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MICROBIAL CONCRETE AND INFLUENCE OF MICROBES ON PROPERTIES OF CONCRETE

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Abstract— **Cracks in concrete are inevitable and are one of the inherent weaknesses of concrete. Water and other salts seep through these cracks, corrosion initiates, and thus reduces the life of concrete. So there was a need to develop an inherent biomaterial, a self-repairing material which can remediate the cracks and fissures in concrete. A specific group of alkali-resistant spore forming bacteria preferably of genus Bacillus are selected and added to concrete or mortar paste for development of self-healing capacity in structures. Bacterial concrete is a material, which can successfully remediate cracks in concrete. This technique is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution free and natural. As the cell wall of bacteria is anionic, metal accumulation (calcite) on the surface of the wall is substantial, thus the entire cell becomes crystalline and they eventually plug the pores and cracks in concrete. It was found that use of bacteria improves the stiffness and compressive strength of concrete. Scanning electron microscope (SEM) is used to document the role of bacteria in microbiologically induced mineral precipitation. Rods like impressions were found on the face of calcite crystals indicating the presence of bacteria in those places. Energy- dispersive X-ray (EDX) spectra of the microbial precipitation on the surface of the crack indicated the abundance of calcium and the precipitation was inferred to be calcite (CaCO3). From the durability studies, the percentage weight loss and percentage strength loss with 5% H2SO4 revealed that Bacterial concrete has less weight and strength losses than the conventional concrete and it also revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" and "Acid Attack Factor" than conventional concrete. Chloride test shows that the addition of bacteria decreases weight incerse due to Chloride exposure and enhances the Compressive Strength.**

Keywords— Bacillus;self-healing; mineral precipitation; calcite crystals ; SEM; EDX

I. INTRODUCTION

Concrete is a vital building material that is an absolutely essential component of public infrastructure and most buildings. It is most effective when reinforced by steel rebar, mainly because its tensile strength without reinforcement is considerably low relative to its compressive strength. It is also a very brittle material with low tolerance for strain, so it is commonly expected to crack with time. These cracks, while not compromising structural integrity immediately, do expose the steel reinforcement to the elements, leading to corrosion which heightens maintenance costs and compromises structural integrity over long periods of time. That being said, concrete is a high maintenance material. It cracks and suffers serious wear and tear over the decades of its expected term of service. It is not flexible and cannot handle significant amounts of strain. Self-healing concrete in general seeks to rectify these flaws in order to extend the service life of any given concrete structure.

There is a material in the realm of self-healing concrete in development, now, that can solve many of the problems commonly associated with standard concrete. This material is bacterial self-healing concrete. Self-healing concrete consists of a mix with bacteria incorporated into the concrete and calcium lactate food to support those bacteria when they become active. The bacteria, feeding on the provided food source, heal the damage done and can also reduce the amount of damage sustained by the concrete structure in place.

SELF HEALING BACTERIAL CONCRETE

Self healing bacterial concrete

Autogenously crack-healing capacity of concrete has been recognized in several recent studies. Mainly micro cracks with widths typically in the range of 0.05 to 0.1 mm have been

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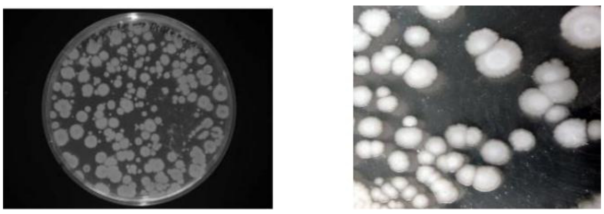
observed to become completely sealed particularly under repetitive dry/wet cycles. The mechanism of this autogenously healing is chiefly due to secondary hydration of non- or partially reacted cement particles present in the concrete matrix. Due to capillary forces water is repeatedly drawn into micro cracks under changing wet and dry cycles, resulting in expansion of hydrated cement particles due to the formation of calcium silicate hydrates and calcium hydroxide. These reaction products are able to completely seal cracks provided that crack widths are small. Larger sized cracks can only be partially filled due to the limited amount of non-reacted cement particles present, thus resulting in only a thin layer of hydration products on the crack surface. With respect to crack-sealing capacity, a process homologous to secondary hydration of cement particles is the process of carbonation. This reaction is also expansive as ingress atmospheric carbon dioxide (CO_2) reacts with calcium hydroxide particles present in the concrete matrix to various calcium carbonate minerals. From the perspective of durability, rapid sealing of particularly freshly formed surface cracks is important as this hampers the ingress of water and other aggressive chemicals into the concrete matrix.

