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Mechanical and Microstructural Characteristics of Self-Healing Bacterial Concrete

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Abstract*: *Concrete is a major part of construction material in the world. The major drawback of concrete is easily cracks by low tensile strength. The innovative technology of introducing bacteria in the concrete to self-remediating of cracks in concrete. Formation of calcium carbonate in the crack surface due to the improvement of crack sealing performance. This current study focus on self-healing development of concrete. An MICCP (Microbiologically Induced Calcium Carbonate Precipitation) technique is an occurrence in managing the concrete cracks. Three different cell concentration of bacillus subtilis bacteria (20×10^5, 20×10^6 and 20×10^7 cells/ml) were introducing in concrete specimen, to find the optimum concentration of bacteria cell. From the optimum cell concentration the crack width measurements are carried out at the age of 7 days, 14 days and 28 days respectively. To calculate the crack width by two (Wet &Dry) different methods of healing agents were used. Microbial concrete have that enhancement of compressive and tensile strength. The formation of calcium carbonate was observed and visualized by scanning electron microscopy (SEM). Chemical composition of sample analyzed by energy dispersive spectrometer (EDS). Identification and quantification of bacterial concrete observed by X-ray diffraction (XRD).

Keywords: Bacillus Subtilis, EDS, MICCP, SEM, XRD

I. INTRODUCTION

In the concrete structures, cracking is a major problem due to shrinkage. Concrete structures hardness and dried to be shrinks. Another problem, excess of water in the concrete mix does not required to achieve the maximum strength. This excess water highly reduce the strength of concrete structures. Several crack repairing techniques are available, the traditional repairing systems number of disadvantages such as thermal expansion, bonding and environment. Bacillus subtilis bacteria introduce the concrete to avoid the cracks and obtain the maximum strength eco-friendly and biologically. When the water enter into crack portion of concrete reacts with bacillus subtilis bacteria and form $CaCO_3$ and makes crack filling concrete.

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Bacteria can produce $CaCO_3$ precipitation in the concrete surface. An MICCP technique involves the hydrolysis of urea by enzyme which produces the micro-organisms of calcium carbonate precipitation. Microbes can be used for carbonate mineralization. This mineralization by microbes is known microbial $CaCO_3$ precipitation. Microorganism involved in this process are called carbonate\mineralizing bacteria. An MICCP technique cure the cracks automatically and the bacillus subtilis bacteria is used to produce the better bonding capacity and permeability. Use of manufacturing of bacterial concrete has increases the performance both mechanical and durability. Resist the freeze and thaw attacks. Reduce the permeability also reduces the corrosion of steel due to crack formation, improves the durability of steel reinforced concrete.

Tziviloglou [1] has described that the self-healing agent is impregnated in light weight aggregate. The concrete with and without bacteria is compared by measuring the crack, water permeability, oxygen consumption, SEM analysis and water tightening recovery test. Crack open gets increased by 0.5µm/s and the lightweight mortar incorporates the bacteria based healing agent which improves the crack than the continuous water immersion. Sandip Mondal [2] observed that the Bacillus subtilis bacteria with different concentrations are discussed. From the results, it was found to be 10^7 cells/ml bacterial concentration (crack width upto 1.2 mm) is more effective for crack healing. Virinine Wiktor [3] discussed that the applied two component of bio-chemical self-healing agent consist of a mixture of bacterial spores and calcium lactate can be successfully applied to promote the self-healing capacity of concrete. The experimental values shows that the crack healing upto 0.46mm wide cracks in the bacterial concrete but only up to 0.18mm wide cracks to control the specimen. Abhishek Thakur [4] discussed about various approaches for addition of bacteria in concrete. This paper explain the some selective media for growth of different bacteria. Bacillus sphaericus, bacillus subtilis, bacillus flexus higher ability of calcite precipitation. Metabolic products and nutrients used for growing calcifying microorganisms. Kunamineni Vijay [5] deals with the types of bacteria used in concrete and the ways that can be applied as a healing agents. Encapsulation method gives better result to direct application method. Microbial concrete can be an alternative and high quality concrete sealant which is cost effective and gets improved in the durability of materials. Dileep Kumar Reddy [6] Bacteria directly added in the concrete mix. Bacterial was added to different concentrations 15ml, 30ml, 45ml, 60ml.

