Experimental Study on Flexural Behaviour of Self Healing Concrete using Bacillus Substilis Bacteria

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***Abstract*— This investigation experimentally deals with the crack healing ability of bacteria, like a small cut in our body can be healed by a simple treatment. The cracks in the concrete is the major problem in construction industry. The repair of cracks is usually carried out by means of some kind of human intervention. As regular and manual maintenance of cracks repair in construction industry is costly and in some cases not at all possible. To solve this problem, insertion of bacteria can be highly favorable as it could both reduce maintenance and increase the durability of concrete. In this study a specific group of alkali resistant spore farming bacteria Bacillus Substilis were selected and added in different proportions with silica gel and calcium carbonate in a glass tube and is kept in the concrete during casting. The M20 grade concrete was used. The cube and cylinder specimens were tested for compressive and split tensile strength test up to the initial cracks at the age of 7, 14 and 28 days. The optimum quantity of bacteria was found from the test results. Beam specimens were casted for the optimum mix and tested for flexural behavior. The Load carrying capacity, Energy absorption capacity, Stiffness and Ductility characteristics of Self-Healing Concrete beam were found and compared with the conventional concrete beam. The test results shows Self -Healing Concrete beam attained higher load carrying capacity, energy absorption capacity and deflection and lesser stiffness and ductility when compared to the conventional concrete beam.**

Keywords—Self heal, Bacillus substilis, Bacteria, Calcite precipitation, Compressive strength, Split tensile strength, Flexural behaviour.

I. INTRODUCTION

Concrete is a strong and relatively cheap construction material and therefore presently used all over the planet and generally measured as imperishable because of their longer service life as compared with the most constructional products. It is a composite material inclusive of cement, fine aggregate, coarse aggregate and water. However, they can get destroyed for exposure conditions, material quality, improper design and low construction practices.

The Self-healing Concrete is the one which senses crack formation and treat itself without human intrusion. Self-healing concrete can produce limestone biologically to repair cracks that appear on the surface of concrete structures. Specially selected types of the bacteria Bacillus is added to the ingredients of the concrete when it is being mixed. These self-healing content can lie inactive within the concrete up to 200 years. The bacterial concrete can be made by injecting bacteria in the concrete that are able to constantly precipitate calcite. Bacillus is a soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. The encouraging conditions do not openly exist in a concrete but have to be created.

II. MATERIAL PROPERTIES

A. Cement

Ordinary Portland Cement of grade 53 was used in this investigation. The property of cement was represented in Table-1.

TABLE -1: PROPERTIES OF CEMENT

Property	Values
Specific Gravity	3.15
Initial Setting Time	37 minutes
Final Setting Time	570 minutes

B. Fine Aggregate

Locally available river sand was used which is passing through 4.75mm sieve. Physical properties of aggregates are found per IS :2386 -1968 and the results are shown in Table-2.

TABLE -2: PROPERTIES OF FINE AGGREGATE

Property	Values
Specific gravity	2.67
Grading Zone	II
Water Absorption (%)	2.55%
Fineness modulus	2.87
Bulk Density (kg/m3)	1678

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C. Coarse Aggregate

Coarse aggregates were collected from permitted quarry and having size of 10mm to 20mm used. The tests are carried out for coarse aggregate as per IS 2386-1968 and the results are given in table-3.

TABLE -3: PROPERTIES OF COARSE AGGREGATE

Property	Values
Specific gravity	2.78
Fineness Modulus	7.74
Water Absorption(%)	1.32%
Bulk Density (kg/m^3)	1755

D. Bacteria

Bacillus substilis is an obligate aerobe bacterium used as a larvicide for mosquito control. It makes spherical endospores. Bacillus substilis is a rod shaped gram positive bacteria which form chains-Medium-sized, smooth colonies with an entire margin. Bacillus substilis is Gram-variable, huge, spore-forming rods and which have diameter less than 0.9µm. Catalase -positive. The Growing range of Temperature is $37^{o}C$. Optimum Temperature is $35^{o}C$ to $37^{o}C$. The density of bacteria used is 106 cells/ml.

E. Culture of Bacteria

1) Inoculation of the Bacteria

The bacteria of primed cell concentration are then inoculated in the arranged broth medium keeping it inside the Laminar Air flow chamber. The Air flow chamber is initially cleaned with the help of methylated spirit and UV radiation which is used to kill the microbes present inside the chamber. The civilization was splashed on nutrient broth with an inoculating loop and the slants were incubated at 37 °C. It ensure that the quality of cultured species. Inside the chamber total backflow of atmospheric air is stopped in which the entry of hazardous microbes can be stopped. For growth of bacteria can be achieved by fired of spirit lamp which increasing the temperature. Intense care must be taken throughout the process to make sure the quality and cleanliness. By using the methylated spirit as sanitizer in hands, cleanliness can be achieved. The face mask may be used to make sure quality of cultured bacteria by avoiding the flow of microbes (if present) into the culture.