BACTERIAS USED

Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life, most organisms die in an environment with a pH value of 10 or above.

Bacteria bacillus subtilis have the ability to withstand hostile environment of concrete. The thick cell membrane of bacteria bacillus subtilis helps to offer resistance against high pH. Therefore bacillus genus bacteria could remain hibernated within the concrete for 200 years until it gets the suitable environment.



Bacillus subtilis

II. REVIEW OF LITERATURE:

The literature available reveals that bacteria can be used to enhance the performance of the cement composites. Ghosh et al, (2004) have studied the strength improvement of cement–sand mortar by the microbiologically induced mineral precipitation. It was found that there was 25% increase in 28 day compressive strength of cement mortar by adding bacteria of 10 5 cells/ml of water. The strength improvement was due to growth of filler material within the pores of the cement–sand matrix as revealed by the scanning electron microscopy. Patil et al, (2008) used Bacillus pasteurii to induce calcite precipitation. It was reported that there was a increase in the compressive strength of treated cubes specimens by 12-13%. Varenyam et.al, (2010) reported that there was 36% improvement in the compressive strength of mortar specimens with bacterial cells compared with control. The improvement in compressive strength by Bacillus sphaericus was caused by the deposition of $CaCO_3$ on the cell surfaces and within the pores of cement–sand matrix, which plugs the pores within the mortar. Deepak et.al, (2009) have studied the deposition of calcite on the surface and in voids of bricks reduces the water absorption substantially. Rafat Siddique et al (2011) have studied the effects of microbes on compressive strength of cement mortar cubes at age of 7 and 28 days. It was reported that by the inclusion of microbial biomass (Bacillus pasteurii) enhanced the compressive strength. Sunil et.al,(2010) have observed that the compressive strength of cement mortar showed significant increase by 16.15% for cell concentration of 106 cells per ml of mixing water.

III. MATERIALS

CEMENT:

The ultra tech ordinary Portland cement of grade 53 is used for the experiment.

COARSE AGGREGATE AND FINE AGGREGATE:

The well graded angular shaped coarse aggregate of 20mm size and fine aggregate used was river sand. The coarse and fine aggregate are obtained from the local area.

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BACTERIAL SOLUTION:

Pure cultures (Bacillus SubtilisJC3) were maintained on nutrient agar slants which form irregular dry white colonies on nutrient agar. Whenever required a single colony of the culture was inoculated into nutrient broth of 25 ml in 100 ml conical flask maintained at a temperature of 37 0C and placed in 125 rpm orbital shaker. Growth was stopped after 48 hours when the concentration of bacteria reached 105 cells/ml and was preserved at a temperature of 50C until further use. Reddy et[13] in their work achieved highest compressive strengths using bacteria concentration of that 105cells/ml from a wide range of experimented values.

Nutrient broth commercially available was obtained in a chemical and laboratory equipment shop and used for the laboratory investigation.

COMPRESSIVE STRENGTH

The compressive strength of concrete is one of the most important and useful properties of concrete. The concrete

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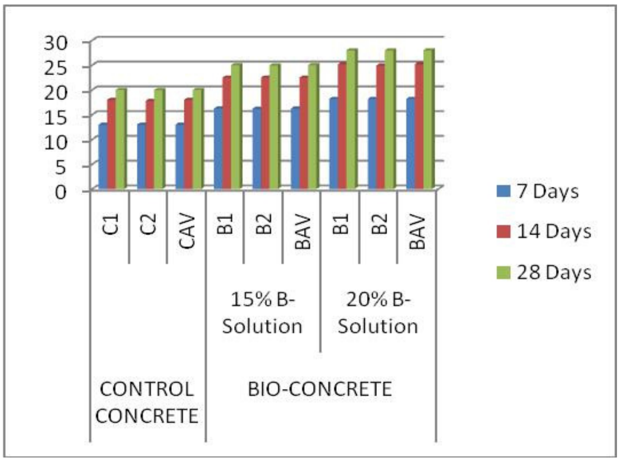
making properties of various ingredients of mix are usually measured in terms of compressive strength. compressive strength is also used as a qualitative measure for other properties of hardened concrete.