Increasing the compressive strength of 45ml and 60 ml bacterial concrete using bacillus subtilis for 7 days is higher than conventional concrete. A microbiologically induced calcium precipitation fill the cracks automatically. Nidhi nain [7] described about the strength parameters of concrete by adding the bacillus mageterium, bacillus subtilis, consortia and controlled concrete. Bacillus mageterium gives higher compressive strength and bacillus subtilis gives higher tensile strength. Bacillus subtilis and bacillus megaterium and consortia of both found to be higher by 15% and more when compared with the conventional concrete. After introducing the bacteria in the concrete specimen along the nutrient, genus bacillus not only proved to be efficient in crack healing ability but also plays a vital role to increase the strength.

II. EXPERIMENTAL INVESTIGATION

A. Materials

In this experiment, consists of OPC (Ordinary Portland Cement) 53 grade, fine aggregate (M-Sand, passing through 4.75 micro sieve), coarse aggregate (20mm downsize), potable water. Two components of self-healing agent are used in this research, the agent consists of bacillus subtilis bacteria and organic minerals like starch, jaggery powder, and yeast powder.

B. Test Specimens and Procedure

Specimens were removed after 24 hours of casting, were cured in potable water at controlled temperature. For all the mix proportion samples for two different dimensions were made. Cube specimens of size used 150×150×150 mm. Cylinder specimens of size 150mm dia and 300mm height. Totally 24 cubes and 16 cylinder were casted. For each proportion 6 cubes and 4 cylinder were tested.

Compressive strength were performed at the ages of 7, 14, 28 days. The specimens are prepared to check the self–healing process after cracking in wet and dry conditions at regular interval of 7, 14 and 28 days of curing. Crack width were measured at different points of the specimens, after measuring the self-healing of crack at the interval of 7, 14 and 28 days and the difference between the original crack was detected.

C. Cultivation of Bacteria

The soil sample were collected from 7 cm depth of agricultural land. Isolation process by serial dilution technique was used. Adopted for 10 g of soil sample was diluted in 100 ml of sterile, 200 ml of distilled water in a conical flask and preserved in orbital shaker at 160 rpm to get a homogeneous soil interruption. The serial dilution was incubated in 37 ºC for 24 hours. Isolated colonies on each diluted plates were transferred into a nutrient agar slants. The bacterial strain were kept in cooling condition for further research. The characteristics of bacillus subtilis bacteria are shown in the Table I.

Table- I: Characteristics of Bacillus Subtilis

Characteristics	Bacillus Subtilis
Shape	Rod shape
Size	4-10 µm
Gram Strain	Gram positive
Colony Morphology	Circular, white or slightly yellow
Lactose	No acid, No gas
Dextrose	No acid, No gas
Sucrose	Acid and gas

D. Mass Multiplication of Bacillus Subtilis

Mass multiplication of bacillus subtilis bacteria with nutrient broth medium were used. Nutrient broth medium is one of the general tenacity for bacteria culture. Nutrient broth is a composition of beef extract and peptone. Peptone provides the organic nitrogen, amino acids, and fatty acids. Lean beef tissue provides the vitamins, carbohydrates, salts and other essential growth nutrients. The ingredients of nutrient broth medium shown in the Table II.

The nutrient broth medium was taken in the conical flask, autoclave and bacillus subtilis were inoculated in nutrient broth medium and incubated for 2 days at 15 lb pressure for 20min. Mass multiplication of the nutrient broth culture was added at 1000ml of water was maintained at room temperature for 2 days.

Table- II: Composition of Nutrient Broth

Ingredients	Grams/lit
Peptone	5.0g
Yeast extract	3.0g
Beef extract	3.0g
Sodium Chloride	3.0g
Glucose	5.0g

III. TEST METHODS AND RESULTS

A. Water Absorption Test

Water absorption characteristics shows an important role for durability. The test were executed mainly for calculating the water absorption characteristics of bacterial concrete and control concrete. Initially, the concrete cubes were oven dried at 105ºC for 24 hours and dry weight of the specimens gets measured. The cubes were kept in water (saturated condition) at room temperature for 24 hours and weighed again.

