CRACK REPAIR IN CONCRETE STRUCTURES USING MICROORGANISMS

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Abstract: The objective of this research work is to develop a type of sustainable self healing concrete using a sustainable self healing agent i.e., calcite producing bacteria. Recent research has shown that specific species of bacteria can actually be useful as a tool to repair cracks in already existing concrete structures. A novel eco friendly self healing technique called Biocalcification is one such approach on which studies were carried out to investigate the crack healing mechanism to enhance the strength and durability of concrete. Microbiologically induced calcite precipitation (MICP), a highly impermeable calcite layer formed over the surface of an already existing concrete layer, due to microbial activities of the bacteria Bacillus subtilis JC3 (cultured at JNTU) seals the cracks in the concrete structure and also has excellent resistance to corrosion therefore increase the strength and durability of concrete structures. This paper aims to discuss the self cracking healing approach of bacterial concrete and reports the investigations on the enhancement of resistance to corrosion by microbiologically induced calcite mineral precipitation (MICP) in ordinary (M20) and standard (M40) grades of concrete. Quantification and Characterization was done using Scanning Electron Micrograph analysis, only to be noted that cracks were sealed up by crystalline material grown over the surface due to microbial activity of the bacteria.

I. INTRODUCTION

Cracks, fractures and fissures are common natural phenomenon in concrete structures, caused due to weathering, ageing, natural hazards such as earthquakes etc and also the faulty construction techniques adopted, results in ingress of water and chloride ions through them dramatically increasing concrete matrix degradation which has a great bearing upon the initiation and sustenance of reinforcement corrosion. Once reinforcement corrosion is initiated, it progresses almost at a steady rate and shortens the service life of the structure, by causing surface cracks and subsequently spalling of the cover concrete due to expansion of the corroded steel. The rate of corrosion directly affects the extent of the remaining service life of a corroding RC structure.

Reinforcement corrosion is one of the major durability problems, mainly when the rebar in the concrete is exposed to the chlorides either contributed from the concrete ingredients or penetrated from the surrounding chloride-bearing environment. From the perspective of durability the cracks formed should be repaired conventionally using epoxy injection, latex treatment etc or by providing extra reinforcement in the structure to ensure that the crack width stays within a certain limit. Especially with current steel prices on steep rise, providing extra steel is not economically viable. Use of synthetic agents such as epoxies for remediation of cracks in these structures introduce a different material system of doubtful long term performance and moreover they may damage the aesthetic appearance of the structures. Sometimes repair is carried out in the areas where it is not possible to shut down the plant or hazardous for human beings such as nuclear power plants where fuel storages should be leak proof ,

repair of waste water sewage pipes etc. Hence, in treating surfaces of structures with strategic and historic heritage importance, self healing materials could be an ideal choice. This common phenomenon of corrosion, if not treated properly and immediately, will tend to expand further deep and eventually increases repair and maintenance costs. So, If in some way a reliable method could be developed that repairs cracks and enhances corrosion resistance in concrete automatically (self healing), which could increase and ensure durability and functionality of structures enormously results in the conception of "Bacterial Concrete".

A novel eco-friendly self healing biological approach, Biocalcification, is chosen to study the self healing mechanism of cracks to performance in concrete structures by embedding bacteria *Bacillus subtilis JC3* in concrete. This concrete crack remediation technique by microbiologically induced calcite precipitation (MICP) using environment friendly bacteria to precipitate calcite ($CaCo_3$) during its microbial activities under prevailing Indian conditions is investigated to formulate a strategy to present Bacterial Concrete as best innovative self crack healing method in Concrete structures. During the process of biocalcification, the enzymatic hydrolysis of urea takes place forming ammonia and corbondioxide. Urease which is provided by bacteria deposits $CaCo_3$, a highly impermeable calcite layer, over the surface of an already existing concrete layer which is relatively dense and can block cracks and thus hamper ingress of water efficiently increasing corrosion resistance and consequently increasing the strength and durability of concrete structures. MICP is a complex mechanism and is a function of cell concentration, ionic strength, nutrient and pH of the medium.

Modern techniques such as X-ray diffraction tests, TEM & SEM analysis can be used to quantify the study of stages of calcite deposition on the surface and in cracks

II. EXPERIMENTAL INVESTIGATION

The main aim of the present experimental investigations is to obtain specific experimental data, which helps to understand the crack healing ability of Bacterial concrete and its characteristics (Strength and Durability).