TEST RESULT FOR COMPRESSIVE STRENGTH

COMPRESSIVE STRENGTH (Mpa) FOR MORTAR CUBES									
Types of specimen	CONTROL CONCRETE			BIO-CONCRETE					
				15% B-Solution			20% B-Solution		
No.of specimen	C_1	C_2	C_{AV}	B_1	B_2	B_{AV}	B_1	B_2	B_{AV}
7 Days	13	13	13	16.25	16.2	16.25	18.2	18.19	18.2
14 Days	18	17.79	18	22.5	22.5	22.5	25.2	24.94	25.2
28 Days	20	19.98	20	25	24.95	25	28	27.99	28

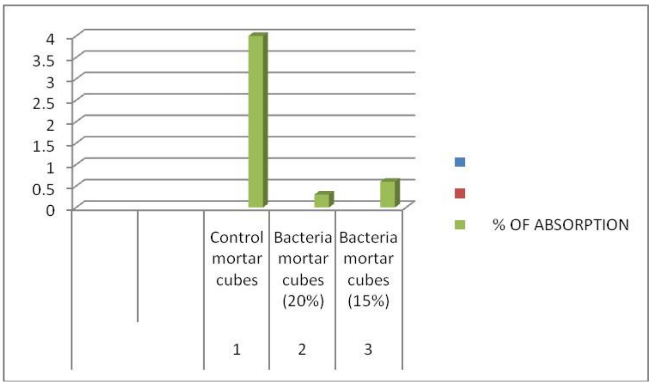


WATER ABSORPTION TEST

When excess water in concrete evaporates, The flow of water through concrete is similar to flow through any porous body. The porous in cement past consist of gel pores and capillary pores. . The results of Water Absorption Test, shows lesser increase in weight of bacteria concrete sample than control, from which it could be reckoned that the concrete will become less porous due to the formation of Calcium Carbonate due to which it resulted in lesser water absorption rate. This test should measure the rate of absorption of water.

TEST RESULT FOR WATER ABSORPTION

SL.NO	CONTENTS	DRY WEIGHT (W1) gms	WET WEIGHT (W2) gms	% OF ABSORPTION
1	Control mortar cubes	260	271	4
2	Bacteria mortar cubes (20%)	293	294	0.3
3	Bacteria mortar cubes (15%)	288	290	0.6



ULTRASONIC PULSE VELOCITY

The ultrasonic pulse is generated by an electro acoustical transducer . When the pulse is induced in to the concrete from a transducer , it undergoes multiple reflection at the boundaries of the differ material phases with in the concrete. A complex system of stress waves is developed which includes longitudinal (compression) , shear (transverse)and surface (Rayleigh) waves . The receiving transducer detects the onset of the longitudinal waves , which is the fastest . Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties , pulse velocity method is a convenient technique for investigating structural concrete.

	Pulse velocity by cross Probing (Km/Sec)	Concrete quality grading
1	> 4.5	Excellent
2	3.5 - 4.5	Good
3	3.0 - 3.5	Medium
4	< 3	Doubtful

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CT METHOD

SAMPLE ID	FREQUENCY (HERTZ)	TIME (SEC)	DISTANCE (MM)	VELOCITY (KM/SEC)
CONTROL CONCRETE	1	25	100mm	4(good)
	2	25		4(good)
	5	25.2		3.9(good)
	10	25.7		3.8(good)
BACTERIA CONCRETE	1	24.4	100mm	4.09(good)
	2	24.5		4.1(good)
	5	25.2		3.9(good)
	10	25.7		3.89(good)

ACID DURABILITY FACTOR TEST

An experimental program was conducted on ordinary Portland cement concrete and bacterial concrete. Specimens are subjected to 5% solutions of H_2SO_4. Cubes are continuously immersed in 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 has 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 immerson. 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.

M = number of days at which the exposure is to be terminated. Acid attack test was terminated at 14 days. So, M is 14 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. Percentage weight and strength loss at7,14 days of immersion has been presented in Table Acid Durability Factors (ADF) and Acid Attack Factors (AAF)

CONVENTIONAL MORTAR		
Weight and compressive strength of mortar cube	7 days (gm)	14 days (gm)
Weight before	295	295
Weight after	249	209
%weight loss	15	29
Compressive strength before	18	18
Compressive strength after	16.58	15.63
%loss in compressive strength	8.56	15.16
BACTERIA MORTAR		
Weight and compressive strength of mortar cube	7 days (gm)	14 days (gm)
Weight before	293	293
Weight after	265	245
%weight loss	9	16
Compressive strength before	25.2	25.2
Compressive strength after	24.46	23.98
%loss in compressive strength	2.20	4.2