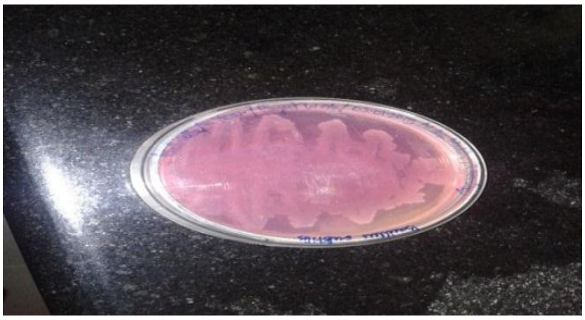

Fig. 1: Inoculation of bacillus substilis bacteria

2) Incubation

The bacteria in inoculated broth medium are now incubated and the incubator temperature of about 34 °C for the period of 20 to 24 hours. This is usually done for the growth of bacteria. since the growth can be enhanced at this temperature level.

Fig. 2: Incubation of bacillus substilis bacteria

3) Storage of Stock Culture

The inoculated broth medium is kept inside the incubator at least 12 to 14 hours at usual room temperature for its cell growth.

4) Maintenance of Stock Cultures

Cultures of Bacillus Substilis were maintained on nutrient broth culture. later than 20 to 24 hours of growth, slant cultures were conserved under refrigeration (12 °C) until further use. Sub culturing was carried out at the interval of every 15 hours. Pollution from other bacteria was checked at times by streaking on nutrient broth plates.

III. CONCRETE MIX PROPORTIONS

The M20 grade of proportioning was done according the Indian Standard Recommended Method IS 10262- 2009 and with reference to IS 456-2000 .The total cement content was 367 Kg/m^3, fine aggregate was taken as 655 Kg/ m^3 and coarse aggregate was taken as 1222 Kg/m^3. Water absorption capacity and moisture content were taken into attention. Cement, Fine aggregate and Coarse aggregate were homogeneously mixed together in the ratio of 1: 1.86: 3.47 by weight before water was added and uniformly mixed. Compaction of concrete in three layers is done and the concrete was left in the mould and permitted to set for 24 hours before the specimens were demoulded. Then specimens were immersed in water for curing for a period of 28 days.

IV. TEST & TEST PROCEDURE

A. Compressive Strength Test

The compressive strength of concrete cube was determined as per IS: 516 –1959. The specimen was placed in the compression testing machine in such a manner that the load applied should be to the contrary sides of the cubes as cast, that is not to the top and bottom. The compressive strength test is conducted in the Compression Testing Machine of 2000kN capacity. The casted cubes after curing are tested in compression testing machine of 2000kN capacity. The load is applied on the opposite side of the cubes as cast. The axis of

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the specimen is carefully aligned on the testing machine. The load is applied gradually until the specimen cracked of crack. Then the cracked specimen is kept in air. After 12 days the test procedure is repeated on the cracked specimen. The test results are paralleled.

Typical image of compression test setup represented below in Fig 3.

Fig. 3: Compressive strength test

Table 4 shows the result of cube compressive strength test.

TABLE -4: CUBE COMPRESSIVE STRENGTH

Si.No	Concrete Mix	Compressive strength at initial crack load (N/mm²)					
		7 Days	*Strength after 12 Days*	*14 Days*	*Strength after 12 Days*	*28 Days*	*Strength after 12 Days*
1	M1	9.85	7.48	14.55	11.45	15.06	12.23
2	M2	9.60	8.78	13.90	12.35	15.87	14.40
3	M3	9.76	9.42	14.36	13.88	15.65	15.27

TABLE -5: REGAIN PERCENTAGE OF COMPRESSIVE STRENGTH

Si.No	Concrete Mix	Average Regain of Compressive Strength in N/mm²			
		7 days	*14 days*	*28 Days*	*Average Regain*
1	M1	75.94	78.69	81.21	78.61
2	M2	91.46	88.85	90.74	90.35
3	M3	96.52	96.66	97.57	96.92

From the table 4, compressive test results of cubes at 7 days, 14 days and 28 days have been observed. And Table 5 shows lesser regain of compressive strength for mix M1 and M2 and almost equal regain of compressive strength for M3. Where M1, M2 & M3 concrete mix consist bacteria concentration of 1 litre/m^3, 2 litre/m^3 & 3 litre/m^3 respectively.