Materials Used
The following are the details of the materials used in the investigation:
Cement
Ordinary Portland cement of 53 grade available in local market is used in the investigation. The cement used has been tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987 having specific gravity of 3.0
Fine Aggregate
Locally available clean, well-graded, natural river sand having fineness modulus of 2.89 conforming to IS 383-1970 was used as fine aggregate.
Coarse Aggregate
Crushed granite angular aggregate of size 20 mm nominal size from local source with specific gravity of 2.7 was used as coarse aggregate,
Water
Locally available portable water conforming to IS 456 is used.
Microorganisms
Bacillus subtilis JC3, a model laboratory bacterium which is cultured and grown at JNTUH Biotech Laboratory was used.

Mix Design
The mix proportions for ordinary grade concrete and standard grade concrete are designed using IS: 10262-1982. Materials required for 1 cubic meter of concrete in

ordinary grade concrete and standard grade concrete are:

Ordinary grade concrete (M20)	Standard grade concrete (M40)
Mix proportion 1: 2.43: 3.48: 0.55	Mix proportion1: 1.76: 2.71: 0.45

Culture of Bacteria

The pure culture was isolated from the soil sample of JNTU and is maintained constantly on nutrient agar slants. It forms irregular dry white colonies on nutrient agar. Whenever required a single colony of the culture is inoculated into nutrient broth of 25 ml in 100 ml conical flask and the growth condition are maintained at 37°C temperature and placed in 125 rpm orbital shaker. The medium composition required for growth of culture is - Peptone: 5 g/lit., NaCl: 5 g/lit., Yeast extract: 3 g/lit.

Maintenance of Stock Cultures

Stock cultures of *Bacillus subtilis* were maintained on nutrient agar slants. The culture was streaked on agar slants with an inoculating loop and the slants were incubated at 37°C. After 2-3 days of growth, slant cultures were preserved under refrigeration (4°C) until further use. Sub culturing was carried out for every 90 days. Contamination from other bacteria was checked periodically by streaking on nutrient agar plates.

III. TESTS ON CONCRETE

To study strength characteristics standard cubes (100mm x 100mm x 100mm) were cast and compacted. All the specimens were cured in water. The mixing process is carried out in electrically operated concrete mixer. The materials are laid in uniform layers, one on the other in the order–coarse aggregate, fine aggregate and cementitious material. Dry mixing is done to obtain a uniform color. Distilled water and the require amount of microorganisms (i.e. 10^5/ml cell concentration were used) with media were mixed. The compressive strength of the concrete cubes at 7 days, 14 days, 28 days. Concrete cubes with and without addition of bacteria were cast. After 28 days of casting, each cube is tested for weight and dimensions. Scanning Electron Microscopy (SEM) analysis was made on the broken sample of 28 days cube specimen. Micrographs were obtained with a RUSKA 3,500 Scanning Electron Microscope.

To study durability characteristics, the specimens are subjected to 5% solution of HCL. Cubes are continuously immersed in the solution. The specimens are arranged in the plastic tubs in such a way that the clearance around and above the specimen is not less than 30 mm. The solution was been changed for an interval of every 15 days after taking the measurements. The response of the specimens to the solutions was evaluated through change in appearance, weight, compressive strength, thickness and solid diagonals. Two specimens from each group were used for testing after every 15 days of immersion. Before testing, each specimen was removed from the baths, and brushed with a soft nylon brush and rinsed in tap water. This process removes loose surface material from the specimens. For determining the resistance of concrete specimens to aggressive environment such as acid attack, the durability factors are proposed by the author, with the philosophy of ASTM C 666–1997, as the basis. In the present investigation, the author derived the "Acid Durability Factors" directly in terms of relative strengths. The relative strengths are always with respect to the 28 days value (i.e. at the start of the test). The "Acid Durability Factors" (ADF) can be designed as follows.

Acid Durability Factor (ADF) = Sr N / M

where, Sr = relative strength at N days, (%)
N = number of days at which the durability factor is needed and M = number of days at which the exposure is to be terminated.

Acid attack test was terminated at 105 days. So, M is 105 in this case. The extent of deterioration at each corner of the struck face and the opposite face is measured in terms of the acid diagonals (in mm) for each of two cubes and the "Acid Attack Factor" (AAF) per face is calculated as follows.

AAF = (Loss in mm on eight corners of each of 2 cubes) / 4

Acid Durability Factors (ADF), Acid Attack Factors (AAF), percentage weight loss and strength loss at 30, 45, 60, 75, 90 and 105 days of immersion are evaluated.