ACID DURABILITY FACTOR AND ACID ATTACK FACTOR

CONVENTIONAL MORTAR						
DAYS OF IMMERSION	RELATIVE STRENGTH S_r	N	M	ADF	TOTAL LOSS IN mm ON 8 CORNERS	AAF
7	91.44	7	14	45.72	10	1.5
14	84.84	14	14	84.84	15	1.9
BACTERIA MORTAR						
DAYS OF IMMERSION	RELATIVE STRENGTH S_r	N	M	ADF	TOTAL LOSS IN mm ON 8 CORNERS	AAF
7	97.8	7	14	48.9	7	1.2
14	95.8	14	14	95.8	11	1.4

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CHLORIDE TEST

An experimental program was conducted on M20 grade concrete cubes of size 70.1mm x 70.1mm x70.1mm with and without addition of microorganisms (B. Subtilis). Specimens were immersed in 5% solution of NaCl for Chloride Test.the test is conducted by immersing the specimen the solution of 5% NaCl for 7 days and 14days. The weigth of specimen before dipping in the solution and after are noted .the increse of weigth of specimen in the control concrete and bacterial concrete will give the chloride resisting factor . Chloride test shows that the addition of bacteria decreases weight incerse due to Chloride exposure and enhances the Compressive Strength.

TYPE OF CONCRETE	WEIGHT OF CUBE (gm)			% INCRESE IN WT.(7 DAYS)	% INCRESE IN WT.(14 DAYS)
	INITIAL WT.	FINAL WT. 7TH DAY	FINAL WT. 14TH DAY		
CONVENTIONAL CONCRETE	876	880	884	0.45	0.91
BACTERIA CONCRETE	834	836	839	0.23	0.59

TYPE OF CONCRETE	COMPRESSIVE STRENGTH OF CUBE (gm)		
	INITIAL STRENGTH	FINAL STRENGTH. 14TH DAY	% DECREASE IN STRENGTH 14TH DAY
CONVENTIONAL CONCRETE	25	23.36	7
BACTERIA CONCRETE	31	30.63	1.2

SELF HEALING ASSESMENT OF BACTERIA CONCRETE

To study the crack healing capacity of bacterial concrete cubes with different crack width (0.1mm, 0.22mm, 0.3mm, 0.4mm, 0.45mm and 0.5mm) were casted for this study. Continuous examination carried out to identify the healing capacity.Bacteria (Bacillus subtilis) were added along with the water in the concentration 2*108 cfu/ml . Conventional concrete can also have the capacity to heal cracks up to the crack width of 0.2mm. Autogenous healing of conventional concrete achieved mainly by three processes 1) Swelling of C-S-H 2) Hydration of unhydrated cementatious components 3) Formation of calcite. Calcite formed by the reaction of CO2 and Ca(OH)2. This healing process in conventional concrete take place in limited amount because availability of CO2 is less within the concrete and also Ca(OH)2 is a soluble product which leach out with the help of ingress water . In bacterial concrete, due to urease enzymatic activity of Bacteria bacillus subtilis produces urease, which catalyzes urea to produce CO2 and ammonia, resulting in an increase of pH in the surroundings, Ca2+ and CO32- ions precipitates as calcite.

(a) **3 days** **b) 7 days** **(c) 14 days** **d) 28 days**

CONCLUSION

The experimental study shows that the addition of bacteria Bacillus Subtilis JC3 in concrete shows improvements in various properties of concrete in terms of compressive strength, split tensile strength, porosity, acid resistance and chloride resistance. As the bacteria can be produced in the laboratory, it could be proved to be safe and very cost effective. Bacterial concrete with a concentration of bacteria of $2*10^8$cfu/ml was found to give best results out of the samples used. Hence it could be concluded that this particular concentration give optimum results which is proven by 40% increase in compressive strength when compared to conventional concrete. Durability tests relieved that bacterial concrete have higher Acid Durability Factor and higher Acid Attack Factor from Acid Tests results. Bacterial concreteexhibited lower rate of water absorption than conventional concrete. This is due to the bacteria induced formation of Calcium Carbonate in the pores present in concrete, leading to a lesser voids and hence a lesser permeability. Bacterial concrete is less vulnerable to Chloride Attack also. The study accomplishes that the use of bacteria (Bacillus Subtilis) in concrete enhances its strength and durability hence using this type of bacteria for self-healing mechanism in concrete can produce cost effective strong or durable structures. After 28 days of curing specimen with 0.1mm crack width healed completely

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