compression tests on concrete and serial dilution technique were also performed.**

***Keywords*- –Bio concrete, bacteria, bacillus subtilise, Polymers, carbonate producing bacteria.**

I. INTRODUCTION

Concrete is one of the most widely used materials in the world. Being one of the most durable materials, concrete is used for different purposes. Concrete is strong, relatively cheap and durable and can be moulded into any shape. It can be made porous or water tight, heavy or light and will even harden under water. These and other variable characteristics of concrete make it ideal for many uses. Durability of concrete is highly reduced by cracks since they allow the entry of liquids and gases that may harm the concrete.

If micro cracks grow and reach the reinforcement, not only the concrete itself may be attacked, but also the reinforcement will be corroded. Therefore, it is important to control the crack width and to heal the cracks as soon as possible. The high costs involved in the maintainance and repair of concrete structures led to the development of self- healing concrete.Self Healing Concrete is a term that is used for cement-based materials that repair themselves after the material or structure gets damaged due to some sort of deterioration mechanism.Thebacteria,either Bacilluspseudofirmus or S porosarcina pasteurii, are found naturally in highly alkaline lakes near volcanoes, and are able to survive for up to a staggering 200 years without oxygen or food. They are activated when they come into contact with water and then use the calcium lactate as a food source, producing limestone that, as a result, closes up the cracks. He calls the material “bio concrete” that can “self-heal.”

II. EXPERIMENTAL INVESTIGATIONS

The materials used for the preparation of concrete were J.K. Lakshmi Ordinary Portland Cement (OPC) of grade 45, zone 2 sand, aggregates of nominal sizes 10 mm and 20 mm.

Fig.1 J.K. Lakshmi OPC 45 grade cement

Fig .2 Zone 2 sand


Fig.3 10mm aggregates


Fig. 420 mm aggregates.

Sand was air dried and pulverized. Cement was made free of lumps, if any. Basic laboratory test, that is, the Determination of specific gravity was conducted on the samples of these materials.

The species of bacteria used in the present study was Bacillus subtilise, a gram positive, spore forming bacteria, which can resist adverse conditions. Calcium lactate was used as the food source. The bacteria consume calcium lactate and precipitates calcium carbonate which heals the cracks formed in concrete.

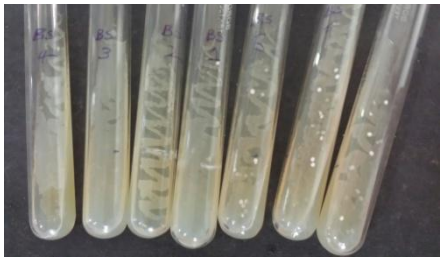
Fig.5 Bacillus Subtilises.

1. Determination of specific gravity

The density bottle along with the stopper was weighed (W1). The cement sample, which had been oven-dried, was transferred to the density bottle directly from the desiccators in which it was cooled. The bottles and contents together with the stopper were weighed (W2). Kerosene is added to it till the bottle was one-third filled and the bottle with cement sample, kerosene and the stopper was weighed (W3).

The bottle was then emptied, cleaned thoroughly and filled with kerosene. The stopper was fitted in the bottle; the bottle was wiped dry from the outside and weighed (W4). Three such observations were taken and the average value was recorded as the specific gravity of the cement sample.

2. Sieve Analysis

The sieve analysis determines the gradation, i.e., the distribution of aggregate particles, by size, within a given sample. The apparatus used are a set of IS Sieves of sizes – 80mm, 63mm, 50mm, 40mm,31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm,4.75mm, 3.35mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm and 75µm, a balance and balance with an accuracy to measure 0.1 percent of the weight of the test sample.


Fig. 6 Sieve Analysis

3. Casting of normal concrete cubes

A sample consists of 3 cube specimens and their average compressive strength represents the test result of that sample. The individual variation of a set of 3 cubes should not be more than ± 5% of the average. If more, the test result of the sample is invalid. The cement and fine aggregate were mixed on a water tight non-absorbent platform until the mixture was thoroughly blended and was of uniform colour.