Water absorption measurements were carried out by measuring the absorption of a drop by the surface of a treated and untreated sample. 0.2 ml of distilled water was placed on the surface of the concrete specimen and the time necessary for complete water absorption was measured. These experiments were done on five points for each sample and the average time is as follows: for the conventional sample absorption was almost immediate (less than 2 sec) while for the bacteria treated sample the drop kept its shape for about 20 sec (like a water drop on a hydrophobic surface) and was completely absorbed after 30 s. It is clear that the permeable properties were modified by the bacteria incorporation by reducing surface porosity. Crack sealing by means of this biological treatment resulted in a decrease in water permeability which can be tested by water permeability setup as shown in Fig 2.

However, intrusive porosity measurements (e.g. mercury porosimetry) would require in order to observe the depth porosity change. This efficient way to measure this porosity can be obtained by image analysis. This study will be the subject of future work and of a forthcoming publication. The ultrasonic measuring method proved to be a very suitable method for checks of repair because it can enable not only the comparison of cracked and repaired concretes with sound concrete through measuring ultrasonic pulse velocity, but also the determination of the depth of the cracks developed.

IV. TEST RESULTS

The compressive strength of concrete at 7 days, 14 days, 28 days were given in Table 1. Percentage of loss in weight and compressive strength of bacterial concrete when compared with conventional concrete when immersed in acid were given in Table 2. The Acid Durability Factor and Acid Attack Factor of concrete with and without bacteria were depicted in Fig 4 to Fig 6.
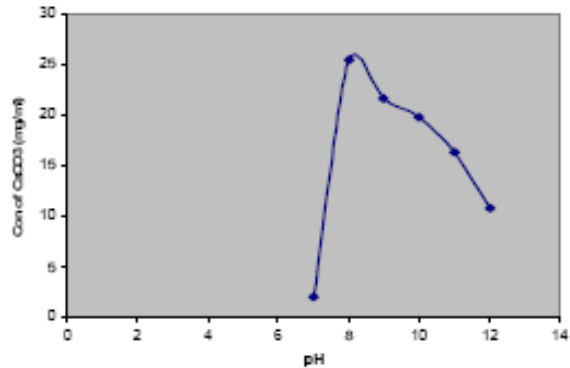

Fig 1: The Calcium carbonate precipitate formation at different pH was assessed and pH 8 was found to be the yielding the best
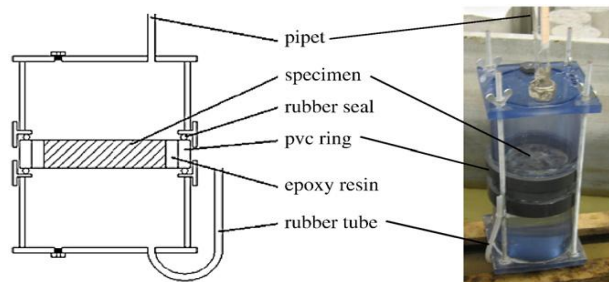

Fig 2: Water permeability setup

Table 1: Effect of the *Bacillus subtilis,* JC3 bacteria addition on Compressive Strength

Age (No. of days)	Compressive Strength (MPa)			
	ordinary (M20) grade concrete		standard (M40) grade concrete	
	Conventional Concrete (MPa)	Bacterial Concrete, (MPa)	Conventional Concrete (MPa)	Bacterial Concrete (MPa)
7	21.32	22.63	35.66	40.09
14	24.12	28.02	45.28	52.13
28	29.11	33.15	51.82	61.12

Table 2: Weight loss and Strength loss of concrete in acid immersion test

(Weight of cube in kg and Compressive strength is in MPa.)

Weight and Compressive strength of cube	Period of Immersion in 5% HCL					
	30 days	45 days	60 days	75 days	90 days	105 days
Conventional Concrete						
Initial Weight	**2.525**	**2.525**	**2.525**	**2.525**	**2.525**	**2.525**
Weight at refined age	**2.508**	**2.478**	**2.451**	**2.434**	**2.409**	**2.372**
% Weight loss	0.67	1.86	2.93	3.60	4.59	6.06
Reference Compressive Strength	**28.23**	**28.23**	**28.23**	**28.23**	**28.23**	**28.23**
Compressive Strength at refined age	**28.08**	**27.86**	**27.49**	**27.19**	**26.85**	**26.40**
% loss in Compressive Strength	0.53	1.31	2.62	3.68	4.89	6.48
Bacterial Concrete						
Initial Weight	**2.525**	**2.525**	**2.525**	**2.525**	**2.525**	**2.525**
Weight at refined age	**2.512**	**2.489**	**2.467**	**2.449**	**2.429**	**2.403**