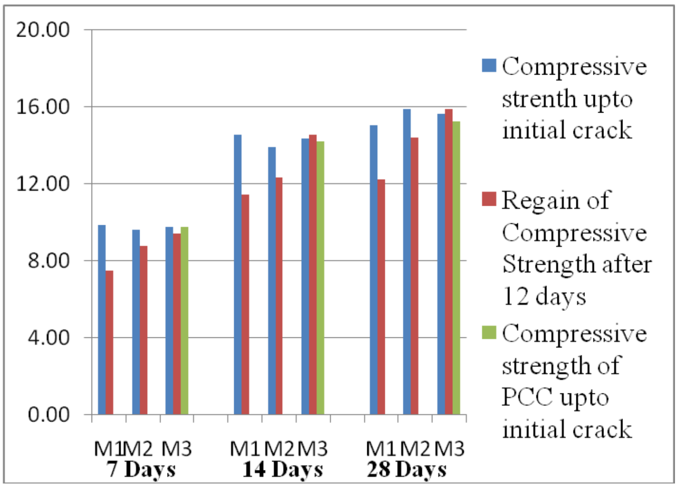

Chart -1: Compressive strength of cubes

B. Split Tensile Strength Test

The split tensile strength of the cylinder was calculated as per IS 5816:1999. For tensile strength test, the dimensions of specimens were 150 mm diameter and 300 mm length was casted. In this test three cylinders were tested and their average value was reported. The split tension test was conducted by using digital compression machine having 2000 kN capacity.

Split tensile strength was calculated by using following formula:

Spilt Tensile strength (N/mm^2) = $2P / \pi DL$

Where, P = Failure Load (kN)
D = Diameter of Specimen (mm)
L = Length of Specimen (mm)

Test results of split tensile strength for M1, M2 and M3 are listed in table 6 below.

TABLE -6: TENSILE STRENGTH OF CYLINDERS

Si.No	Concrete Mix	Split tensile strength at initial crack load (N/mm²)					
		7 Days	*Strength after 12 Days*	*14 Days*	*Strength after 12 Days*	*28 Days*	*Strength after 12 Days*
1	M1	2.35	1.67	3.10	2.30	3.97	3.16
2	M2	2.14	1.95	3.35	2.92	4.14	3.70
3	M3	2.10	1.92	3.15	2.95	3.85	3.70

From the Table 6, Split tensile test results of cylinder at 7 days, 14 days and 28 days has been observed.

TABLE -7: REGAIN PERCENTAGE OF SPLIT TENSILE STRENGTH

Si.No	Concrete Mix	Average Regain of Split Tensile Strength in N/mm^2			
		7 days	14 days	28 Days	Average Regain
1	M1	71.07	74.19	81.21	79.59
2	M2	91.12	87.16	90.74	89.37
3	M3	91.42	93.65	97.57	96.10

The above test results show lesser regain of split tensile strength for M1 and M2 and almost equal regain of split tensile strength for M3 are observed.

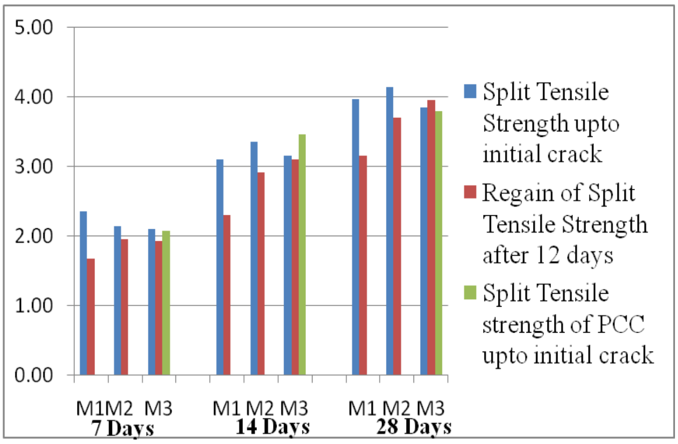

Chart -2: Split Tensile Strength

From the Compressive and Split Tensile strength test results we found the optimum content of bacteria: M3, Hence the beam was casted for M3 and tested for up to initial cracks. After 12 days the beam was again tested for flexure.