Coarse aggregates were mixed with cement and fine aggregates until the coarse aggregate was uniformly distributed throughout the batch. Then water is added and mixed until the concrete appears to be homogenous and of desired consistency. This mixing can also be done using batch mixer. The moulds were cleaned and oil is applied on the inner faces of the mould. The concrete mixture was then placed in the moulds.

When compacting by vibration each layer was vibrated by means of an electric or pneumatic hammer or vibrator or by means of a suitable vibrating table until the specified condition is attained. The cubes were removed from the moulds at the end of 24 hours and immersed in clean water at a temperature 240C to 300C till the 7 or 28-days age of testing.


Fig.7 Vibration of Concrete

4. Slump Cone Test

The internal surface of the mould was cleaned and oil was applied. The mould was placed on a smooth horizontal non- porous base plate. The mould was filled with the prepared concrete mix in 4 approximately equal layers. Each layer was stamped with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mould.

For the subsequent layers, the tamping should penetrate into the underlying layer. The excess concrete was

removed and the surface was levelled with a trowel. The mortar or water leaked out between the mould and the base plate was cleaned. The mould was raised from the concrete immediately and slowly in vertical direction. The slump was measured as the difference between the height of the mould and that of height point of the specimen being tested.

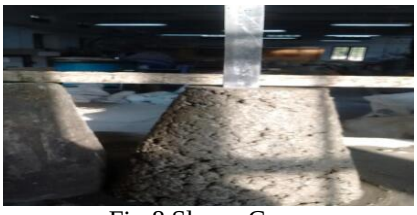

Fig.8 Slump Cone

5. Selection of bacteria

There are various types of bacteria that can be used in the concrete such as Bacillus subtilis, Bacillus pasteurii, Bacillus cohnii, Bacillus licheniformis etc. Bacillus Subtilis was selected in this study, due to its capability of producing calcium carbonate and due to ease of availability. It was formally known as hay bacillus or grass bacillus. It is a gram positive, catalane- positive bacterium, found in soil and gastric intestinal tract of ruminants and humans.

A member of the genus bacillus, Bacillus subtilus is rod shaped, and can form a tough, protective endospores, allowing it to tolerate extreme environmental conditions. Bacillus subtilus has historically been classified as an obligate aerobe, though evidence exists that it is a facultative aerobe.

Bacillus subtilis is considered the best studied gram positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation. It is one of the bacterial champions in secreted enzyme production and used on an industrial scale by biotechnology companies.

6. Cultivation of bacteria

The pure culture of bacteria i.e. Bacillus Subtilises was preserved on nutrient agar slants. It forms irregular dry and white colonies on nutrient agar slants. These colonies of bacteria obtained in the slants were removed by using surfactant and poured in the nutrient broth medium (liquid medium) of 200ml in a 250 ml conical flask and incubated at the temperature of 37 degree Celsius and 150 ml orbital shaker incubator.

7. Experimental procedure for cultural growth of bacteria

Bacillus subtilise is a common soil bacterium, which can produce calcium precipitation suitable media supplemented with calcium source. The bacteria were cultured in liquid medium according to suppliers recommendations. In the first step, from the pure culture 8 slants were sub cultured and incubated for 3 days. After 3 days, the slants were taken out from the incubator to remove the colonies obtained from the slants. Before taking out the colonies, a surfactant was prepared by placing two drops of Tween 20 (surfactant) in 10 ml of distilled water in 8 test tubes and was autoclaved. In the mean while, a nutrient broth medium of 180 ml was prepared in four 250 ml conical flasks, the medium used to grow bacteria consisted of 5.0 g peptone, 3.0 g meat extract, per liter of distilled water, to which 1.5% agar was added to obtain a solid medium for the stock culture. This medium was supplemented with 0.01 g MnSO4.H2O to enhance sporulation and pH was adjusted to 7.0 by using 1 N HCl.

The mixture was first sterilized by autoclaving for 20 min at 121oC and allowed to cool to room temperature (25oC). Then, the bacterial culture obtained along with the surfactant of 20ml (2 test tubes with 10ml culture each) was poured into the 4 conical flasks with prepared medium. Care is taken that the whole culturing process was performed under sterile conditions. Then, cultures were incubated at 30^{o}C on a shaker incubator at 130 rpm for 72 hrs.