The water absorption of control and bacterial concrete at 7 and 28 days curing indicates the presence of bacteria in concrete mixes reduce the water absorption at all cell concentration. Besides, water absorption decreases with increase of bacterial cells in the mix, in that way the maximum reduction is attained at the cell concentration 10^6 cells/ml. at 28 days of curing. The water absorption results were tabulated in the Table III.

Table- III: Water Absorption Test

Mix ID	Water absorption (%) @ 7 days	Water absorption (%) @ 28 days
Control concrete	0.9	1.35

10^5cells/ml	0.85	1.05
10^6 cells/ml	0.12	0.33
10^7cells/ml	0.32	0.56

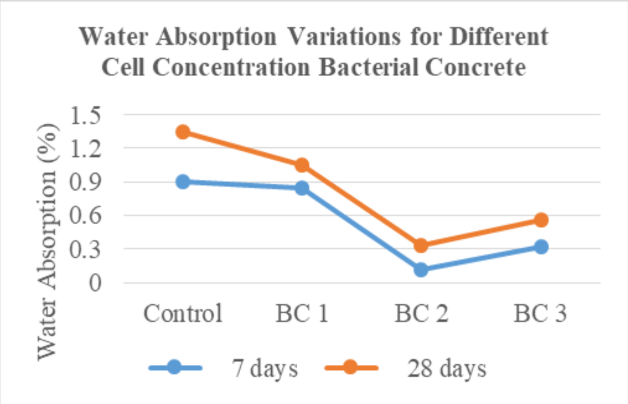


Fig. 1. Test Results of Water Absorption

B. Ultrasonic Pulse Velocity

Ultrasonic Pulse Velocity testing of concrete is based on the pulse velocity method mainly to provide the information on the uniformity of concrete presence of voids, cracks, defects. The pulse velocity depends upon its density and elastic properties.

The UPV test on control and bacterial concrete specimens under direct method of testing were done. UPV test used to measure correlation of pulse velocity and quality of concrete. High pulse velocity of bacterial concrete filling the crack arrested by the $CaCO_3$ precipitation. The pulse velocity can be calculated and tabulated in the Table IV.

Table- IV: Pulse Velocity

Mix ID	Ultrasonic Pulse Velocity (km/s)		
	7 days	*14 days*	*28 days*
Control concrete	3.98	4.26	4.6
10^5cells/ml	4.42	4.68	4.76
10^6 cells/ml	5.10	5.24	5.68
10^7cells/ml	4.62	4.84	4.98

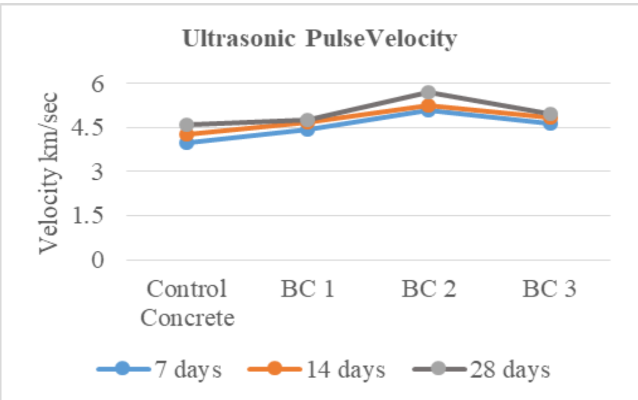


Fig. 2. Test Result of UPV

C. Compressive Test Result

The compressive test is used to determine the hardness of concrete. The strength of a concrete specimen depends upon cement, aggregate, bond temperature water-cement ratio. The load was applied to the specimen continuously until visible cracks appeared on the surface. The test is carried out by following the guide lines of IS: 3495(part 1) – 1992.The high compressive strength was observed for concrete specimen with bacillus bacteria.it shows an increases of bacterial concrete than without bacteria.

The result shows that the strength is improved by combination of bacteria in all the considered concentrations at all ages. The maximum improvement in strength is succeeded at the cell concentration of 10^6 cells/ml at all ages. The compressive strength were tabulated in the Table V.