C. Flexural Test

The beam was exposed to two points loading to expose the behaviour of the RCC beam. As the load increases the crack width is also improved and prolonged towards the top of the beam. The mode of failure of RCC beam was flexure which is due to yielding of steel in tension zone. The concrete was crushed and spalling down. Fig. 4 represents the failure pattern of RCC beam

Fig -4: Failure mode of RCC beam

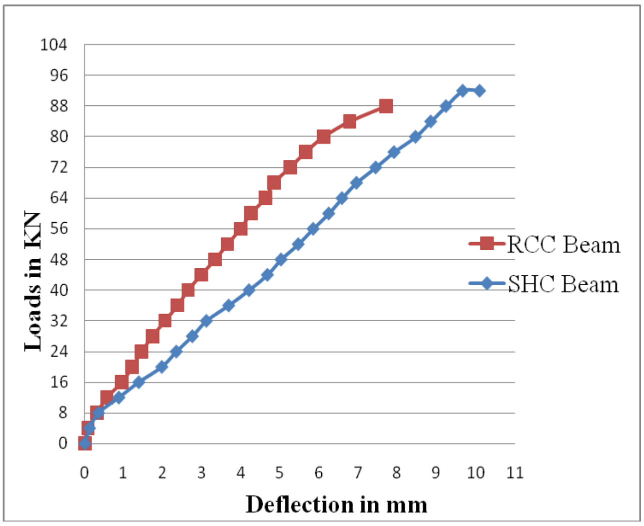

Chart -3: Load-Deflection curve

1) Energy Absorption Capacity of Beams

The cumulative energy absorption capacity of RCC and SHC beams are plotted as in the Chart -4 shows below. The Self-Healing Concrete beams shows higher Energy absorption value when compared to RCC beams.

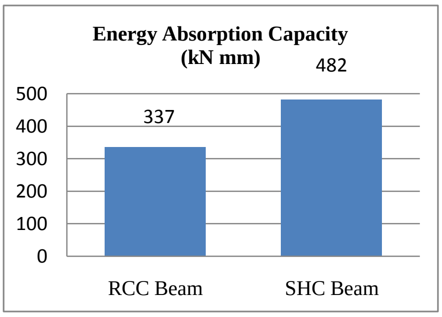

Chart -4: Energy Absorption Capacity

2) Stiffness Factor of Beams

The stiffness factor of RCC and SHC beams under lateral monotonic loading was calculated and comparison chart was drawn as shown in Chart -5. The SHC beam shows lesser stiffness when compare to RCC beam.

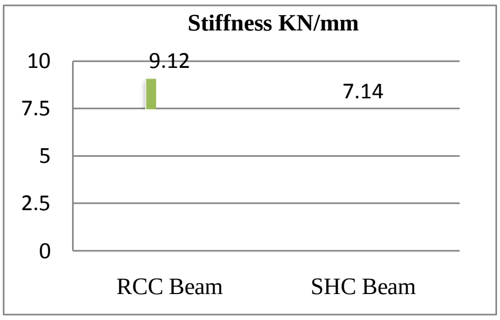

Chart -5: Stiffness of Beams

3) Ductility Factor of Beams

The ductility factor of RCC and SHC beams under lateral monotonic loading was calculated and comparison chart was drawn as shown in Chart -6. The SHC beam shows lesser ductility when compare to RCC beam.

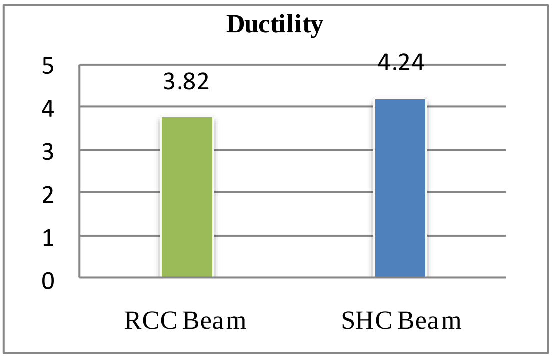

Chart -6: Ductility of Beams

V. CONCLUSIONS

The following conclusions are arrived from the conducted experimental study and the results are indicated as follows.

- When the Bacterial concentration increases the Calcite precipitation increases.
- The load carrying capacity of conventional beam and Self- healing concrete beam were found as 88 KN and 92 KN respectively.
- The deflection of Conventional beam and SHC beams were found as 7.75 mm and 10.1 mm for the ultimate load.
- The energy absorption capacity of SHC beams was found as 481.76 KN-mm which is 30% greater than that of RCC beams.
- The stiffness factor of SHC beam was 21.70% lesser than Conventional beams.
- The ductility factor for SHC beams was 4.24 where as for conventional beam was 3.82.
- The ingress of liquids and ions that start reinforcement corrosion can be stopped and thus durability of the structure is enhanced.

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