% Weight loss	0.51	1.43	2.30	3.01	3.80	4.83
Reference Compressive Strength	**32.69**	**32.69**	**32.69**	**32.69**	**32.69**	**32.69**
Compressive Strength at refined age	**32.56**	**32.34**	**31.98**	**31.72**	**31.38**	**31.01**
% loss in Compressive Strength	0.40	1.07	2.17	2.97	4.01	5.14

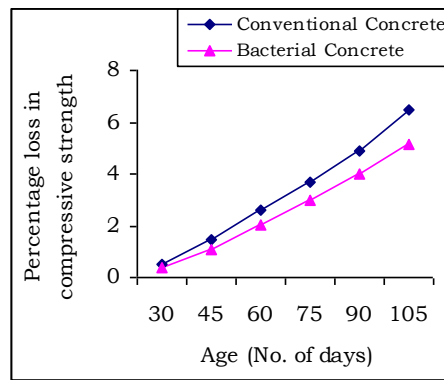Fig.3: Graph showing Variation of Compressive Strength with age in standard grade concrete

Fig.5: Graph showing Variation of percentage loss in Compressive Strength with age in ordinary grade concrete for the cubes immersed in 5% HCL
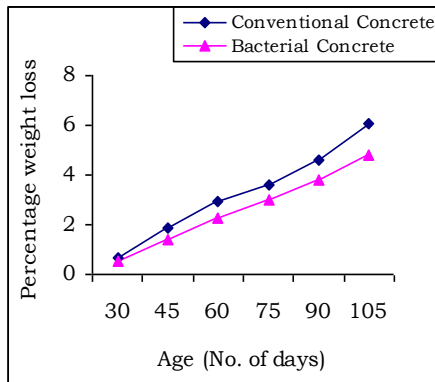

Fig.4: Graph showing Variation of percentage weight loss with age in ordinary grade concrete for the cubes immersed in 5% HCL
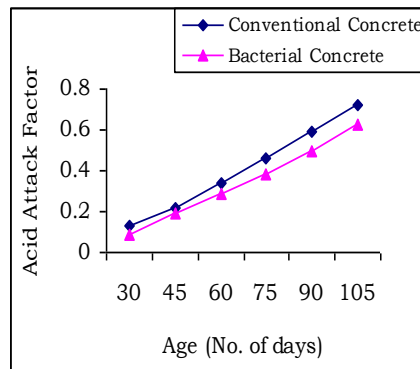

Fig.6: Graph showing Variation of Acid Attack Factor with age in ordinary grade concrete for the cubes immersed in 5% HCL

V. DISCUSSION

Self healing concrete should be able to heal or seal by filler material formation, freshly formed in cracks to inhibit ingress of water and other chemicals which would cause preliminary degradation of the material matrix or embedded reinforcement .In this study we investigated the crack repair ability of concrete in which bacteria was incorporated as self healing agent. The integrated bacterium applied in this study is Bacillus subtilus, alkaliphilic species of genus bacillus. When this bacterium integrated with concrete enhances the properties of concrete as stated:

The compressive strength of concrete at 7 days, 14 days, 28 days for optimum cell concentration of 10^5 cells per ml of mixing water were given in Table 1. It is observed that with the addition of bacteria the compressive strength of concrete showed significant increase by 14.92% at 28 days.

The Loss in Weight and Loss in Compressive Strength at different ages were given in Table 2. With the addition of bacteria it is observed that there is less percentage of loss in weight and compressive strength.

VI. CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn

1. Bacillus subtilis can be produced from lab which is proved to be a safe and cost effective. Deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary suction.
2. The addition of bacillus subtilis bacteria improves the hydrated structure of cement in concrete for a cell concentration of 10^5 cells per ml of mixing water. So, bacteria with a cell concentration of 10^5 cells per ml of mixing water was used in the investigation.
3. The addition of bacillus subtilis bacteria increases the compressive strength of concrete. In standard grade concrete the compressive strength is increased upto 14.92% at 28 days when compared to conventional concrete.
4. From the durability studies, the percentage weight loss and percentage strength loss with 5% HCl revealed that Bacterial concrete has less weight and strength losses than the conventional concrete. *Durability* studies carried out in the investigation through acid attack test with 5% HCl revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" than conventional concrete and bacterial concrete is less attacked in terms of "Acid Attack Factor" than conventional concrete.
5. From the above proof of principle, it can be concluded that *bacillus subtilis* can be safely used in crack remediation of concrete structure

VII. REFERENCES

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