Fig. 9 Bacterial culture.

8. Casting of Bio Concrete Cubes

Direct application method was used in this study. In the direct application method, bacterial spores and calcium lactate were added into concrete directly when mixing of concrete was done. The use of this bacteria and calcium lactate doesn't change the normal properties of concrete.

When cracks occur in the structure due to obvious reasons, the bacteria will be exposed to climatic changes. When water comes in contact with bacteria, they germinate and feed on calcium lactate and produce limestone, thus healing the cracks.The bacteria were added in different concentrations, i.e., 20, 30 and 40ml. The bacteria and the food were mixed in the ratio of 2:1, i.e., for a 30ml solution 20ml of bacterial solution and 10gms of food (calcium lactate) were added.

- For 30 ml solution - 20ml bacterial solution and 10 grams of calcium lactate was added.
- For 40 ml solution - 30ml bacterial solution and 15 grams of calcium lactate was added.
- For 60 ml solution - 40ml bacterial solution and 20 grams of calcium lactate was added.

After addition of bacterial solution the concrete was thoroughly mixed and was placed in the moulds,

compaction was done by the vibrator and the concrete was cured thereafter.

When the concrete was slightly hardened, small cracks, crack width not exceeding 200 micro meters, were provided on the surface of the cubes. The healing of the cracks during the curing period, shows the effectiveness of the healing agent.

9. Compressive test on normal concrete cubes

The cubes were tested after 7 and 28 days of curing. The cubes were taken from the curing tank, excess water was wiped out from the surface and the cubes were dried in air for about an hour. The dimension of the specimen was taken to the nearest 0.2m.

The bearing surface of the testing machine was cleaned. The specimen was placed in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. The specimen was aligned centrally on the base plate of the machine.

The movable portion was rotated gently by hand so that it touches the top surface of the specimen. The load was applied gradually without shock and continuously till the specimen failed. The maximum load was recorded and any unusual features in the type of failure were noted.

10. Compressive test on bio concrete cubes

The bio concrete cubes were tested after 28 days of curing period. The procedure for testing was similar to that of the normal concrete cubes. The aim of this test was to compare the compressive strength of normal concrete and bio concrete.

Fig. 10 Bio concrete cubes.

III. RESULT AND DISCUSSION

1. Determination of specific gravity of cement

Table 1 Determination of specific gravity of cement.

Weight of empty density bottle, W1	26.5 g
Weight of density bottle + cement, W2	36.96 g
Weight of density bottle + cement + kerosene, W3	71.88 g
Weight of density bottle filled with kerosene, W4	64.08 g

Specific Gravity of cement =3.15

Table 2 Determination of specific gravity of 20

Weight of empty pycnometer, W_1	574 g
Weight of pycnometer + aggregate, W_2	1698.5 g
Weight of pycnometer + aggregate + water, W_3	2628.83 g
Weight of pycnometer filled with water, W_4	1900 g

Specific Gravity of 20 mm aggregates =2.842

Table 3 Determination of specific gravity of 10 mm coarse aggregate

Weight of empty pycnometer, W_1	574 g
Weight of pycnometer + aggregate, W_2	1501 g
Weight of pycnometer + aggregate + water, W_3	2499.48 g
Weight of pycnometer filled with water, W_4	1900 g

Specific Gravity of 10 mm aggregates=2.836

Table 4 Determination of specific gravity of fine.

Weight of empty pycnometer, W_1	574 g
Weight of pycnometer + aggregate, W_2	1824 g
Weight of pycnometer + aggregate + water, W_3	2676.5 g
Weight of pycnometer filled with water, W_4	1900 g