Table- V: Compressive Strength

Mix ID	Compressive Strength @ First Crack			Compressive Strength @ Ultimate Load		
	7 day	*14 day*	*28 day*	*7 day*	*14 day*	*28 day*
Control concrete	2.92	4.13	6.30	9.96	15.16	20.98
10^5cells/ml	3.79	5.42	7.98	20.21	23.16	29.18
10^6cells/ml	4.78	5.60	8.56	22.20	27.56	32.12
10^7cells/ml	4.32	5.28	7.76	19.68	22.54	24.10

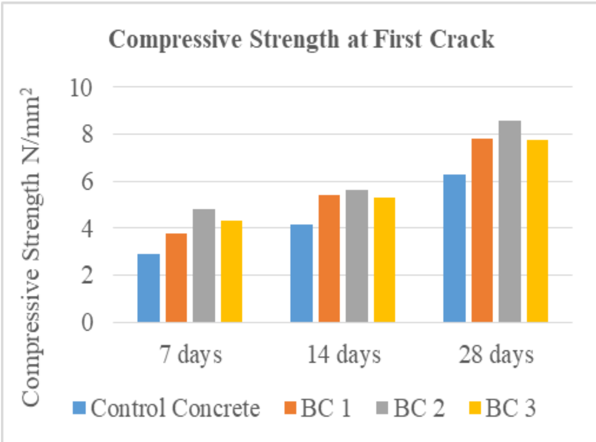


Fig. 3. Test Result of Compressive Strength at First Crack

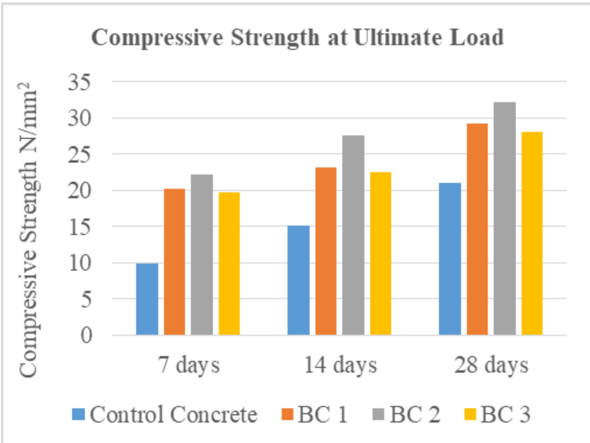


Fig. 4. Test Result of Compressive Strength at Ultimate Load

D. Split Tensile Test

An indirect testing method (split tensile) can be performed when direct method is not applicable to find the true axial load. The tests were done on the smooth surface of the concrete with the help of the base plates. The splitting of the cylinder across the vertical diameter occurs. The tensile strength were tabulated in the Table VI.

Table- VI: Split Tensile Strength

Mix ID	Average Split Tensile Strength of Concrete	
	14 days	*28 days*
Control concrete	1.12	1.68
10^5cells/ml	1.76	2.25
10^6 cells/ml	1.95	2.98
10^7cells/ml	1.80	2.56

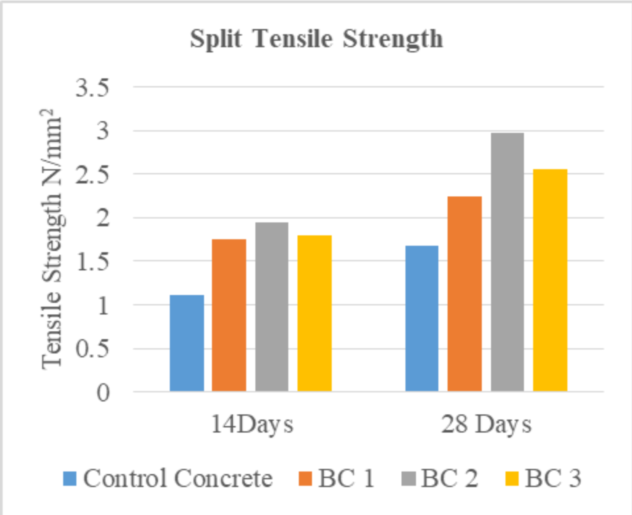
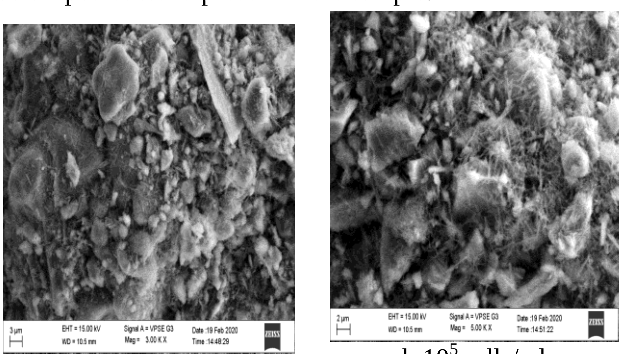