Specific Gravity of fine aggregates =2.64

2. Sieve Analyses

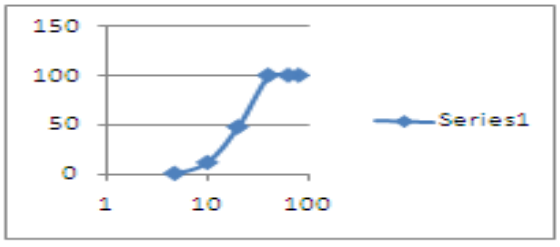

Fig.11 Gradation of Coarse Aggregate

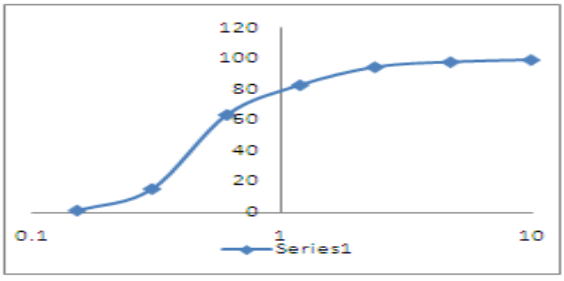

Fig.12 Gradation Curve For Fine Aggregates

2. Strength of normal concrete cubes

The concrete cubes were tested after 7 and 28 days of curing. The compressive strength obtained were as follows:

7 days strength

Table 5 7 days strength of normal concrete

Trial	Maximu load(in kN) F	Compressive strength (in MPa) = F/A
1.	520	23.11
2.	530	23.55
3.	530	23.55

Where A is area of cross-section of the cube = 15 × 15 = 225 cm^2

Average 7 days strength = 23.40 M Pa

28 days compressive strength

Table 6 28 days strength of normal concrete

Trail	Maximum load (in kN)F	Compressive strength (in M Pa) = F/A
1.	720	32
2.	730	32.44
3.	720	32

where A is area of cross-section of the cube = 15 × 15 = 225 cm^2

Average 28 days strength = 32.15 Mpa.

3. Healing Capacity of Bacillus subtilis

Bacillus subtilis was found to be very effective in healing small cracks. As per previous literatures, autogenous method can be used to heal cracks of very less width of about 200 microns. The smaller cracks were completely healed within 14 days of curing as shown in the following figures

Fig.13 20 ml inoculum + 10 g calcium Lactate 1 day shaking.

Fig.14 40 ml inoculums + 20 g calcium Lactat 5 days shaking.

IV. SUMMARY AND CONCLUSION

The present study was conducted to analyze the effectiveness of Bacillus subtilis as a self healing agent. Bio concrete was prepared by autogenous approach. The limitations of this aproach were dependency on age of concrete, need for a long-lasting internal source of water, survival of bacteria for carbonate precipitation and need for limitation on the width of the crack that can be healed. This method can be used for healing of cracks upto a width of 200 microns, in the areas where water source is available.

In the present study, bio concrete was successfully prepared. Bacillus subtilis effectively healed the tiny cracks, introduced in the concrete at the time of casting the cubes. However, the cracks of larger width could not be healed by this species. Hence it was proved that the autogenous method of self healing of cracks imposes a limitation on the crack width to be healed.

Also, the concentrations of bacteria added to the concrete were varied. It was observed that the healing capacity was greater for higher concetrations of bacteria. The bio concrete prepared with 40 ml inoculum and 20 g of calcium lactate sealed the cracks more effectively. All the tiny cracks disappeared completely within 14 days of curing. The bio concrete prepared with 30 ml inoculum and 15 g food was also capable of healing all the tiny cracks completely. Bio concrete prepared with 20 ml inoculum and 10 g food was comparatively less effective.

It was observed that there was an effect of shaking period of bacteria on the self healing capacity. The 1 day shaking period for bacteria was found to be more effective. The inoculum subjected to 3 and 5 days of shaking was relatively less effective when compared to the inoculum which was subjected to 1 day shaking.

Compression test on the bio concrete cubes are yet to be conducted. The results of this test can be compared to that of the normal concrete cubes to study the effect of concentration, shaking period and the addition of bacteria on the strength of concrete.

Therefore, the following conclusions can be drawn from the present study :

- Bio concrete prepared using Bacillus subtilis using autogenous method was effective in healing micro cracks.
- However, cracks of larger width could be healed.
- Greater the concentration of bacteria added to the concrete, more was healing capacity.
- Self healing mechanism occurs only in the prescence of water as water is required to activate the bacterial spores.
- Inoculum subjected to 1 day shaking in the incubator was the most effective in healing cracks.

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