Fig. 5. Test Result of SplitTensile Strength

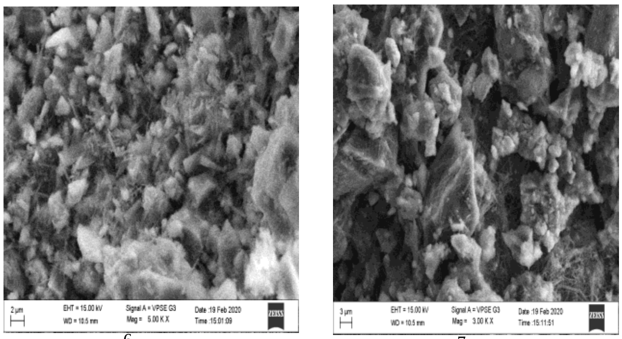
IV. MICROSTRUCTUAL INVESTIGATION

A. SEM Analysis

Scanning Electron Microscope analysis can be used to determine the presence of $CaCO_3$ crystals inside by bacterial concrete. SEM is an electronic microscope which produces an image scanned with an absorbed beam of electrons. The electrons act together with each electrons in the sample specimen that creates the various signals can be identified, which contains information about the sample topography and composition. The porosity was reduced due to presence of bacterial concentration. Morphology test used to identify the rod shaped bacteria present in the sample.



a.Control Concrete b.10^5 cells/ml



c.10^6 cells/ml d. 10^7cells/ml

Fig. 6.SE analysis

B. EDXM

Energy Dispersive X-ray (EDX) method used to detect the element composition of material. The presence of calcium element can be recognized by using EDX analysis and can be used to correlate with the presence of $CaCO_3$.

Element Line	Weight %	Weight % Error	Atom %
C K	6.79	± 1.00	11.35
O K	52.16	± 1.79	65.47
Mg K	0.82	± 0.14	0.68
Al K	1.72	± 0.16	1.28
Si K	8.09	± 0.35	5.78
Si L	---	---	---
S K	1.59	± 0.16	1.00
S L	---	---	---
Ca K	28.84	± 0.77	14.45
Ca L	---	---	---
Total	100.00		100.00

Fig. 7. EDX Analysis Result

C.XRD

X-Ray Diffraction is a technique used to understand the crystalline, different polymeric forms and mineral properties of material. The presence of $CaCO_3$ and calcium silicate hydrate (CSH) in the concrete sample with bacillus subtilis bacteria can be identified by using X-Ray diffraction analysis. The presence of calcite peaks will conform the $CaCO_3$ precipitation by bacteria which is intended for increasing the strength of concrete.

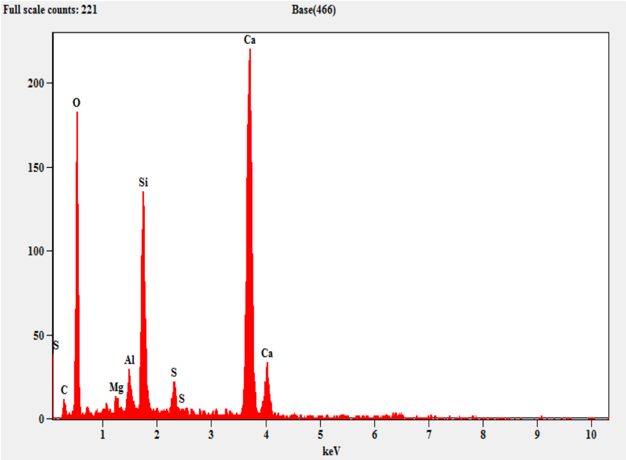


Fig. 8. XRD Mineral Composition

V.CONCLUSION

From the above results, it was observed that the strength of concrete indicates significant increase with the addition of bacterial concentrate-on. Water absorption of the control concrete is more than the bacterial concrete of all mixes. 20×10^6 cells/ml of Bacillus Subtilis in concrete mix M20 shows the maximum improvement in compressive strength as compared to conventional concrete at all the ages. The compressive strength of 10^6 cell concentration increases 53.1 % than the control concrete.

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